CONNECTING NATURE

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INDICATOR REVIEWS

CONNECTING NATURE INDICATOR REVIEWS

BRINGING CITIES TO LIFE, BRINGING LIFE INTO CITIES

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CONNECTING NATURE INDICATOR REVIEWS

BRINGING CITIES TO LIFE, BRINGING LIFE INTO CITIES

THE PROJECT

Source: https://connectingnature.eu/

Coordinated by Trinity College Dublin, Connecting Nature is a consortium of 30 partners in 16 European countries, and hubs in Brazil, China, Korea & The Caucasus (Georgia and Armenia). We are co-working with local authorities, communities, industry partners, NGOs and academics who are investing in large scale implementation of nature–based projects in urban settings. We are measuring the impact of these initiatives on climate change adaptation, health and well-being, social cohesion and sustainable economic development in these cities. We are also developing a diversity of innovative actions to nurture the start-up and growth of commercial and social enterprises active in producing nature-based solutions and products.

THE INDICATORS

University of A Coruña

The Connecting Nature indicators have been produced by science-practice partners in co-production with the Front-runner cities of the project (Genk, Glasgow and Poznan). Each indicator provides a description, a review of its scientific robustness, as well as recommendations on different methodological options for its measurement and the type of data required.

The indicators are structured in five different categories of outcomes: environmental, health and wellbeing, social cohesion, economic, participatory planning and governance. The environmental indicators include a broad range of outcomes covering the areas of climate resilience, water management, natural and climate hazards, green spaces management, biodiversity enhancement, air quality and place regeneration. Each category includes a set of core indicators, and a wider range of feature indicators. **Core** indicators are a small set of outcomes considered broadly relevant to most nature-based solutions projects. **Feature** indicators include many scientifically supported outcomes that are relevant to some, but not all types of nature-based solutions. Furthermore, we include an additional category of indicators, named Primary Indicators, which offer a way to map the frequency and duration of human activities taking place in relation to nature-based solutions.

Together, the indicators presented here form a comprehensive and robust framework that cities can use to assess their projects. Although indicators are an important part of the impact assessment process, designing an impact assessment plan requires a broader vision. If you are interested in gaining a deeper understanding of the process behind the development of robust impact assessment plans, we recommend consulting the **Connecting Nature Impact Assessment Guidebook** for a framework of simple building blocks to facilitate the design of an impact assessment plan adapted to the characteristics of each locality.

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INDICATOR REVIEWS

PRIMARY

Primary indicators offer a way to map the frequency and duration of human activities taking place in relation to nature-based solutions. They are grouped into four interrelated sub-groups of indicators: 1. Type of interaction with NBS, 2. Frequency of interaction with NBS, 3. Duration of interaction with NBS, and 4. Perceived quality of space. The first three are related to behaviour patterns in places, whereas the fourth one refers to people's perception of a place. All together they give a picture of the whole conception of a place manifested via actual usage and its perceived qualities.

INDICATOR REVIEWS

TYPE OF INTERACTION WITH NBS

FREQUENCY OF INTERACTION WITH NBS

DURATION OF INTERACTION WITH NBS

PERCEIVED QUALITY OF SPACE

FOR MORE INFORMATION:
HTTPS://CONNECTINGNATURE.EU/INNOVATIONS/IMPACT-ASSESSMENT

PRIMARY INDICATORS

CONNECTING NATURE

Type of interaction with NBS

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Description

The type of interaction with NBS assesses the types of activities people perform, or interactions they have, with NBS spaces. Users can then be classified by age and gender, thus providing a picture of what a particular space is used for.

Methodology

Quantitative Procedure:
Scale/Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)

Selective Tool: ad hoc questions

Quantitative Procedure:
Observational study-GIS

Level of expertise

. Quantitative data collection requires no expertise

. Methodology and data analysis require high expertise in GIS analysis and people-environmental studies research

Data collection

Required data

Data which is collected is behaviour data about individual or group users showing type of activity, age related information; and circumstantial data showing weather conditions, holiday/workday conditions. Data required as contextual frame are structural map of the area and technical data about the NBS.

Data input type

Location of individual user, pair or a group attributed by type of activity, age, gender and purpose of visit.

Data collection frequency

Data collection frequency depends on the type of place observed and accuracy level of observation or tool(s) selected. However, data collection frequency is defined in the Protocol of observation. It must be considered that although the protocol must be set up in advance, it must stay open for adaptation regarding some unexpected situations (e.g., very bad weather for a longer period). However, generally it is recommended that the entire observation period takes at least 4 weeks in a representative time of a year for occupancy of the specific place.

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Extended description

This indicator focusses on people-place relationship in urban areas designed as or equipped with NBS. It looks at the facilitates and the design of these spaces, both in terms of occupancy and conductivity with other areas. The key source of information is the behaviour pattern that occurs in a place and the circumstances that (may) influence or generate it.
The measurement of the type of interaction can help to elucidate soft urban planning aspects, as well as show what kind of activities can be compatible with the NBS implemented, address its limitations and potentials for one or more uses or for one or more user groups. The main contribution lies in the assessment of the NBS in terms of its compatibility with or appropriateness for social usage. Although in majority of cases the NBS implementation in cities is implemented through greenery or water renaturation, NBS can reflect variety of places, not necessarily made of natural elements, and allowing several usages.
There are two crucial dimensions resulted from this indicator which can entrance urban planning/design decision making, monitoring and governance:

1. Physical spatial dimensions of occupancies, including social distances among users/user groups (e.g. Goličnik and Ward Thompson, 2010, Goličnik Marušić, 2016).
2. Place carrying capacity which refers to the ability of place/nature to sustain the usage and being able to keep its ecological (regeneration) capacity (e.g. Goličnik Marušić et al., 2020). This later is a very new concept but is especially worth to develop further and test in the context of NBS based urban planning.

The indicator Type of interaction with NBS measures user related characteristics of interaction, considering activity type and user type.

Activity type refers to two key general attributes:
a. Type of involvement with a place/NBS expressed by two values: passive engagement, active engagement.
b. Type of place occupation expressed by two values: being present in a place for a certain period, being in transition through a place.

Further, it is recommended that daily observation is divided into significant section (e.g., morning, lunch time, afternoon, evening, or as appropriate for the place observed). To follow characteristics of weekend and weekdays, it is recommended that observation take place across 7 days a week. Monthly (4 weeks) observation can be repeated with regards to the needs of case studied. Instead of the repetition of the whole 4-weeks observation, several daily checkpoints can be done (with regard to the resulted significant patterns of occupancy in the main observation period).

Participatory process

Data collection follows place centred mapping, which implies that a place or sub-areas of a place are observed, and annotation of the observed activities is made on manual or digital maps (depending on the approach agreed). User is not aware of being observed and he/she cannot manipulate the result. This is an important issue as heterogeneity of users and inclusion of various user-groups is assured. In such approach direct participation is meaningless, instead of indirect participation.

In case when any ICT supported recording is agreed as data collection means, and automatized data gathering is provided, users are aware of being part of the study and some sort of participatory process is established, as they must agree at the first place, that the data of their usage of places can be used for monitoring and analysis. In such frame additional participatory engagement is possible. However, heterogeneity of users can be harmed. Such approach can be applied when a user-group is addressed and is familiar with the ICT supported tool handling.

Connection with SDGs

Goal 3
Goal 9
Goal 11
Goal 13
Goal 15
Goal 16

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User type refers to three key general attributes:
a. Age group (suggested to rank so, that it can be compared with social or well-being indicators).
b. Purpose of visit (e.g. recreation, work, relaxation etc.).
c. Mode of visit (individual, pair, group).

In addition, this indicator measures physical space related characteristics of interaction, considering space type and NBS type (specific attributes are outlined in the Primary Indicators Appendix).

Space type addresses three key general attributes:
a. Typology of open space and green areas expressed by its (main) function (e.g. recreation, natural reserve, representation).
b. Accessibility of a place (e.g. by means, time distance).
c. Landscape character of the place (natural/designed).

Typology of NBS is indicated via (main) type of solution addressed (e.g. heat island reduction, water retention, flood related area, wind protection, soil protection).

Strengths and weaknesses

+ Actual knowledge about users in places, their interaction among themselves and with the place, i.e. the strength is in knowing actual patterns of uses, their placing in a place, social distancing, patterns of individuals as well as sizes of groups and their (un)cohabitation.

+ Planning tool for NBS that can help to evaluate its added value in terms of multifunctionality of places and conduciveness to usage.

+ Evaluation tool for NBS that can help to assess carrying capacity of places with merged NBS and social usability functions.

- Time consuming monitoring technique.

- Protocol and method of information gathering. There are some ways for data collection, its analysis and interpretation. Final decision on the method applied is case-specific. See section Measurement procedure and tool.

References

Goličnik Marušić, B., Mihevc, N. and Dremel, M. (2019) Patterns of using places for recreation and relaxation in peri-urban areas: The case of Lake Podpeč, Slovenia. Urbani izziv, vol. 30(2), pp. 113-123, http://urbaniizziv.uirs.si/Portals/urbaniizziv/Clanki/2019/urbani-izziv-en-2019-30-02-05.pdf, doi: 10.5379/urbani-izziv-en-2019-30-02-005.

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Parc de la Feyssine, Lyon: Urban natural park of Feyssine https://thisislyon.fr/things-to-do/parks-and-recreation/parc-de-la-feyssine/

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Extended methodology

- Quantitative Procedure (ad hoc questions):

How many times a month do you visit (name of the place)?

- Less than once a month
- Average number per month
- Average time per visit (in minutes)

Considering these visits to (name of the place), how many times do you do the following activities? (Less than once a month / Average number per month / Average time per visit (expressed in minutes)

- Physical activities (walking, cycling, hiking, exercising, playing team sports walking the dog)
- Social activities (meeting family or friends, chatting with neighbours, having a picnic, playing board games)
- Relaxation and quietness (being in a peaceful and quiet place, reading, resting, watching people)
- Experiencing nature (observing flora and fauna, enjoying the weather and the fresh air)
- Taking children out to play
- Attending organized events
- Growing food or plants

- Observational study-GIS

Data are gathered on site, in scale 1:1. Attributes collected are: number of users, gender, type of activity, age referenced data, location and dimension of occupancy, backgrounded by circumstantial data such as observation day (i.e., date, time of a day, weather conditions of a day). For the observation table, see the final section of this review (appendix).
The basic method applied is systematic observation study in a form of behaviour mapping. It consists of the protocol of observation which defines location of observation and its sub-areas if there is a need for subdivisions, timetable of observation as well as the number of repetitions, coding system for activities observed and the attributes attached, such as gender, age and the weather conditions. This gives a basic framework which allows repetition of the method in other cases and cross-comparable studies.
There are various accuracy levels of observation and data collection possible. The most robust option is limited on merely counting (not necessary marking the position of a person on a map) and differentiating between passive/active engagement, whereas the most advanced approach is grounded on actual activities recorded (geo-positioned) in a place (which later in an analytical phase can be grouped regarding the way of engagement and presence in a place).
The most objective way is direct observation, as it allows also in-situ notes and interpretations. Beside direct observation and map making, technology supported techniques are possible, too. However, one most bear in mind privacy-data limitations as well as users' willingness to participate when data collection can be linked to user's mobile-phones. This later may have impacts also on sampling, as not all user-groups are mobile-phone users.

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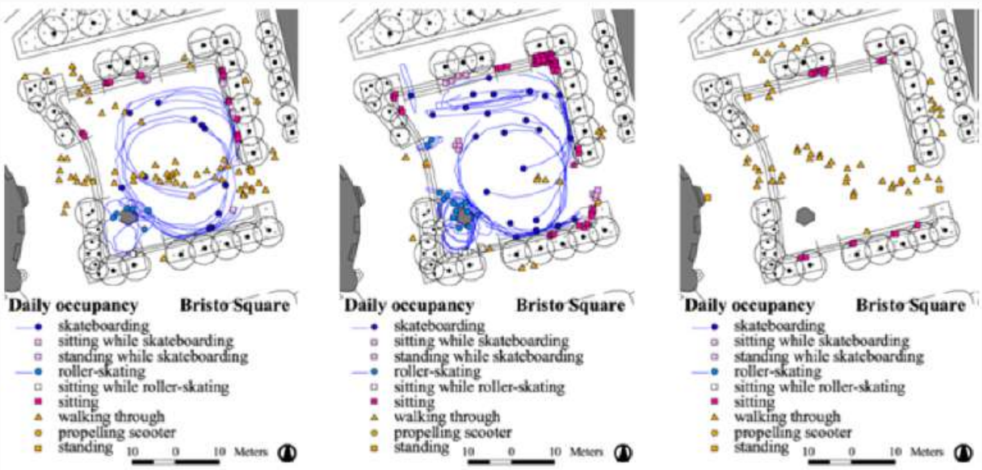
However, each approach has advantages and disadvantages: direct participant-observation and behaviour mapping is the most objective, but time consuming and requires a lot of repetition in office-work because of transcription of the fieldwork gathered data. Implementation of drone techniques may provide accurate location and social distances data; however physical-recognition and privacy data protection may be an issue. Similarly, GPS devices such as mobile phone may provide accurate location and data referring to gender and age (when user agrees to upload the application and insert some general personal data during an installation process), but the research can face sample representativity issue. The following table summarizes the comparison between the various methods:

	Participant observation & Behaviour mapping	Drone observation	GPS device (smart phone app)
Activity	Exact recognition, exact value	Assessed or Exact value	Relaying on APP user – with trust – Exact value
Age	Assessed value	Assessed value	Relaying on APP user – with trust – Exact value
Location	Assessed value	Exact value	Exact value
Purpose of visit	Assessed value (based on the type of activity)	Assessed value (based on the type of activity)	Assessed value (based on the type of activity)
Coverage of users using a place	full	full	limited on APP users

Furthermore, once the behavioural maps are obtained as final outlook of the observation, they can result in two significant forms: a) single maps: place centred maps showing records of activities in a map within a single observation, (i.e., one exact time-observation term); b) cumulative maps: place centred maps showing records of activities of more single maps together (i.e., entire observation period, selected sections of a day such as afternoons, or selected sections of a week, such as weekends)

Visual examples

Single maps of daily occupancies in Bristo Square, Edinburgh, UK (Goličnik, 2005)



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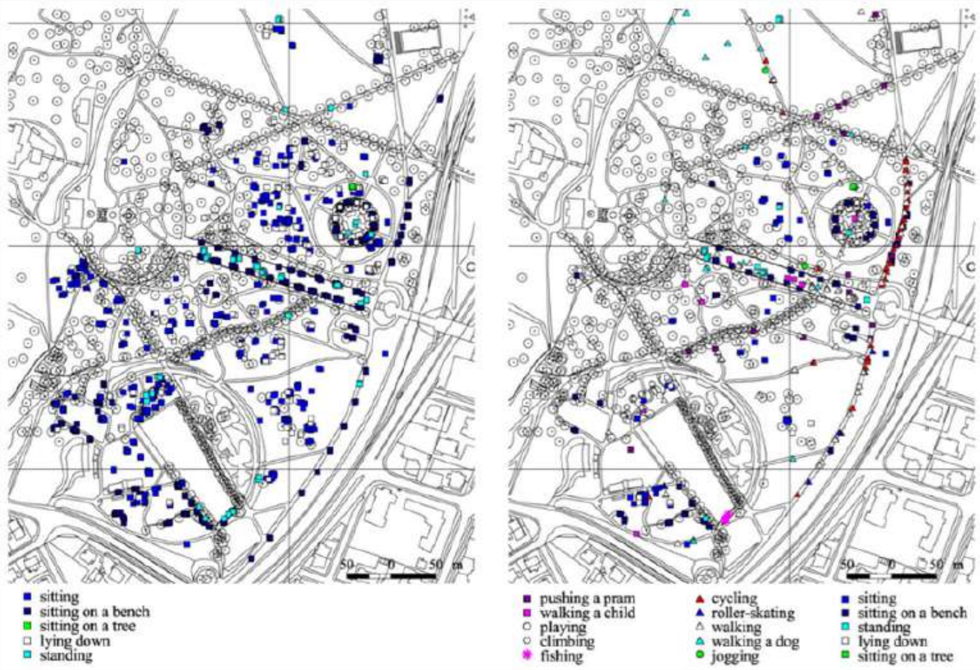
Cumulative map of passive engagements and Single maps of daily occupancies in Tivoli Park, Ljubljana, Slovenia (Goličnik, 2005)



Common remarks among Primary Indicators

Primary indicators address usage-spatial relationships among the NBS as a type of place or its parts and the activities which people may engage with. They are grouped into four interrelated sub-groups of indicators: 1. Type of interaction with NBS, 2. Frequency of interaction with NBS, 3. Duration of interaction with NBS, and 4. Perceived quality of space. The first three are related to behaviour patterns in places, whereas the fourth one refers to people's perception of a place. All together they give a picture of the whole conception of a place manifested via actual usage and its perceived qualities. Each sub-group is addressed separately in an adequate factsheet.

Appendix. Data collection sheet for observational study

On the next page you will find a table to record the observations made through an observational study. We recommend that you view the page in landscape format to make it easier to read.

Instructions: simply mark the short lines (as manual statistical counting) in the appropriate box. For example seeing group of youngsters playing with a ball (they were there before you came in) mark the short lines in a box cross-section ACTIVE x AGE 13-18 within a main column GROUPS, and place an index number next to the mark which say the number of people playing with a ball; or if observe people sitting on benches in a park mark in a box cross-section PASSIVE x relevant AGE within a main column INDIVIDUALS. Please see examples in the table.

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		Please select if the observation is a short stay (less than 10 minutes) or long stay (more than 10 minutes): ☐ SHORT STAY ☐ LONG STAY																				
		INDIVIDUALS							PAIRS							GROUPS						
		AGE UP TO 5Y	AGE 6Y-12Y	AGE 13Y-18Y	AGE 19Y-30Y	AGE 31Y-50Y	AGE 51Y-65Y	AGE MORE THAN 65Y	AGE UP TO 5Y	AGE 6Y-12Y	AGE 13Y-18Y	AGE 19Y-30Y	AGE 31Y-50Y	AGE 51Y-65Y	AGE MORE THAN 65Y	AGE UP TO 5Y	AGE 6Y-12Y	AGE 13Y-18Y	AGE 19Y-30Y	AGE 31Y-50Y	AGE 51Y-65Y	AGE MORE THAN 65Y
SUBAREA 1	ACTIVE																	I9 I3 I5 I5				
	IN TRANSITION																					
	PASSIVE			II		III	卌 II															
SUBAREA 2	ACTIVE																					
	IN TRANSITION																					
	PASSIVE																					

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PRIMARY INDICATORS

CONNECTING NATURE

Frequency of interaction with NBS

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Description

Frequency of interaction with NBS indicates and/or measures the cumulative occupancy of a place measuring number of days (including section of a day) the activity occurs in a place, and number of people participating in it mapped against the character of a place and type of NBS as such.

Methodology

Quantitative Procedure:
Scale/Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)

Selective Tool: ad hoc questions

Quantitative Procedure:
Observational study-GIS

Level of expertise

. Quantitative data collection requires no expertise

. Methodology and data analysis require high expertise in GIS analysis and people-environmental studies research

Data collection

Required data

Data which is collected is behaviour data about individual or group users showing type of activity, age related information; and circumstantial data showing weather conditions, holiday/workday conditions.
Data required as contextual frame are structural map of the area and technical data about the NBS. Required data for calculation of this indicator are these data structured against date and day sections, as well as type of activity per day, so the frequency and intensity of use can be calculated. Additionally, in site interviews or ICT based questionnaires can be used asking about individual's actual visits of a place, and about closeness of his/her start destination.

Data input type

GIS based information about location of individual user, pair or a group attributed by type of activity, purpose of visit, day of visit, day section of visit.

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Extended description

This indicator addresses capacity of NBS-designed places or their parts for occupancy as well as differentiations among sub-locations in terms of frequency, intensity and day-part sequence of use. It shows the levels of occupation of a place in terms of number of days people are participating in a particular activity, and the number of people being involved with that activity in a specific place or sub-area of this place. It shows on the popularity and/or appropriateness of a place for occupancy. The indicator is directly linked to "Type of interaction with NBS", addressing the following questions:

1.How the impact of activity types affects the frequency of visits to different types of spaces and NBS?
2.How different distances of NBS areas depending on spatial context affect the frequency of visits to different types of spaces and NBS?
3.How quality of space affects the frequency of visits to different types of spaces and NBS?
4.How user type affects the frequency of visits to different types of spaces and NBS?

The indicator PI2 reflects on cumulative behaviour patterns addressing three attributes: frequency of use, intensity of use, and occupancy time of a day:

1. Frequency of use shows appearance of particular activity in a place by the number of days the activity was present regarding the entire observation period, and can take the values: frequent (e.g. more than 70% of days), occasional (e.g. 40-70% of days), rare (less than 40% of days).
2. Intensity of use refers to the number of people involved with the activity in the entire observation period, and can take the values: high, intermediate, low; actual ranks are calculated regarding the data collected.
3. Occupancy time of a day refers to a day section in which a particular activity was performed, and can take the values: morning, lunch time, afternoon, evening or a set of sequences the most suitable for the place observed, e.g. before work time (before 8am), before lunch time (8am-12pm), lunch time (12 -13pm), after lunch time (13-17pm), after work time (17-19pm), evening (after 19pm). The time zones are different depending on the geographical location and their cultural habits.

Data collection frequency

Data collection frequency depends on the type of place observed and accuracy level of observation or tool(s) selected. However, data collection frequency is defined in the Protocol of observation. It must be considered that although the protocol must be set up in advance, it must stay open for adaptation regarding some unexpected situations (e.g. very bad weather for a longer period). However, generally it is recommended that the entire observation period takes at least 4 weeks in a representative time of a year for occupancy of the specific place. Further, it is recommended that daily observation is divided into significant sections, e.g. morning, lunch time, afternoon, evening, or as appropriate for the place observed. To follow characteristics of weekend and weekdays, it is recommended that observation take place across 7 days a week. Monthly (4 weeks) observation can be repeated with regards to the needs of case studied. Instead of the repetition of the whole 4-weeks observation, several daily checkpoints can be done (with regard to the resulted significant patterns of occupancy in the main observation period).
Site questions addressing PI2 referring to individual's actual visits of a place, and closeness of his/her start destination can also address aspects relevant for PI1 addressing purpose of visit.

Participatory process

Data collection follows place centred mapping, which implies that a place or sub-areas of a place are observed, and annotation of the observed activities is made on manual or digital maps (depending on the approach agreed). User is not aware of being observed and he/she cannot manipulate the result. This is an important issue as heterogeneity of users and inclusion of various user-groups is assured. In such approach direct participation is meaningless, instead of indirect participation.

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These attributes are directly interpreted from behaviour maps (specific attributes are outlined in the Primary Indicators Appendix). However, they can be elucidated from other related data addressing:

a) Actual individual frequency of use of a place addressing individual's actual visits of a place, using self-reported measure, taking the values such as: frequent (I have been visiting/using urban green spaces often); on a regular basis (I have been visiting/using urban green spaces regularly in the past 4 weeks), rare (I have visited/used urban green spaces in the past 4 weeks).

b) Closeness of start destination (e.g. home, school, work, public services such as library, museum etc.), which may additionally explain the attribute Occupancy time of a day, addressing the location issue and measure where in a city user reaches the NBS place, using self-reported measures, taking the values such as: near your home, in your city, close to your city

Strengths and weaknesses

+ Actual knowledge about users in places, their distribution in terms of frequency and intensity of occupancy and by this getting to know less/more popular areas of the place.

+ Planning tool for NBS that can help to evaluate its added value in terms of multifunctionality of places and conduciveness to usage.

+ Evaluation tool for NBS that can help to assess carrying capacity of places with merged NBS and social usability functions

- Time consuming monitoring technique.

- Protocol and method of information gathering. There are some ways for data collection, its analysis and interpretation. Final decision on the method applied is case-specific. See section Measurement procedure and tool.

In case when any ICT supported recording is agreed as data collection means, and automatized data gathering is provided, users are aware of being part of the study and some sort of participatory process is established, as they must agree at the first place, that the data of their usage of places can be used for monitoring and analysis. In such frame additional participatory engagement is possible. However, heterogeneity of users can be harmed. Such approach can be applied when a user-group is addressed and is familiar with the ICT supported tool handling.
This indicator is based on data gathered via behaviour mapping and in site questionnaire. For questions relaying on self-report measures participatory data collection is also possible.

Connection with SDGs

Goal 3 Goal 11 Goal 15
Goal 9 Goal 13 Goal 16

References

Goličnik Marušić, B., Mihevc, N. and Dremel, M. (2019) Patterns of using places for recreation and relaxation in peri-urban areas: The case of Lake Podpeč, Slovenia. Urbani izziv, vol. 30(2), pp. 113-123, http://urbaniizziv.uirs.si/Portals/urbaniizziv/Clanki/2019/urbani-izziv-en-2019-30-02-05.pdf, doi: 10.5379/urbani-izziv-en-2019-30-02-005.
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Extended methodology

- Quantitative Procedure (ad hoc questions):

How many times a month do you visit (name of the place) during autumn and winter?

- Less than once a month
- Average number per month
- Average time per visit (in minutes)

How many times a month do you visit (name of the place) during spring and summer?

- Less than once a month
- Average number per month
- Average time per visit (in minutes)

- Observational study-GIS

Data are processed upon the data gathered on site, in scale 1:1. The key attributes to address frequency of use, intensity of use and time of a day of use for to interpret occupancy as frequency of interaction with NBS are: number of users participating in the activity, number of days of the participated activity, location and dimension of occupancy, and backgrounded circumstantial data such as weather conditions of a day. For the observation table, see the final section of this review (appendix).

This indicator relays on the data collected for "Type of interaction with NBS" and requires further analytical operations upon the single behaviour maps on the level of cumulative data as it addresses overall capacity of places and multi-days effect of occupancy of places on NBS designed place. They are processed in the GIS environment.

Data gathered from behavior maps can be additionally elucidated from the sample, using self-reported measure. These maps can result in two significant forms: a) single maps: place centred maps showing records of activities in a map within a single observation, (i.e., one exact time-observation term); b) cumulative maps: place centred maps showing records of activities of more single maps together (i.e., entire observation period, selected sections of a day such as afternoons, or selected sections of a week, such as weekends).

Visual examples

Map for frequency of use is not provided, as the results are usually shown with charts. There are presentations for intensity of use in terms of number of people participating in the activity (Figure 1) and the further interpretation showing the intensity of occupancy in terms of location occupied for any activity taking place in the park (Figure 2)

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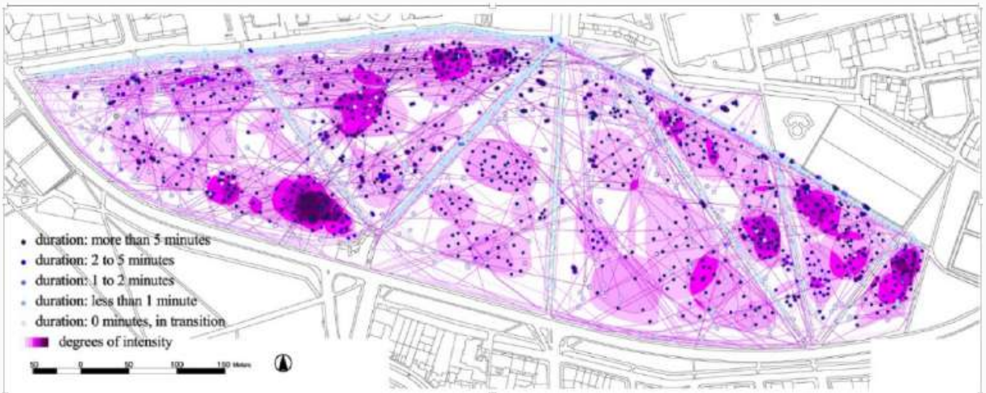
Intensity of use in terms of number of people participating in any activity in the entire observation period, The Meadows, Edinburgh, UK (Goličnik, 2005)

Intensity of occupancy in terms of location occupied for any activity taking place in the park in the entire observation period (Goličnik, 2005).



Common remarks among Primary Indicators

Primary indicators address usage-spatial relationships among the NBS as a type of place or its parts and the activities which people may engage with. They are grouped into four interrelated sub-groups of indicators: 1. Type of interaction with NBS, 2. Frequency of interaction with NBS, 3. Duration of interaction with NBS, and 4. Perceived quality of space. The first three are related to behaviour patterns in places, whereas the fourth one refers to people's perception of a place. All together they give a picture of the whole conception of a place manifested via actual usage and its perceived qualities. Each sub-group is addressed separately in an adequate factsheet.

Appendix. Data collection sheet for observational study

On the next page you will find a table to record the observations made through an observational study. We recommend that you view the page in landscape format to make it easier to read.

Instructions: simply mark the short lines (as manual statistical counting) in the appropriate box. For example, seeing individual people walking or cycling in a place in a certain part of a day, mark the short lines into the appropriate boxes as shown above.

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		SUBAREA 1								
		PASSIVE			IN TRANSITION			ACTIVE		
		GROUP	PAIRS	INDIVIDUALS	GROUP	PAIRS	INDIVIDUALS	GROUP	PAIRS	INDIVIDUALS
OBSERVATION DAY 1	TERM1: BEFORE WORK - before 8am						卌卌 卌卌 卌卌 ||			
	TERM2: BEFORE LUNCH - 8am-12pm						卌卌			
	TERM3: LUNCH TIME - 12 - 13pm						卌卌 卌卌 卌卌			
	TERM4: AFTER LUNCH - 13-17pm						卌|| 卌卌			
	TERM 5: AFTER WORK 17-19pm						卌||| 卌卌 卌卌			
	TERM6: EVENING - after 19pm						卌			
OBSERVATION DAY 2	TERM1: BEFORE WORK - before 8am									
	TERM2: BEFORE LUNCH - 8am-12pm									
	TERM3: LUNCH TIME - 12 - 13pm									
	TERM4: AFTER LUNCH - 13-17pm									
	TERM 5: AFTER WORK 17-19pm									
	TERM6: EVENING - after 19pm									
OBSERVATION DAY 3	TERM1: BEFORE WORK - before 8am									
	TERM2: BEFORE LUNCH - 8am-12pm									
	TERM3: LUNCH TIME - 12 - 13pm									
	TERM4: AFTER LUNCH - 13-17pm									
	TERM 5: AFTER WORK 17-19pm									
	TERM6: EVENING - after 19pm									

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PRIMARY INDICATORS

CONNECTING NATURE

Duration of interaction with NBS

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Description

Duration of interaction with NBS indicates and/or measures the duration of occupancy of a place measuring length of stay and the way the activity occurs in a place (i.e. whether passive or active).

Methodology

Quantitative Procedure: Scale/Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)

Selective Tool: ad hoc questions

Quantitative Procedure: Observational study-GIS
This indicator relays on the data collected for "Type of interaction with NBS" and requires further analytical operations upon the single behaviour maps on the level of cumulative data as it addresses overall capacity of places and multi-days effect of occupancy of places on NBS designed place. They are processed in the GIS environment.

Level of expertise

. Quantitative data collection requires no expertise

. Methodology and data analysis require high expertise in GIS analysis and people-environmental studies research

Data collection

Required data

Data which is collected is behaviour data about individual or group users showing type of activity and duration of activity; and circumstantial data showing weather conditions, holiday/workday conditions. Data required as contextual frame are structural map of the area and technical data about the NBS. Required data for calculation of this indicator are these data structured against date and day sections, so the duration of use can be interpreted also regarding the time of a day or week. Additionally, in site interviews or ICT based questionnaires can be used asking about individual's actual visits of a place, and about closeness of his/her start destination, as it may affect the length of stay in a place.

Data input type

GIS based information about location of individual user, pair or a group attributed by type of activity, purpose of visit, day of visit, day section of visit.

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Extended description

This indicator measures occupancy related characteristics for interaction with NBS designed place. The indicator is directly linked to "Type of interaction with NBS" and indirectly to "Frequency of interaction with NBS" as it reflects on temporal-spatial occupancy addressing duration in relation to activity type. Temporal-spatial occupancy relates to timescale, in terms of presence and duration of an activity in place, and to subject, i.e. the user him/herself, in terms of the way he/she is engaged with it. It reflects the relation of activity type and user type addressed within the "Type of interaction with NBS" in more detail. As "Duration of interaction with NBS" addresses duration of interaction with NBS it excludes those uses referred to the activity type (according to "Type of interaction with NBS") being in transition through the place. It addresses only those being present in a place. There are several situations usually significant:

Passive long stay: being continuously passively present in the scene (e.g. sitting there for a long time, laying down for a long time).

Active long stay: being continuously active in the scene (e.g. playing with a ball).

Active short stay: occurring while in transit through the scene (e.g. stopping for a play and then continue walking or playing with a ball or any other play for short period).

Passive short stay: occurring while in transit through the scene (e.g. sitting for a break and then continue walking; stopping, chatting and then continue walking or sitting for short period).

Repeating active-passive pattern: combining passive-active engagement (e.g. working - taking a break, skateboarding - taking a break, cycling within a place – taking a break).

Measuring this indicator provides knowledge about addressing actual activities by their common denominators such as the way of active involvement, presence and time occupation at the same time. The indicator can contribute to understanding of dimensions and spatial requirements of different uses and can illustrate how some activities can be contiguous, while some others require buffer zones between them for effective use.

Data collection frequency

Data collection frequency depends on the type of place observed and accuracy level of observation or tool(s) selected. However, data collection frequency is defined in the Protocol of observation. It must be considered that although the protocol must be set up in advance, it must stay open for adaptation regarding some unexpected situations (e.g. very bad weather for a longer period). However, generally it is recommended that the entire observation period takes at least 4 weeks in a representative time of a year for occupancy of the specific place. Further, it is recommended that daily observation is divided into significant sections, e.g. morning, lunch time, afternoon, evening, or as appropriate for the place observed. To follow characteristics of weekend and weekdays, it is recommended that observation take place across 7 days a week. Monthly (4 weeks) observation can be repeated with regards to the needs of case studied. Instead of the repetition of the whole 4-weeks observation, several daily checkpoints can be done (with regard to the resulted significant patterns of occupancy in the main observation period).
Site questions addressing "Frequency of interaction with NBS" referring to individual's actual visits of a place, and closeness of his/her start destination can also address aspects relevant for "Type of interaction with NBS" addressing purpose of visit.

Participatory process

Data collection follows place centred mapping, which implies that a place or sub-areas of a place are observed, and annotation of the observed activities is made on manual or digital maps (depending on the approach agreed). User is not aware of being observed and he/she cannot manipulate the result. This is an important issue as heterogeneity of users and inclusion of various user-groups is assured. In such approach direct participation is meaningless, instead of indirect participation.

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Strengths and weaknesses

+ Actual knowledge about users in places, their distribution in terms of length of stay and way of engagement with occupancy in terms of being passive or active.

- Time consuming monitoring technique.

Extended methodology

- Quantitative Procedure (ad hoc questions):

(See Extended methodology for "Type of interaction with NBS")

- Observational study-GIS

Data gathered from behavior maps can be additionally elucidated from the sample, using self-reported measure. These maps can result in two significant forms: a) single maps: place centred maps showing records of activities in a map within a single observation, (i.e., one exact time-observation term); b) cumulative maps: place centred maps showing records of activities of more single maps together (i.e., entire observation period, selected sections of a day such as afternoons, or selected sections of a week, such as weekends).
Data are processed upon the data gathered on site, in scale 1:1. The key attributes to address duration of interaction with NBS are minutes of stay in a place. For the observation table, see the final section of this review (appendix).

Common remarks among Primary Indicators

Primary indicators address usage-spatial relationships among the NBS as a type of place or its parts and the activities which people may engage with. They are grouped into four interrelated sub-groups of indicators: 1. Type of interaction with NBS, 2. Frequency of interaction with NBS, 3. Duration of interaction with NBS, and 4. Perceived quality of space. The first three are related to behaviour patterns in places, whereas the fourth one refers to people's perception of a place. All together they give a picture of the whole conception of a place manifested via actual usage and its perceived qualities. Each sub-group is addressed separately in an adequate factsheet.

Appendix. Data collection sheet for observational study

(See Appendix for "Type of interaction with NBS")

In case when any ICT supported recording is agreed as data collection means, and automatized data gathering is provided, users are aware of being part of the study and some sort of participatory process is established, as they must agree at the first place, that the data of their usage of places can be used for monitoring and analysis. In such frame additional participatory engagement is possible. However, heterogeneity of users can be harmed. Such approach can be applied when a user-group is addressed and is familiar with the ICT supported tool handling.
This indicator is based on data gathered via behaviour mapping and in site questionnaire. For questions relaying on self-report measures participatory data collection is also possible.

Connection with SDGs

Goal 3	Goal 11	Goal 15
Goal 9	Goal 13	Goal 16

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PRIMARY INDICATORS

CONNECTING NATURE

Perceived quality of space

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Description

Self-reported perceptions of the NBS space quality

Methodology

Quantitative Procedure:
Scale/Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)

Selective Tool. Ad hoc questions based on:
- Parks and Recreation Questionnaire Results Summary (The City of Ellensburg, 2015)
- Safety concerns issues for park users (Gökçen Firdevs, 2006)
- The experience of nature: A psychological perspective (Kaplan & Kaplan, 1989)
- Personal, community, and environmental connections (Christopher et al., 2010)

Level of expertise

. Quantitative data collection requires no expertise

. Methodology and data analysis require high expertise in psycho-social research

Data collection

Required data

Essential: NBS characteristics for each city/site, more specifically objectives and challenges

Data input type

Quantitative (quantitative and qualitative, if case study methodology and/or participatory data collection are opted for)

Data collection frequency

- Data collection frequency for general promotion of social benefits of the NBS: Before NBS implementation and aligned with timing of targeted (especially long- term) objectives

- Data collection frequency as a monitoring tool: assessment of the specific aspects of individual NBS that can help maintain, improve NBS (e.g. maintenance of the place, A sense of security in a place, the attractiveness of place in terms of smell, sound and other senses)

Connection with SDGs

Goal 2
Goal 3
Goal 4
Goal 6
Goal 11
Goal 13
Goal 15
Goal 16

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Extended description

Perceived quality of space is one of the important factors that influences the successfulness of public space, especially in terms of engaging users in activities (Fongar et al., 2019). The value of this indicator is seen in the assessment and promotion of social benefits of NBS in general, and as a monitoring tool for specific aspects of individual NBS (e.g. maintenance of the place, attractiveness of place in terms of various senses such as smell, sound, easiness of finding a place etc.).
Within the scientific literature, aspects of quality of space have been defined through varying features:

Attractiveness of the area for a specific use: this indicator is understood in terms of stimulation for users to get involved with a particular activity in the space. For example, natural elements and their arrangement in (green) spaces can provide calmness and serenity, enable recovery from stress and improve mental fatigue. Also, certain arrangement of elements can stimulate the user to actively use the space.

Maintenance of the place is understood as an appropriate handling of vegetation (i.e., pruning, cutting branches, mowing grass, vegetation conditions) as well as urban equipment and cleanliness (i.e., waste management). Such indicator addresses the pleasantness of a place to use.

A sense of security in a place is an important aspect of the perceived quality of space, because it is considered as one of the most important parameters in decision making for visiting and spending leisure time in that location (Rezaie at al.,2019). Additionally, to the social indicators developed this measure focuses on spatial parameters addressing safety, such as, good orientation in the place, the appropriate lightness of the place and settings of spatial components, which can motivate people to explore. Thus, this indicator addresses sense of security via spatial characteristics and reflects on coherence & legibility as well as complexity and mystery as defined by Kaplan and Kaplan (1989).

Easiness of finding a place (structural accessibility): access to green space is associated with better health outcomes, such as lower body mass index scores, overweight and obesity levels; improved mental health and wellbeing and increased longevity in older people (Institute of Health Equity, 2014).

Participatory process

Participatory methods (e.g., collaborative participatory data collection, GIS with top-down goals of understanding neighborhood dynamics, location-based GIS) may be applied to collect community-relevant information about factors that play a role in members' perception of quality; data can further inform NBS implementation and expansion.

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Accessibility is often considered in terms of proximity from green space to user's home, however, the perceived accessibility is also very important and is influenced by safety, easy access (no physical barriers), connectivity, continuity of paths, etc. (Žlender, 2017).

The pleasantness of place in terms of sound, smell and microclimatic conditions: although the vision is the most reliable sense, the perception of the environment is multi-sensory (Shahhosseini, Sharif, & Maulanour, 2014). Sensory stimulation is particularly important for elderly suffering from dementia since it can improve orientation and trigger memory (Haas et al. 1998). Also, pleasant microclimatic conditions, such as air temperature, humidity etc. affect human comfort, his/her experiencing the space and his/her behaviour patterns.

Place attachment & identity refer to a positive emotional bond between user and place. Giving character and identity to a place is essential to creating a meaningful place for people (Lyinch, 1960; Memluk, 2012). In order to promote NBS concept, it is especially important to consider this indicator, because stronger place identity was significantly associated with a greater agreement regarding the balance between humans and nature as well as with weaker support for the domination of humans over nature (Budruk at al. 2009).

Strengths and weaknesses

+ General promotion of social benefits of the NBS, which can contribute to the implementation of NBS in spatial planning practice

+ Gathering information about compatibility of different types of NBS regarding their ability to enable certain aspects of quality of space.

+ Monitoring tool for NBS (e.g. maintenance of the place, easiness of finding a place) that can help to maintain, improve specific aspect of space design

+ Gathering information about community's shared notion of perceived quality of space and information about their needs

- NBS can address various city challenges and because of NBS process characteristics the assessment of the perceived quality must therefore be understood in relation to the specific context, solution and purpose of the evaluation. The questionnaire cannot be standardized but adjusted according to the individual NBS

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Extended methodology

- Quantitative Procedure (ad hoc questions):

In order to elaborate the following questions, the studies presented in the previous sections were followed. However, some of the variables considered, such as "Place attachment", have their own indicators in Connecting Nature. Items of these indicators were not included since the recommended methodology is detailed in greater depth in their particular reviews.

How do you rate the quality of the following elements in (name of the place)? (Very poor / Poor / Average / Good / Very good)

- Aesthetics qualities (visual elements and beauty of the place)
- Elements of small architecture (e.g. street furniture, playground, fountain)
- Greenery
- Accessibility (easy to get to, several entry points)
- Distance to your home
- Safety
- Upkeep and maintenance (cleanliness, maintenance of urban equipment and vegetation)
- Organised events
- Attractiveness in terms of smell and sound
- Tree shade to provide a lower temperature feeling in Summer

In general, would you say that overall quality in (name of the place) is... (Very poor / Poor / Average / Good / Very good)

What amenities are missing? (please give examples)

What other activities would you like to do at (name of the place)?

Common remarks among Primary Indicators

Primary indicators address usage-spatial relationships among the NBS as a type of place or its parts and the activities which people may engage with. They are grouped into four interrelated sub-groups of indicators: 1. Type of interaction with NBS, 2. Frequency of interaction with NBS, 3. Duration of interaction with NBS, and 4. Perceived quality of space. The first three are related to behaviour patterns in places, whereas the fourth one refers to people's perception of a place. All together they give a picture of the whole conception of a place manifested via actual usage and its perceived qualities. Each sub-group is addressed separately in an adequate factsheet.

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INDICATOR REVIEWS

ENVIRONMENTAL

The following section presents all of the nature-based solution indicator reviews for the Environmental 'Core' and 'Feature' Indicators. Environmental indicators cover the range of environmental impacts that can be achieved through urban nature-based solutions, from impacts on biodiversity to more anthropogenic focused impacts such as thermal comfort and greenspace accessibility. Due to the diversity of potential environmental impacts, and the broad range of approaches for evaluating these, separate reviews were carried out for Applied/Participatory approaches and Earth Observation/Remote Sensing approaches for each of the Core Indicators. This was to ensure that holistic reviews could be carried out that were relevant to the range of target audiences involved in nature-based solution evaluation, without overwhelming the reader with content not relevant to their evaluation approach and expertise. For the Feature Indicators (the indicators that are less likely to be applied universally), the Applied/Participatory and Earth Observation/Remote Sensing approaches were combined into a single, more condensed, review.

INDICATOR REVIEWS

CORE

- Air temperature change
- Rainfall storage (water absorption capacity of NBS)
- Flood peak reduction/delay
- Water quality
- Inundation risk for critical urban infrastructures (probability)
- Public green space distribution
- Recreational value of blue-green spaces
- Cultural value of blue-green spaces
- Connectivity of urban green and blue spaces (structural and functional)
- Supporting/increasing biodiversity conservation
- Species diversity
- Land use change and greenspace configuration
- Access to public amenities
- Blue space area
- Soil sealing
- Change in ecosystem service provision
- Community garden area per capita and in a defined distance

INDICATOR REVIEWS

FEATURE

- Carbon storage OR carbon sequestration in vegetation/soil
- Albedo
- Air temperature – Energy demand
- Flood damage (economic)
- Community accessibility
- Mapping ecosystem services and spatial-temporal biodiversity legacies
- Accessibility of greenspaces
- Ratio of open spaces to built form
- Green space area
- Local food production
- Cultivated crops
- Intensity of landuse
- Landuse mix
- Air quality change
- Tree shade for local heat change
- Community garden area per child capita and in a defined distance

ENVIRONMENTAL INDICATORS - CORE

CONNECTING NATURE

Air temperature change

Applied/Participatory Review

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Description

Measurement of the cooling effect of NbS by evapotranspiration and/or shading using applied methods

Methodology

Metrics are based on changes in air temperature and can be employed on a range of scales. Typically, this is in relation to the scale of the NbS being implemented. For example, small-scale interventions would not be expected to have a quantifiable impact in terms of city-wide temperatures but might provide local benefits in terms of providing an oasis from thermal stress for residents (impacting the urban canopy layer locally). As such, local scale monitoring metrics would be more appropriate. However, large-scale NbS projects, or city-wide replication of small-scale projects, might have a detectable impact at a city-wide scale (urban boundary layer).

Level of expertise

Some expertise is required for the spatial design of the sampling and choice of instrumentation. Once installed though, basic measurements of air temperature associated data processing require little expertise. For more complex thermal parameters, analysis requires a greater level of expertise if equipment used does not process such data automatically. The ENVI-met microclimate analysis software requires some expertise to operate and collect the environmental data necessary. Once trained, however, data processing is relatively straightforward.

Data collection

Cost

Can be low cost particularly if pre-existing weather stations can be used. If these are not available, cost is linked to the scale of monitoring and the complexity of equipment used. Basic digital thermometers and thermocouples are relatively cheap, cost increases when these are linked to dataloggers, but these additional costs are generally offset by decreased staff costs for data collection. Overall cost also tends to be linked to the level of precision of equipment and the number of sampling points. Costs can be reduced by participatory approaches that involve residents with mobile heat sensors (reducing staff costs), or temperature perception surveys of users (reducing equipment costs).

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Scientific solid evidence

Robustness of evidence depends upon the level of precision of the equipment, the spatial design of the monitoring and the duration of temperature recording. Generally direct measurement can provide greater confidence than microclimate simulations, particularly for small-scale interventions.

Extended methodology

It should be noted that, if NbS is poorly designed, leading to disruption of airflows, localised increases in air temperature could also be caused by NbS.

Basic measurements are typically carried out in relation to:

·Air temperature (how hot or cold the air is);

·Apparent temperature (is the temperature equivalent perceived by humans – based on air temperature, relative humidity and wind speed);

·Land surface temperature (the radiative skin temperature of the land derived from solar radiation);

·Thermal comfort - Physiological Equivalent Temperature (PET) (thermal perception of an individual including thermal physiology);

These temperature parameters are usually quantified in relation to specific thresholds:

·Decrease in mean/peak daytime local temperatures (in relation to mean radiant temperatures);

·Percentage change in annual/monthly temperatures (citywide);

·Heat stress (in Europe - exposure of people to temperatures >30°C);

·Heatwave risk (number of combined tropical nights (>20°C) and hot days (>35°C));

·Urban heat island (temperature difference between urban areas and surrounding rural landscapes).

For local measurements of air temperature, a variety of thermometers/thermocouples can be used, usually in combination with dataloggers. When using the most basic types of thermometers and thermocouples, it is important that they are kept shaded. If the equipment is exposed to direct solar radiation, it can heat them and the reading thus measures heating due to solar radiation rather than the true air temperature.

Effort

Automated in-site data gathering is very low effort, with installation, data analysis and equipment maintenance the only inputs required. The only onerous aspect can be the volume of data generated. If samples are taken manually, effort is related to frequency and number of measurements.

Data availability

Generates new data. Baseline data prior to intervention is not always necessary as it may be possible to measure temperature at increasing distances away from NbS to quantify effect. If comparison to a previous green or grey space is required though, establishing baseline data prior to installation can be of benefit.

Geographical scale

Typically, the type of metrics selected are based on the scale of the NbS being implemented. For example, small-scale interventions would not have a quantifiable impact on city-wide temperatures, thus city-wide networks of thermal sensors or remote sensing methods would not be appropriate. Small-scale NbS might, however, provide quantifiable local benefits in terms of creating an oasis from thermal stress for residents.

Temporal scale

Monitoring methods can be adopted for short-term snapshots associated with days of extreme heat, or for long-term monitoring projects over months or years. Long-term in-situ monitoring is generally more effective in terms of capturing a more comprehensive overview of the performance of the NBS over a range of environmental conditions. Long-term monitoring is also recommended as NbS performance would be expected to change over time. Establishing a network of sensors across the city would provide a useful baseline as NbS is upscaled across the city.

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To avoid this, thermometers/thermocouples need to be combined with some kind of insulation from solar radiation to ensure they are measuring air temperature (Yu and Hien 2006). An example of a very basic solution to this is the combination of datalogging thermocouples with polystyrene insulation to measure the air temperature above green roofs (Connop et al. 2013). By using networks of such insulated thermocouples, it is possible to measure temperature at increasing distances away from an NbS such as a living wall or park (Doick et al. 2014; Eisenberg et al 2015; Ottelé et al. 2017; Morakinyo et al. 2019).

For broader area measurements, standard practice for local temperature measurement involves the use of weather stations to monitor climatic parameters such as air temperature, windspeed, humidity. Such an approach is useful as it provides data on a wider range of temperature parameters in addition to air temperature, it also provides other climate parameters that can have synergies with other NbS indicators. Weather stations can range in size from off-the-shelf systems that have versatility in terms of installation location, to more accurate location-based monitoring, typically using a platinum resistance thermometer (PRT) inside a station fixed to the ground. The thermometer is exposed to air flow by natural ventilation through side louvers. This equipment includes a datalogger that takes readings at pre-programmed intervals to capture temperature changes for calculation of daily, monthly or annual temperature fluctuations (MET Office 2019).

Ambient air temperature quantification is commonly calculated using combined ventilated temperature and relative humidity sensors (Jänicke et al. 2014). Apparent air temperature, or the temperature equivalent perceived by people, is measured by Dry- and Wet-bulb temperatures. These are common parameters measured to assess the apparent temperature regulation associated with NbS implementation (Shashua-Bar et al. 2009; Fung and Jim 2017). Typically, values recorded are referenced to climatic data from a nearby meteorological station (Shashua-Bar et al. 2009).

Frequency or duration of exposure to heat stress is typically measured using Wet Bulb Globe Temperature (WBGT) heat stress meters. It is a measure of the heat stress in direct sunlight, combining temperature, humidity, wind speed, sun angle and cloud cover (solar radiation). These meters can be used to measure the effects of NbS on evapotranspiration/cooling in relation to how somebody would feel at different distances from an NbS.

Participatory process

Opportunities are available for a participatory process, particularly in relation to carrying out measurements, and downloading and processing data. Weather stations located at local schools can be an effective method for engaging local communities in urban heat island education (Clough and Newport 2017). Participatory approaches can also include use of thermal comfort perception surveys (Canan et al. 2019). Other participatory methods include the use of wearable sensors to detect thermal stress (Sim et al. 2018) and the use of other types mobile dataloggers (e.g. attached to bicycles) (Yokoyama et al. 2018).

Earth observation/remote sensing/modelling

Numerous earth observation, remote sensing and modelling approaches have been developed to address this indicator. For further information on these, including those used on past and current EU projects, see indicator guidelines: Air temperature change – Earth observation/Remote Sensing Review

Connection with SDGs

Goal 1
Goal 3
Goal 4
Goal 6
Goal 8
Goal 9
Goal 10
Goal 11
Goal 13
Goal 14
Goal 15
Goal 16
Goal 17

References

Original reference for indicator

Eklipse

Metric references

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Emerging approaches to thermal temperature analysis also include the use of thermal imaging cameras to measure air temperatures. Thermal cameras have previously been used to capture the impact of NbS interventions (Connop and Clough 2016; Ottelé et al. 2017), however this method generally captures a measure of surface temperature rather than air temperature. Surface temperature is assumed to correlate with air temperature as it is strongly affected by the mean radiant temperature (Matzarakis et al. 1999*), as such it should give a good indication of local human comfort. However, the magnitude of any cooling effect in relation to distance from the NbS will be correlated with the scale of the NbS in comparison to surrounding hard surfaces. This correlation makes assumptions on the impact of small-scale NbS on air temperatures unreliable for distances greater than a few centimetres from the NbS. However, methods for capturing air temperatures using thermal cameras are now being developed using white test sheets and foil (to estimate background radiation), and might have potential as a small-scale rapid method to measure local air temperatures (Chui et al. 2018).

Many studies investigating the performance of NbS combine the use of dataloggers with dynamic simulation tools for microclimate analysis (Toparlar et al. 2017). Such simulation enables potential cooling benefits of NbS interventions to be calculated at a planning stage (Zölch et al. 2019), and for NbS to be appraised compared to predicted values following installation (Chow et al. 2011). The software ENVI-met (Bruse and Fleer 1998) has emerged as the industry standard simulation technique with good results when compared to physical monitoring (Tsoka et al. 2018). However, there are limitations to the ENVI-met simulation results (Tsoka et al. 2018), with some evidence to suggest that its reliability decreases with decreasing NbS scale of NbS intervention (López-Cabeza et al. 2018).

For evaluation of larger-scale NbS interventions or city-wide impacts, surface temperature modelling approaches have generally been adopted (Rizwan et al. 2008; Hall et al. 2012; Li et al. 2018). Drones are also increasingly used to measure surface temperatures over large scales (Honjo et al 2017). Networks of automatic weather stations have also been utilised to quantify urban heat islands over entire city scales (Yang et al. 2013).

Data on the reduction of air temperature by nature-based solutions collected in these ways can be used to:

·Quantify the benefits of NbS in terms of providing thermal comfort zones for residents;

·Quantify reduction in temperature extremes/heatwaves on a city-wide scale;

·Contribute towards health and well-being evaluation linked to temperature extremes.

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ENVIRONMENTAL INDICATORS - CORE

CONNECTING NATURE

Air temperature change

Earth Observation/Remote Sensing Review

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Description

Measurement of the cooling effect of NbS by evapotranspiration and/or shading using earth observation/remote sensing indicators and tools for the effectiveness of NbS in cities based on the literature review and experience of the NbS projects presented in the CN database

Methodology

In order to assess exposure to heat stress, different methodological approaches can be applied. Along with the analysis of a single parameter, such as air temperature (Ta), surface temperature, or mean radiant temperature (Tmrt), either by taking regular measurements, the use of remote-sensing or modelling-based approaches, which are spatially explicit, are recognised in several research papers (e.g. Alavipanah et al., 2015; Chen et al., 2014; Lindberg & Grimmond, 2011).

Level of expertise

Expertise in mapping and interrogation of data using GIS software is typically required. Level of expertise required is greater with increasing complexity of software processing.

Data collection

Cost

Satellite images are the easiest way to obtain geographic information. Generally, the average cost of a raw satellite image is approximately one dollar for each sq km. There are lots of considerations when purchasing imagery but in general satellite images are cheaper than aircraft, low resolution images are cheaper than high, and old images are cheaper then new. To get some idea, you can look at the cost per sq.km of newly acquired imagery to get an idea of comparison:

- Worldview 2, 50cm pan is about €30 / sqkm
- IKonos pan, 0.8-3m resolution is about €25 /sqkm
- Deimos -1, 22m res is 15c/sqkm
- Landsat, MODIS and MERIS sensors – free.
- A high quality airborne lidar survey would be in the order of €450/sq.km.

There are a lot of ways to analyze cost (e.g. per pixel worldview is much the cheapest of the three listed above). Also note as price per km may be quoted but you will often be obliged to have minimum order of a few hundred sq.km – which may compare project costs back toward airborne if you are only interested in a small area.

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Scientific solid evidence

There are a great number of research projects which confirm the usefulness of approach to derive air temperature from satellites (see references provided above). Their work contributes to better understanding of climate monitoring and land-climate interactions.

Monitoring the status of air temperature at 2 metres above the land surface is essential for scientists to tackle climate change issues, because air temperature is a key element of all processes that guarantee life on Earth. While weather stations regularly detect and collect air temperature records, their number is limited and their distribution scattered over the Earth surface, with a stronger concentration in developed countries, mainly USA and EU. The resulting records are often patchy in both space and time. For this reason, scientists constantly test new methods to collect better and more complete global air temperature data. In this regard, an innovative method to enhance the quality of global air temperature information by analysing the land surface temperature records collected by weather stations and detected by satellites was recently developed. Based on this, a statistical model was developed that can improve monthly predictions of global air temperature. A novelty concerns the geographical coverage of the analysis: satellites can access remote areas of the planet with few weather stations or poor-quality information.

It is important to note, that there are errors in the factors used as input to these model simulations (these include factors due to anthropogenic gases and aerosols, volcanic aerosols, solar input, and changes in ozone), errors in the satellite observations (partially addressed by the use of the uncertainty ensemble), and sequences of internal climate variability in the simulations that are different from what occurred in the real world. We call these four explanations “model physics errors”, “model input errors”, “observational errors”, and “different variability sequences”. They are not mutually exclusive. In fact, there is hard scientific evidence that all four of these factors contribute to the discrepancy, and that most of it can be explained without resorting to model physics errors.

Effort

Although the satellite image is the easiest way to obtain geographic information and in general, average cost of a raw satellite image is approximately one dollar for each sq km, the important point here is whether the data which are obtained from satellite imagery will give the required accuracy in GIS or not. The strong improvement in space-borne data and consequently in the reference scale, can be evaluated by considering the following features:

- from 1 (Ikonos) to 0,61 m (Quick Bird) of panchromatic resolution at nadir
- from 4 (Ikonos) to 2,44 m (Quick Bird) of multi-spectral resolution at nadir
- simultaneous panchromatic and multi-spectral acquisitions
- radiometric range of 11 bits (2048 levels of grey) instead of the usual 8
- panchromatic band ranging from blue to near infrared

The two last characteristics in particular enable, through a proper spectral and radiometric enhancement (vs. analogical air photos e.g.), to reach a better contrast, visibility and information content and then a better target distinction

Data availability

It differs from the local context. In general, the easiest would be freely accessible RS data from:

- Glovis - Global Visualization Viewer, with easy-to-go navigation tolls, http://glovis.usgs.gov/
- NASA - http://reverb.echo.nasa.gov
- Hyperspectral Unmixing, Ground Truths: http://www.escience.cn/people/feiyunZHU/Dataset_GT.html
- http://openremotesensing.net – in this website, you not only can access to MATLAB codes of different remote sensing fields, but also you can reach some invaluable data freely.
- http://freegisdata.rtwilson.com - a categorised list of links to over 300 sites providing freely available geographic datasets - all ready for loading into a Geographic Information System.

For downloading users have to register. The images are provided as jpg for a quick preview, but also as the complete spectral-data set. There are the manuals to explain how to use the portal.

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Extended methodology

The combined usage of high-resolution satellite images and thermal infrared (TIR) data helps understanding the thermal effect of urban fabric properties and the mechanism of urban heat island (UHI) formation. In particular, it is suggested to undertake typical urban functional zoning, e.g. of downtown, for quantifying the relationship between fine-scale urban fabric properties and their thermal effect. As a result, a particular number of land surfaces and a number of aggregated land parcels extracted from, for instance, a QuickBird image can be used to characterize urban fabric properties. The thermal effect can be deduced from land surface temperature (LST), intra-UHI intensity, blackbody flux density (BBFD) and blackbody flux (BBF). The net BBF can be retrieved from the Landsat 8. The products should be resampled to fine resolution using a geospatial sharpening approach and further validated. The final results can show for instance that:
(i) On the level of urban functional zones, there is a significant thermal differential among land surfaces. Water, well-vegetated land, high-rises with light color and high-rises with glass curtain walls exhibited relatively low LST, UHI intensity and BBFD. In contrast, mobile homes with light steel roofs, low buildings with bituminous roofs, asphalt roads and composite material pavements showed inverse trends for LST, UHI intensity, and BBFD;
(ii) It can be found that parcel-based per ha net BBF, which offsets the “size-effect” among parcels, is more reasonable and comparable when quantifying excess surface flux emitted by the parcels;
(iii) When examining the relationship between parcel-level land surfaces and per ha BBF, a partial least squares (PLS) regression model can show that buildings and asphalt roads are major contributors to parcel-based per ha BBF, followed by other impervious surfaces. In contrast, vegetated land and water contribute with a much lower per ha net BBF to parcel warming.

Remote-sensing based indices used for this purpose

·Temperature condition index (TCI) – Singh et al. 2003
·Satellite remote sensing with on-the-ground observations (combination of methods) - Lotze-Campen and Lucht, 2001
Methods for acquiring the surface air temperature include:

Geographical scale

Since meteorological stations are at a low spatial density that usually cannot satisfy the needs either in scientific research or in practical applications, and many spatial interpolation methods in order to extend the air temperature from a point scale to a regional scale usually cannot reflect the detailed spatial variability as well as produce large errors, the use of remote sensing data can be beneficial. Benefiting from the fast development of remote sensing techniques, spatially distributed information on the underlying surface can be obtained. Remote sensing techniques provide a straightforward and consistent way to estimate air temperature at a regional scale with more details than meteorological data. Many studies attempted to retrieve near surface air temperature by thermal infrared remote sensing data. In general, remotely sensed data are inherently suited to provide information on urban land cover characteristics, and their change over time, at various spatial and temporal scales. In most cases, however, methods of EO and RS have been used at meso-scales using satellite imagery to map and quantify the cooling effects of green infrastructures (Koc et al., 2017).

Temporal scale

Remotely sensed data are inherently suited to provide information on urban land cover characteristics, and their change over time, at various temporal scales.

Participatory process

None

Connection with SDGs

Goal 1
Goal 3
Goal 4
Goal 6
Goal 8
Goal 9
Goal 10
Goal 11
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·temperature-vegetation index approaches (TVX)
·statistical approaches
·neural network approaches
·and energy balance approaches.

As underlined by a number of studies, remote sensing is one of the most used techniques to investigate the cooling effects of green infrastructures because large areas can be monitored and analysed simultaneously and continuously (Liwen et al., 2015). However, remote sensing does not allow for the prediction of the effects of possible NBS, or the prediction of how the NBS will develop in the future. For this purpose, modelling approaches are useful tools, that allow simulation of non-existing/future scenarios. The literature review has revealed that there are several studies which followed this methodology. Table 1 summarizes the reviewed studies that analysed NBS and urban temperature. However, in reality, heat stress is determined by multiple parameters, the most important being Ta, Tmrt, wind patterns and humidity (from the meteorological perspective), and metabolic rate, activity, age and clothing (from the physiological perspective) (Höppe, 1999). In this regard, use of ecosystem-based approaches can also have positive effects on a larger scale – for example a district of a city, or the whole city. Studies using remote sensing approaches (e.g. Alavipanah et al., 2015) or meso-scale climate modelling (e.g. Fallmann et al., 2014) show that the urban heat island effect can be significantly reduced by increasing the vegetative cover within a city, e.g. through green roofs or parks. Changes in albedo change the radiation balance of the urban environment, and lower surface temperatures (Zölch et al. 2016, 2017, 2018).
As evidenced by the studies in Table 1, there is a plethora of models for studying the effects of NBS on urban air temperature. However, not all models are adequate for all objectives, and given a specific purpose, the models should be chosen accordingly.
In order to properly assess the urban heat component of a site, there is a need to analyse the heat fluxes (EEA, 2017a, 2017b).
According to Rafael et al., (2016) the study of energy fluxes can be conducted in three main approaches:

Applied methods

For greater detail on applied and participatory methods for quantifying changes in air temperature related to NBS please see: Air temperature change - Applied/Participatory Review

References

Original reference for indicator

Eklipse

Metric references

a) References from literature review:

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i)studies that only consider the measurements of energy fluxes through the eddy covariance method, and usually compare different types of land;
ii)studies that combine flux measurements with model simulations;
iii)Studies that use models designed to simulate the key processes governing heat, moisture and momentum exchanges of the urban canopy for different applications.

All these approaches offer different benefits and present different challenges, and the chosen method should be dependent on the case study.

Table 1 Summary of the reviewed studies that analysed NBS and Urban temperature

Studies	Objective	Model
Boukhabla and Alkama, 2012	Study the impact of vegetation on air temperature	ENVI-MET
Hu, et al., 2016	Quantify land surface temperature	MODIS LST
Kim et al. , 2016	Understand the cooling effect of changes in land cover on surface and air temperatures in urban micro-scale environments	ENVI-MET
Kong et al., 2014	Explore and quantify the combined effects of factors related to the urban cooling islands intensity	LINEAR REGRESSION MODELS
Kong et al., 2016	Examine the outdoor 3D thermal environmental patterns with and without green spaces	ENVI-Met
Koc et al., 2017	Methodological framework for a more accurate assessment of the thermal performance of green infrastructure	Remote Sensing
Mackey et al., 2012	Attempt to analyse a real large-scale application by observing recent vegetated and reflective surfaces in LANDSAT images	LANDSAT
Lin & Lin, 2016	Characterize the influence of the spatial arrangement of urban parks on local temperature reduction	ENVI-MET
Sun et al., 2017	Assess the impacts of modifications in a park on the thermal comfort improving-effect of urban green spaces	ENVI-Met
Takebayashi, 2017	Examine air temperature rise in urban areas that are on the leeward side of green areas	Numerical Model
Wai et al., 2017	Determine the change in evapotranspiration from the new ecosystems	Variable infiltration capacity
Zölch, et al., 2016	Quantify the effectiveness of three types of UGI in increasing outdoor thermal comfort in a comparative analysis	ENVI-MET
Wu & Chen, 2017	Investigate how different spatial arrangements of trees in residential neighbourhoods affect the cooling effects of vegetation	ENVI-Met
Žuvela-Aloise, 2017	Evaluate the cooling potential of the blue and green infrastructure to reduce the UHI effect when applied to large areas of the city	MUKLIMO_3

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

b) References for Indicator based on the NbS projects from the CN database

AMICA (Adaptation and Mitigation – an Integrated Climate Policy Approach)

http://www.amica-climate.net
One of the project tasks was Risk and Disaster management. In this regard it is based on:
·GIS data and tools for risk assessment and management as help for decision local and regional makers for planning and disaster preparedness,
·remote sensing data on impacts and damages and urgent needs in case of disasters (GMES),
·remote sensing of urban areas (Wilson et al. 2003) has revealed a patchwork of discrete heat islands related to the distribution and structure of buildings and streets, as well as areas with much lower temperatures associated with parks and green space (Yu & Hien 2006).
Charlesworth, S.M. 2010. A review of the adaptation and mitigation of global climate change using sustainable drainage in cities. Journal of Water and Climate Change, volume 1 (3): 165-180. http://dx.doi.org/10.2166/wcc.2010.035
Wilson, J.S., Clay, M., Martin, E., Stuckey, D. & Vedder-Risch, K. 2003 Evaluating environmental influences of zoning in urban ecosystems with remote sensing. Remote Sensing of Environment. 85, 303–321.

OPERAs (Ecosystem Science for Policy & Practice)

http://www.operas-project.eu
·Remote sensing algorithms to estimate evapotranspiration are available but often not at sufficient resolution, and do not provide predictions on upcoming water use.
·More experience needs to be gained in combining technologies and scales: direct mapping of soil moisture as done with in-situ, air- or space borne radar, crop water stress mapping by thermal infrared sensors or derived from crop vigour and/or modelling of the crop/soil/atmosphere continuum.
Derkzen, M.L., van Teeffelen, A.J.A., Verburg, P.H. Quantifying urban ecosystem services based on high-resolution data of urban green space: an assessment for Rotterdam, the Netherlands. Journal of Applied Ecology, 52, 1020-1032, 2015.

OPPLA – open platform, an EU Repository of Nature-Based Solutions (https://oppla.eu)

Some projects (selected):
1) Amsterdam - NBS for greening the city and increasing resilience https://oppla.eu/amsterdam-nbs-greening-city-and-increasing-resilience
· Analysis of the cooling effect of evapotranspiration.
· Regulation of air quality by urban trees and forests
· Urban temperature regulation
Amsterdam is involved in several European research projects (Green Surge, Climate-ADAPT).
http://climate-adapt.eea.europa.eu
http://greensurge.eu
Azarakhsh R., Diasa E., Koomen E. (2016). Local impact of tree volume on nocturnal urban heat island: A case study in Amsterdam. Urban Forestry & Urban Greening 16 (2016) 50–61
City of Amsterdam (2014). Best-practices in Amsterdam Metropolitan Region. Amsterdam, 9 July 2014.
http://www.mbpr.pl/user_uploads/image/AKTUALNOSCI/akt%2011072014/Best_Practices_in_Amsterdam_Julian_Jansen.pdf
2) Barcelona: Nature-based Solutions (NBS) Enhancing Resilience to Climate Change
https://oppla.eu/casestudy/17283
· peri-urban forest of Collserola natural park and Montjuic urban Park contributes to urban cooling, notably through evapotranspiration.
Laghai H. A., Bahmanpour H. (2012) GIS Application in Urban Green space Per Capita Evaluation. Annals of Biological Research, 2012, 3 (5):2439-2446.
3) Climate Proof Glasgow: Nature-based solutions as indicators towards a climate-just transition
One of the key indicators used – cooling effect of GI.
The hypothesis underlying the estimation of cooling potential is as follows:
·Cooling provided by different types of GIs is similar
·Cooling potential depends on the extent of the GI
·Cooling effect of GI is not confined to the exact area of GI but spreads outwards (more GI means greater the extent of cooling)
We used the methods proposed by Zardo et al. (2017), Keeley (2011), and Emmanuel and Loconsole (2015) to a) group the different types of GI available in Glasgow into 3 broad types of cooling classes of GI; b) assign weight factors for 'cooling' and c) amalgamate types of green from a) above according to their spatial extent.
Zardo L, Geneletti D, Pérez-Soba M, Van Eupen M. 2017. Estimating the cooling capacity of green infrastructures to support urban planning, Ecosystem Services, 26, pp. 225-235
Dimitrov, S., Georgiev, G., Georgieva, M., Gluschkova, M., Chepisheva, V., Mirchev, P., Zhiyanski, M. 2018. Integrated assessment of urban green infrastructure condition in Karlovo urban area by in-situ observations and remote sensing. One Ecosystem 3:e21610. doi:10.3897/oneeco.3.e21610

Naturvation (2017 – ongoing)

From the NATURVATION database on the value and benefit assessment methods for urban NBS:
·modeling and detecting heat islands at different scales depending on a kernel smoothing and using remote sensing. Greenness and heat islands showed high correlation (input data: ASTER remote sensing images; output data: temperature in Kelvin).
·modeling the needs of green space for several ecosystem services, using GIS information, remote sensing and Pareto optimization (input data: GIS raster layers with information about green spaces; output data: air temperature.
·remote Sensing and LIDAR data used to estimate vegetation volume and NVDI. A 3D NVDI as constructed by multiplying the NVDI with the vegetation volume. Measured temperatures was modelled using Maximum Likelihood as a function of NVDI, 3D NVDI, distance to green / blue areas and built-area volume (input data: Remote images (1 m resolution), LIDAR data, temperature measurements; output data: temperature).
·a set of modelled GIS and remote sensing parameters used to model temperature as an effect of greenness, aerosols, buildings. Likely the method needs to be calibrated for each city/town separately (input data: GIS data of buildings, Landsat data; NVDI & AH CHRIS/PROBA satellite images, ASTER image data; output data: temperature).

URBAN Green-UP* (2017 – ongoing)

As based on Technical report by the Joint Research Centre (JRC), the European Commission's science and knowledge service and references below:
·mapping and assessing the contribution of urban vegetation to microclimate regulation (a) Deriving a map of Land Surface Temperature based on Landsat 8 Data, using a methodology based on (Du et al. 2015); b) Aggregating Land types to assess the changes in average temperature (see Figure 12), c) Estimate the Influence of green cover on surface temperature index (Under development)
·mapping urban temperature using remote sensing information (split window algorithm), using the model for assessing urban temperature and the indicator for microclimate regulation
Du C, Ren H, Qin Q, Meng J, Zhao S. 2015. A Practical Split-Window Algorithm for Estimating Land Surface Temperature from Landsat 8 Data. Remote Sens. 7:
Wegmann M, Leutner BF, Metz M, Neteler M, Dech S, Rocchini D. 2017. A grass GIS package for semi-

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

ENVIRONMENTAL INDICATORS - CORE

CONNECTING NATURE

Rainfall storage (water absorption capacity of NBS)

Applied/Participatory Review

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(2) Humboldt-Universität zu Berlin, Germany

Description

Calculating/predicting stormwater performance of NbS, for example run-off coefficients in relation to precipitation quantities measured in mm/% from NbS (e.g. green roofs, tree pits, grass etc).

Methodology

Basic measures of stormwater storage volume can be calculated without detailed analysis of flowrates. Such metrics can provide a coarse measure of the performance of nature-based solutions, such as Sustainable Drainage System (SuDS) basins, under storm conditions.

Level of expertise

Some expertise required for installation. Data analysis/interpretation can be very basic once systems are in place.

Data collection

Cost

Can be very low cost, depends on the level of sophistication and automation of the equipment.

Effort

It requires relatively low effort when using in-situ data gathering. The only onerous aspect can be the volume of data generated. If rain simulation is utilised, there can be a substantial time input in relation to planning and delivery. This is just for the duration of the testing though, so this can represent low time input compared to long-term in-situ monitoring.

Data availability

Generates new data. Baseline data prior to intervention is not necessarily required unless adapting landscape from one green state to another.

Geographical scale

Implementation is typically on a component or site level. It can be scaled-up to much larger scales through replication. However, it is more typical to model the impacts of up-scaling once results have been obtained.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

Scientific solid evidence

Strong evidence in terms of local performance but tends to be of a more binary nature (i.e. enough capacity to cope with storm event or not) compared to quantification of peak flows and delays (Env 09). These methods do however provide a good simple basis for production of infographics and figures to influence opinion. They are less valuable as methods for generating precise flowrate measurements to be embedded into flood management models.

Extended methodology

Typically, a weather station or weather radar data are used to calculate total rainfall during a rain event. Data on the stormwater performance of the nature-based solution during the event is then generated using cameras (Connop et al. 2018; Connop and Clough 2016; Clough and Newport 2017), soil moisture sensors (Alves et al. 2014), and/or pressure sensors (Connop et al. 2018; Connop and Clough 2016; Clough and Newport 2017). This data is then analysed to monitor how long after the initiation of the rain event the nature-based solution began to fill, whether the capacity was ever exceeded resulting in the release of stormwater to storm drains, and how long it took to empty following the cessation of the rain event.

If duration of monitoring is a limitation (i.e. waiting for a 1 in 100 year storm can, by definition, take a long time), simulation of storm events can also be carried out (Alves et al. 2014; Connop et al. 2018; Connop and Clough 2016; Clough and Newport 2017). By doing so, it is possible to assess the performance of the nature-based solution during rain events of known magnitude without having to wait for such events to occur naturally. Such a method is not only a useful tool for testing the SuDS performance of nature-based solutions, it can also be an effective tool for engagement and understanding of SuDS for communities not familiar with the practice.

Temporal scale

Monitoring methods are generally required over a minimum 1 year time period. Because methods are dependent upon natural rain events and performance can vary seasonally, this represents a minimum recommended time. Long-term monitoring is more advisable as NbS performance would be expected to change over time.

Participatory process

Good approach for community/stakeholder participation. This can include participation in terms of data downloading, stewardship of equipment or nature-based solution, etc. The method can also include the appointment of SuDS champions to monitor and report on any evidence of basins being overloaded. Storm simulation on SuDS features can also be an excellent mechanism to demonstrate performance to local communities and decisionmakers. In so doing, it represents a mechanism for breakdown barriers to delivery and upscaling.

Earth observation/remote sensing/modelling

For earth observation, remote sensing and/or modelling approaches, including those used on past and current EU projects, see indicator guidelines: Rainfall storage (water absorption capacity of NBS) – Earth observation/Remote Sensing Review

Connection with SDGs

Goal 2	Goal 11	Goal 15
Goal 3	Goal 12	Goal 16
Goal 4	Goal 13	Goal 17
Goal 6	Goal 14	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

Data on the stormwater performance of nature-based solutions collected in these ways can be used to:

- provide approximated values for total rainfall diverted from storm drains;
- monitor performance of SuDS systems in relation to original designed-for capacity;
- assess the potential for any additional capacity in SuDS features and therefore potential for additional catchment areas to be diverted into existing SuDS systems;
- assess long-term performance and inform management requirements;
- provide proof-of-concept for testing new/novel systems;
- assess infiltration rates in soils beneath SuDS features;
- provide easily accessible data/demonstrations to communities and decision-makers to change perceptions of SuDS.

References

Original reference for indicator

Eklipse

Metric references

Alves, L., Lundy, L., Ellis, J.B., Wilson, S. and Walters, D. The Design and Hydraulic Performance of a Raingarden for Control of Stormwater Runoff in a Highly Urbanised Area. In: ICUD (International Conference on Urban Drainage), 13th International Conference on Urban Drainage, Urban Drainage in the Context of Integrated Urban Water Management: A Bridge between Developed and Developing Countries, Sarawak, Malyasia, 7-12 September 2014. London, Middlesex University.

Clough, J and Newport, D. (2017) Renfrew Close Rain Gardens – Year two monitoring and project evaluation report, May 2017. London: University of East London.

Connop, S. and Clough, J. (2016) LIFE+ Climate Proofing Housing Landscapes: Interim Monitoring Report. London: University of East London.

Connop, S., Clough, J., Alam, R. and Nash, C. (2018) LBHF Climate Proofing Housing Landscapes: Monitoring Report 3 - October 2016 to September 2017. London: University of East London.

Connop, S., Nash, C., Gedge, D. Kadas, G, Owczarek, K and Newport, D. (2013) TURAS green roof design guidelines: Maximising ecosystem service provision through regional design for biodiversity. TURAS FP7 Milestone document for DG Research & Innovation

CONNECTING NATURE

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

ENVIRONMENTAL INDICATORS - CORE

CONNECTING NATURE

Rainfall storage (water absorption capacity of NBS)

Earth Observation/Remote Sensing Review

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Description

Earth observation and remote sensing methods for calculating/predicting stormwater performance of NbS, for eaxample run-off coefficients in relation to precipitation quantities measured in mm/% from NbS (e.g. green roofs, tree pits, grass etc).

Methodology

The use of remote sensing and GIS in water monitoring and management has been long recognized. Potential application and management are identified in promoting the concept of sustainable water resource management. Remote sensing and GIS technologies coupled with computer modelling are useful tools in providing a solution for future water resources planning and management to government especially in formulating policy related to water quality.

Level of expertise

Expertise in mapping and interrogation of data using GIS software is typically required. Level of expertise required is greater with increasing complexity of software processing.

Data collection

Cost

In hydrological and watershed modelling, remotely sensed data are found to be more valuable for providing cost-effective data input and for estimating model parameters

Effort

Urban run-off increases significantly due to increased impervious area and reduced drainage network. Evaluation of land use in urban areas plays a vital role as input to the estimation of runoff. The hydrological design standard for urban water resources planning and management is commonly based on the frequency of occurrence of heavy rainfall events. Earth observation/remote sensing/modelling approaches can play an important role in understanding how catchments function and change following NBS implementation. Effort for this tends to be related to accessibility of data and level of automation of analytical techniques.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

Scientific solid evidence

In general, it is relatively easy to delineate inundation areas using optical remote sensing data, as the water signal is much lower than the land signal, especially in the NIR spectrum due to significant water absorption. Unfortunately, the water storage of natural lakes or man-made reservoirs in some regions has rarely been studied, as it is difficult to characterize using traditional field surveys or remote sensing methods. Theoretically, the estimation of the water volume of a lake or reservoir requires both bottom topography and water level (or water surface elevation), where the water storage is the integration of the difference between the water level and the bottom. Water levels can be determined using gauged hydrological stations, but this is difficult at large scales and in less developed regions where hydrological stations are not available. Satellite radar altimetry provides a complementary means of obtaining water surface elevations. However, the sparsely distributed data constrain the large-scale application of this technique. With synoptic and frequent observations, optical remotely sensed images are able to delineate water/land the boundaries, where the water surface elevations can be determined based on their overlap with boundaries and the bottom typography. Conversely, determining the bathymetry of a lake or reservoir tends to be more challenging, requiring special equipment and considerable labour and money. Thus, the bottom topographical measurements of hundreds of large water bodies in the YRB appear to be practically impossible.

Extended methodology

Remote sensing of precipitation is pursued through a broad spectrum of continuously enriched and upgraded instrumentation, embracing sensors which can be ground-based (e.g., weather radars), satellite-borne (e.g., passive or active space-borne sensors), underwater (e.g., hydrophones), aerial, or ship-borne. There are a variety of papers on all aspects of remote sensing of precipitation, including applications that embrace the use of remote-sensing techniques of precipitation in tackling issues, such as precipitation estimations and retrievals along with their methodologies and corresponding error assessment, precipitation modelling including:

Data availability

Remotely sensed data are nowadays commonly used for regional/global monitoring of hydrological variables including soil moisture, rainfall, water levels, flood extent, evapotranspiration or land water storage and the forcing, the calibration or the assimilation into hydrodynamics or hydrological or hydrometeorological models. In the years to come, recent and future satellite sensors, some of them specifically designed for hydrological purposes, will provide systematic observations of hydrological parameters (e.g., surface and sub-surface storages, and fluxes) at high spatial and temporal resolutions. This will offer new applications for the hydrological community.

Geographical scale

At various geographical scales, but tends to be better suited to larger scales than micro-scales.

Temporal scale

Can be used at various temporal scales. Access to high resolution historical data can be a limiting factor in assessing past change.

Participatory process

A methodology for identifying the suitability for different rainwater harvesting interventions using a participatory GIS approach and field survey was proposed by Ziadat et al. (2012). Options for implementing different rainwater harvesting interventions can be identified with the participation of local communities. Field investigations indicated that the applied approach helped to select the most promising fields. The approach showed that participatory GIS approaches may be used to integrate socio-economic and biophysical criteria and facilitate the participation of farmers to introduce rainwater harvesting interventions in dry rangeland systems to mitigate land degradation.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

Validation, instrument comparison and calibration, understanding of cloud microphysical properties, precipitation downscaling, precipitation droplet size distribution, assimilation of remotely sensed precipitation into numerical weather prediction models, measurement of precipitable water vapor, etc. Recently, there have been several papers on new technological advances as well as campaigns and missions on precipitation remote sensing (e.g., TRMM (Tropical Rainfall Measuring Mission), GPM (Global Precipitation Measurement).

The latitude, longitude and elevation data for selected points within the urban area limits can be taken as input to the Surfer worksheet to generate a data file for Surfer Plotter. Kriging methods can be used for generating grid data. Using the map option, a 3D surface map with wire frame can be obtained. The flow direction can be obtained for the drainage system using the grid vector map option available in the Surfer 8.0. The vector map option provides direction and magnitude which can be derived from a grid.

In-fill of SuDS features such as detention basins can be measured using satellite imagery, but this is dependent upon the frequency of image capture over the area in question. Imagery is frequently used to measure flood extent (see Env09_RS).

There is potential to monitor water storage variation (e.g. ground water, soil water) surface waters (lakes, wetlands, rivers), water stored in vegetation and snow and ice using time variable gravity field satellite observation. The Gravity Recovery and Climate Experiment (GRACE), an Earth System Science Pathfinder mission, will provide highly accurate terrestrial water storage change estimates in large watersheds.

b) References for Indicator based on the NbS projects from the CN database

OPERAs

http://www.operas-project.eu

·Remote sensing algorithms to estimate evapotranspiration are available but often not at sufficient resolution, and do not provide predictions on upcoming water use.

OPPLA – different projects.

Connection with SDGs

Goal 2	Goal 11	Goal 15
Goal 3	Goal 12	Goal 16
Goal 4	Goal 13	Goal 17
Goal 6	Goal 14	

Applied methods

Hydrologist have increasingly started using GIS-based distribution modeling approaches. However, more applied and participatory approaches are possible. For these approached please see: Rainfall storage (water absorption capacity of NBS) - Applied/Participatory Review

References

a) From the literature review

Gabella, M.; Morin, E.; Notarpietro, R.; Michaelides S. (2013) Precipitation field in the Southeastern Mediterranean area as seen by the Ku-band spaceborne weather radar and two C-band ground-based radars. Atmos. Res., 119, 120–130.

Katsanos, D.; Retalis, A.; Tymvios, F.; Michaelides, S. (2016) Analysis of precipitation extremes based on satellite (CHIRPS) and in situ dataset over Cyprus. Natural Hazard., doi:10.1007/s11069-016-2335-8.

Lane, J.; Kasparis, T.; Michaelides, S.; Metzger, P. (2017) A phenomenological relationship between vertical air motion and disdrometer derived A-b coefficients. Atmos. Res., doi:10.1016/j.atmosres.2017.07.011.

Michaelides, S.; Levizzani, V.; Anagnostou, E.; Bauer, P.; Kasparis, T.; Lane, J.E. (2009) Precipitation: Measurement, remote sensing, climatology and modeling. Atmos. Res. , 94, 512–533.

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Schultz G A (1997) Use of remote sensing data in a GIS environment for water resources management. In: Remote sensing and geographic Information Systems for Design and Operation of Water Resources Systems (Proceedings of Rabat Symposium S3, April 1997). IAHS Publ. no. 242, 1997

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ENVIRONMENTAL INDICATORS - CORE

CONNECTING NATURE

Flood peak reduction/delay

Applied/Participatory Review

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Description

Assessment of co-benefits/dis-benefits of different SuDS options - in relation to peak flow reduction (e.g. % reduction in absolute height of peak floodwaters) and/or delay (e.g. increase in time to flood peak)

Methodology

Monitoring of SuDS performance using in-situ gauges. Typically, a weather station or weather radar data is used in combination with flowrate or water depth monitoring devices (e.g. datalogging v-notch weirs, tipping bucket rain gauges, in-line turbine flowmeters, depth sensors, soil moisture sensors, and infiltrometers). The weather data is used to calculate total rainfall entering the study area (e.g. rainfall depth/unit time x catchment area).

Level of expertise

Expertise needed for design and implementation and management of equipment. Relatively straightforward data analysis once systems are in place.

Data collection

Cost

Can be relatively low cost. Depends on the level of sophistication and automation of equipment.

Effort

In-situ data gathering therefore relatively low effort. Data analysis can be more onerous depending on frequency and duration of data capture.

Data availability

Generates new data. Baseline data prior to intervention is beneficial.

Geographical scale

Implementation is typically on a site or street level. It can be scaled-up to much larger scales. However, it is more typical to model the impacts of up-scaling once results have been obtained.

Temporal scale

Monitoring methods are generally required over a minimum 1 year time period. Because methods are dependent upon natural rain events and performance can vary seasonally, this represents a minimum recommended time. Long-term monitoring is more advisable as NbS performance would be expected to change over time.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

Scientific solid evidence

Strong evidence in terms of local performance. Can be scaled-up across many sites. Results need to be added into flood management models in order to understand the overall impact across a city/neighbourhood/site.

Extended methodology

Monitoring devices are then used to calculate the rate that water enters and/or leaves a nature-based solution feature. If compared to a control feature (without nature-based solution) or a baseline calculated for the site before the nature-based solution was installed, it is possible to calculate the percentage reduction in absolute height of peak floodwaters and the delay to peak flow.

Several projects have reported the methods and results of such monitoring (Asleson et al. 2009; Royal Haskoning 2012; Alves et al. 2014; Perales-Momparler et al. 2014; 2017; Philadelphia Water Department 2014; Connop et al. 2013; 2018; Connop and Clough 2016; Clough and Newport 2017; De-Ville et al. 2018; Susdrain 2018).

A review of selected SuDS that were monitored to test hydrologic/hydraulic efficiency can be found in Lampe et al. (2005).

Key drivers for such monitoring include:

- ensuring that systems installed perform as designed following installation;
- to assess long-term performance and inform management requirements;
- proof of concept for testing new/novel systems;
- community engagement with new SuDS installations.

Extended metric references

Perales-Momparler, S., Hernández-Crespo, C., Vallés-Morán, F., Martín, M., Andrés-Doménech, I. and Andreu Á, J. and Jefferies, C. (2014) SuDS efficiency during the start-up period under Mediterranean climatic conditions. Clean-Soil Air Water 42(2), pp. 178-186.
Philadelphia Water Department (2014) Green City, Clean Waters Comprehensive Monitoring Plan: City of Philadelphia Combined Sewer Overflow Long Term Control Plan Update. Available from: http://www.phillywatersheds.org/doc/Revised_CMP_1_10_2014_Finalv2.pdf
Royal Haskoning (2012) Lamb Drove SuDS monitoring project, final report. Report produced for Cambridge County Council. Available from: https://ccc-live.storage.googleapis.com/upload/www.cambridgeshire.gov.uk/business/planning-and-development/Final_Monitoring_Report.pdf?inline=true
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Participatory process

Can include participation in terms of data download, stewardship, etc.

Earth observation/remote sensing/modelling

For earth observation, remote sensing and/or modelling approaches, including those used on past and current EU projects, see indicator guidelines:
Flood peak reduction/delay – Earth observation/Remote Sensing Review

Connection with SDGs

Goal 2	Goal 11	Goal 15
Goal 3	Goal 12	Goal 16
Goal 4	Goal 13	Goal 17
Goal 6	Goal 14	

References

Original reference for indicator

Eklipse

Metric references

Alves, L., Lundy, L., Ellis, J.B., Wilson, S. and Walters, D. The Design and Hydraulic Performance of a Raingarden for Control of Stormwater Runoff in a Highly Urbanised Area. In: ICUD (International Conference on Urban Drainage), 13th International Conference on Urban Drainage, Urban Drainage in the Context of Integrated Urban Water Management: A Bridge between Developed and Developing Countries, Sarawak, Malyasia, 7-12 September 2014. London, Middlesex University.
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ENVIRONMENTAL INDICATORS - CORE

CONNECTING NATURE

Flood peak reduction/delay

Earth Observation/Remote Sensing Review

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Description

Assessment of co-benefits/dis-benefits of different SuDS options - in relation to peak flow reduction (e.g. % reduction in absolute height of peak floodwaters) and/or delay (e.g. increase in time to flood peak) using earth observation and remote sensing methods

Methodology

The use of remote sensing and GIS in water monitoring and management has been long recognized. Potential application and management is identified in promoting the concept of sustainable water resource management. In conclusion remote sensing and GIS technologies coupled with computer modelling are useful tools in providing a solution for future water resources planning and management to government, especially in formulating policy related to water quality.

Level of expertise

Expertise in mapping and interrogation of data using GIS software is typically required. Level of expertise required is greater with increasing complexity of software processing.

Data collection

Cost

In hydrological and watershed modelling, remotely sensed data are found to be more valuable for providing cost-effective data input and for estimating model parameters. Freely available remote sensing data include e.g. Rain Measurement Mission satellite precipitation data, Digital Elevation Model (DEM), Geographic Informational System (GIS), Hydrological model (Hydrologic Engineering Centre's Hydraulic Modelling System: HEC-HMS) and Hydraulic model (Hydrologic Engineering Centre's River Analysis System: HEC-RAS).

Effort

Effort is generally related to the automation of the data processing technique and the availability of data. In hydrological and watershed modelling, remotely sensed data are found to be more valuable for providing cost-effective data input and for estimating model parameters.

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Scientific solid evidence

Advances in remote sensing technology and new satellite platforms such as ALOS sensors widened the application of satellite data. One of the many fields that these technologies can be applied to is to validate flood inundation models. For a long-time flood extent from flood inundation models were validated using ground-truthed surveys with limited reliability. Where available, high resolution satellite data allows the simultaneous assessment of large areas for generating evidence of flooding extent.

Remotely sensed data are now commonly used for regional/global monitoring of hydrological variables including soil moisture, rainfall, water levels, flood extent, evapotranspiration or land water storage and the forcing, the calibration or the assimilation into hydrodynamics or hydrological or hydrometeorological models. In the years to come, recent and future satellite sensors, some of them specifically designed for hydrological purposes, will provide systematic observations of hydrological parameters (e.g., surface and sub-surface storages, and fluxes) at high spatial and temporal resolutions. This will offer new applications for the hydrological community.

Most of the time non-structural measures like flood forecasting, proper early warnings and conducting awareness programs among the flood affected community, etc., can be very effective. Modelling of watersheds with modern technology makes this easy. Application of GIS and remote sensing technology to map flood areas will make it easy to plan non-structural measures which reduce the flood damages and risks involved.

Extended methodology

Different studies have extracted flood extent from satellite images available for flood events that occurred in a particular period. That can then be compared with the flood extent derived from the flood extent obtained for the annual rainfall using HEC-HMS and HEC-RAS. Based on the flood extent, it is possible to develop, demonstrate and validate an information system for flood forecasting, planning and management using remote sensing data with the help of Flood Hazard Maps for different return periods (10, 20, 50 and 100 years). This supports assessment of the population vulnerability and physical vulnerability of the lowest administrative division subjected to floods.

Data availability

Freely available remote sensing data include e.g. Rain Measurement Mission satellite precipitation data, Digital Elevation Model (DEM), Geographic Informational System (GIS), Hydrological model (Hydrologic Engineering Centre's Hydraulic Modelling System: HEC-HMS) and Hydraulic model (Hydrologic Engineering Centre's River Analysis System: HEC-RAS). However, there are some limitations in accuracy due to the course resolution of the precipitation and DEM data. The Rain Measurement Mission generated a global estimation of precipitation based on remote sensing observation. This algorithm, also known as Multi-Satellite Precipitation Analysis (TMPA), has high spatial (0.258) and temporal (3h) resolution, and is widely used in hydrological modelling, especially in data sparse regions. The result of flood modelling based on remote sensing rainfall data will be useful for developing regional flood early warning and flood mitigation systems in flood hazardous areas.

Geographical scale

Techniques are applicable at range of geographical scales. Automated methods are particularly valuable for large-scale analyses. High resolution data is needed for finer-scale analysis.

Temporal scale

Techniques can be applied at various temporal scales. Lack of access to high resolution data can be a limiting factor for historical studies.

Participatory process

A participatory approach to monitoring flood extent can supplement remote sensing approaches. This can help to strengthen and increase awareness of non-structural measures like flood forecasting and early warning systems.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

b) References for Indicator based on the NbS projects from the CN database

IMPRESSIONS (Impacts and risks from high-end scenarios: strategies for innovative solutions)
http://www.impressions-project.eu/
·Mapping land use, ecosystem functions, and ecosystem services using cutting-edge remote sensing and machine learning techniques
·A coordinated effort to integrate and analyse a higher quantity and quality of CO2 and CH4 data, from in situ and remote sensing observations encompassing atmosphere, land and oceans.
·Remote sensing of forestry

NAIAD (2016 – ongoing) (Nature Insurance Value: Assessment & Demonstration)
no data found on the use of remote sensing. However, there is an information in the task:
Demonstrating and assessing the insurance value of nature-based solutions to prevent flooding and drought risks

OPERANDUM (2018 – ongoing) (OPEn-air laboRAtories for Nature baseD solUtions to Manage environmental risks)

- design and development of the Natural based solutions planned for the Italian OAL: introduce a novel-vegetated sand dune in the complex land- marine environment of the north Emilia-Romagna coastline to reduce storm surge and related coastal erosion; install herbaceous perennial deep rooting plants as coverage of earth embankments for the mitigation of flood risk and salt wedge intrusion in the Po delta
  https://www.operandum-project.eu/the-project/

OPPLA (https://oppla.eu)
The project in this regard selected from the OPPLA data base:
a)Wetlands to reduce flood risks in Aarhus (DK)
b)De Doorbrak (NL)
c)Urban hybrid dunes in Barcelona (ESP)
d)Natur in grauen Zonen (DE)
e)Ljubljana Region: Dealing with flood risk and mobility challenges (SLO)
f)SUDS (SUstainable Drainage Systems) (UK)
Embankments against flooding in Kristlandstad (SE)

Synergies

Much of the spatial data required can be used for many other of the mapping indicators, including those for social and economic indicators.

Connection with SDGs

Goal 2	Goal 11	Goal 15
Goal 3	Goal 12	Goal 16
Goal 4	Goal 13	Goal 17
Goal 6	Goal 14	

Applied methods

For greater detail on applied and participatory methods for quantifying changes in air temperature related to NBS please see: Flood peak reduction/delay - Applied/Participatory Review

References

Original reference for indicator

Eklipse

Metric references

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ENVIRONMENTAL INDICATORS - CORE

CONNECTING NATURE

Water quality

Applied/Participatory Review

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Description

Calculating/predicting the change in water quality caused by diverting rainfall or surface water flow through an NbS (e.g. green roof, tree pit, bioretention pond, rain garden, wet woodland, naturalised waterway, etc). Implementing an NbS can result in a positive or negative impact on water quality. This is dependent upon: the quality of water entering the system, the type of NbS, the age of NbS, and the water quality parameters being investigated. Both positive and negative impacts of NbS on water quality are of relevance for this indicator.

Methodology

Choice of parameter to measure should be related to issues of water pollution, the type of plant species and substrates used in the bioretention process, physio-chemical processes, and the desired quality of water at the end of processing (Dagenais et al. 2018; Payne et al. 2018, Batalini de Macedo et al. 2019).

Level of expertise

Some expertise required for installation of equipment and/or sampling methodology. Expertise required for sample analysis depends on the level of automation of the sampling equipment (e.g. in stream dataloggers carry out sample analysis automatically). Samples taken may require specialist analytical methods, these are typically carried out through an accredited laboratory. Data analysis/interpretation against statutory guidelines can be very basic once systems are in place.

Data collection

Cost

Can be low cost, but this is very dependent upon the level of sophistication, frequency of sampling, and automation of the equipment. The financial requirements associated with this indicator tend to be associated with a sliding scale of cost. Cost increases with: greater numbers of water quality parameters; greater numbers/frequency of sampling; and greater levels of precision and accuracy. Cheapest solutions are generally represented by the use of citizen science, particularly in relation to monitoring biological indicators.

Effort

Automated in-site data gathering is very low effort, with installation, data analysis and equipment maintenance the only inputs required. The only onerous aspect can be the volume of data generated. If samples are taken manually, effort can be substantially more with container preparation and site visits required.

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Scientific solid evidence

Robustness of evidence depends upon the precision and accuracy of the method adopted. Frequency and design of sampling is also linked to the strength of evidence. For example, regular sampling may provide long-term and seasonal patterns but may miss significant short-term events such as 'first flush' of urban areas following long dry periods.

Extended methodology

Basic measurements of water quality associated with NbS have included:

- NO3, NO2 and NH3 (Payne et al., 2014; Batalini de Macedo et al. 2019)
- Phosphorus (Bratieres et al. 2008a)
- Heavy metals (Blecken et al. 2011; Batalini de Macedo et al. 2019)
- Suspended/Sedimentary solids (Hatt et al 2008; Batalini de Macedo et al. 2019, Fowdar et al. 2017)
- Micropollutants (such as hydrocarbons and pesticides) (Zhang et al. 2014)
- Colour (Batalini de Macedo et al. 2019)
- Turbidity (Batalini de Macedo et al. 2019)
- Chemical Oxygen Demand (Batalini de Macedo et al. 2019; Leroy et al. 2016)
- Biological Oxygen Demand (Fowdar et al. 2017; Leroy et al. 2016)
- Pathogens (Bratieres et al. 2008b)
- Hydrocarbons (Hong et al. 2006)
- Total organic carbon (TOC) and dissolved organic carbon (DOC) (Fowdar et al. 2017)

Sampling can be done using in-situ stormwater sampling equipment (e.g. Teledyne ISCO 6712/7400 (Hong et al. 2006), ISCO GLS auto-sampler (Lucke and Ncihols 2015), ISCO Model 6712 Portable Sampler (Stagge et al. 2012)). This allows continuous and simultaneous sampling. Where this is not possible, or is prohibited by cost, v-notch weirs installed to monitor flow rate can be used to create a reservoir that can be sampled using a manual sampling technique (Hong et al. 2006). Alternatively, artificial drain/reservoir features can be incorporated into the NbS design from which water samples can be collected (Leroy et al. 2016).

Effort under this scenario will be strongly linked with frequency of sampling. Effort can also be linked to the duration of the monitoring, with short term analysis of impact relatively low effort compared to long term monitoring schemes that evaluate change in NbS performance over time (linked to changing performance with maturation of the NbS).

Data availability

Generates new data. Baseline data prior to intervention is not always necessary as it may be possible to measure water quality entering and leaving the NbS to get a measure of water quality change. If comparison to a previous green or grey space is require though, establishing baseline data prior to installation can be of benefit.

Geographical scale

Implementation is typically on a component or site level. It can be scaled-up to much larger scales through replication. However, it is more typical to model the impacts of up-scaling once results have been obtained that can be fed into the model.

Temporal scale

Monitoring methods can be adopted for short-term snapshots associated with specific pollution/flow/rain events, or for simulated pollution incidents. However, long-term in-situ monitoring is generally more effective in terms of capturing a more comprehensive overview of the performance of the NBS over a range of environmental conditions. Long-term monitoring is also recommended as NbS performance would be expected to change over time.

Participatory process

Opportunities are available for a participatory process, particularly in relation to carrying out visual inspection of water (e.g. in relation to combined sewage overflow occurrences and water sampling (Farnham et al. 2017; Jollymore et al. 2017).

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Laboratory analysis of each parameter is then carried out based on standardised analytical methods (e.g. Standard Methods for Examination of Water and Wastewater (APHA, 2015)). An alternative, and more participatory method of monitoring water quality can be achieved through the use of biological indicators to monitor moving or still waterbodies. An example of this is the Biological Monitoring Working Party (BMWP) scoring system (Armitage et al. 1983) or adapted versions of this protocol (e.g. Romero et al. 2017). Samples are typically collected by kick sampling or surber sampling (Everall et al. 2017), providing opportunities for community engagement (including as part of school curricular activities). Wetland plants have also been used as biological indicators of water chemistry in wetland areas (US EPA 2002). Simulated storm events with artificially created water pollution can be used as a mechanism to validate performance of NbS (Lucke and Nichols 2015). This is of particular value to ensure continuity of performance as the NbS ages/matures.

Data on the water quality performance of nature-based solutions collected in these ways can be used to:

- Quantify the benefits of NbS in terms of stormwater/waterway quality improvement;
- Assess any negative impact on water quality of diverting rainwater through NbS;
- Calculate total pollution loading being released from an NbS (when combined with flow rate calculations);
- Assess compliance with Water Framework Directives;

Provide easily accessible data to communities and decision-makers to change perceptions of SuDS. The water quality assessment for SuDS developments (SuDS manual) tool is a simple way of comparing the treatment effectiveness of various SuDS schemes. http://www.uksuds.com/drainage-calculation-tools/water-quality-assessment-for-suds-developments

Extended metric references

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Water quality analysis can be linked to local schools/universities, especially through schemes that use BMWP methodologies to monitor water quality in waterways. Automated dataloggers offer less opportunity for such participation with participation limited to observing and processing the data produced. There are also opportunities for stewardship of equipment or nature-based solution, etc.

Earth observation/remote sensing/modelling

For earth observation, remote sensing and/or modelling approaches, including those used on past and current EU projects, see indicator guidelines: Water quality – Earth observation/Remote Sensing Review

Connection with SDGs

Goal 2	Goal 11	Goal 15
Goal 3	Goal 12	Goal 16
Goal 4	Goal 13	Goal 17
Goal 6	Goal 14	

References

Original reference for indicator

Eklipse

Metric references

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ENVIRONMENTAL INDICATORS - CORE

CONNECTING NATURE

Water quality

Earth Observation/Remote Sensing Review

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Description

Using earth observation and remote sensing to calculate the change in water quality caused by diverting rainfall or surface water flow through an NbS (e.g. green roof, tree pit, bioretention pond, rain garden, wet woodland, naturalised waterway, etc). Implementing an NbS can result in a positive or negative impact on water quality. This is dependent upon: the quality of water entering the system, the type of NbS, the age of NbS, and the water quality parameters being investigated. Both positive and negative impacts of NbS on water quality are of relevance for this indicator.

Methodology

Remote sensing and earth observation approaches are only generally used to provide background/mapping data that can be fed into water quality modelling. However, some remote sensing techniques are emerging.

Level of expertise

Data processing expertise is needed.

Data collection

Cost

Can be low cost but cost is dependent upon the availability of data and level of automation of the data processing.

Effort

Can be low effort compared to physical monitoring but depends upon the level of automation.

Data availability

Remote sensing techniques depend on the ability to measure these changes in the spectral signature backscattered from water and relate these measured changes by empirical or analytical models to a water quality parameter. The optimal wavelength used to measure a water quality parameter is dependent on the substance being measured, its concentration, and the sensor characteristics. Major factors affecting water quality in water bodies across the landscape are suspended sediments (turbidity), algae (i.e., chlorophylls, carotenoids), chemicals (i.e., nutrients, pesticides, metals), dissolved organic matter), thermal releases, aquatic vascular plants, pathogens, and oils. Suspended sediments, algae, oils, aquatic vascular plants, and thermal releases change the energy spectra of reflected solar and/or emitting thermal radiation from surface waters which can be measured using remote sensing techniques.

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Scientific solid evidence

Methods can provide robust data, but the range of water quality parameters that this can provide for is limited.

Extended methodology

Methods for delivering this indicator include:
The remote sensing technology uses high resolution satellite or airborne optical imagery (visible and infrared), DSM (Digital Surface Model) height information and existing building out- lines maps (footprints) to estimate the percentage of vegetated areas on building roofs and to identify potential green roof sites.
The new remote sensing technology provides municipalities with the opportunity to use this data for urban planning decisions in the field of climate modelling, drainage system calculation and biodiversity networks.
According to Ritchie et al. (2003), remote sensing techniques can be used to monitor water quality parameters (i.e., suspended sediments (turbidity), chlorophyll, and temperature). Optical and thermal sensors on boats, aircraft, and satellites provide both spatial and temporal information needed to monitor changes in water quality parameters for developing management practices to improve water quality. Recent and planned launches of satellites with improved spectral and spatial resolution sensors should lead to greater use of remote sensing techniques to assess and monitor water quality parameters. Integration of remotely sensed data, GPS, and GIS technologies provides a valuable tool for monitoring and assessing waterways. Remotely sensed data can be used to create a permanent geographically located database to provide a baseline for future comparisons. The integrated use of remotely sensed data, GPS, and GIS will enable consultants and natural resource managers to develop management plans for a variety of natural resource management applications.
In addition, Massoudieh et al. (2017) developed a modelling framework to predict the water quality impacts of urban stormwater green infrastructure systems. Shi et al. 2017 demonstrated links between urban water quality and different landuse patterns that could be used to predict improvements in water quality.

Most chemicals and pathogens do not directly affect or change the spectral or thermal properties of surface waters, so they can only be inferred indirectly from measurements of other water quality parameters affected by these chemicals. Remote sensing tools provide spatial and temporal views of surface water quality parameters that are not readily available from in situ measurements, thus making it possible to monitor the landscape effectively and efficiently, identifying and quantifying water quality parameters and problems.

Geographical scale

Typically used on medium/large scale monitoring as resolution of satellite imagery can create a barrier to monitoring smaller scale areas.

Temporal scale

Temporal scale is generally linked to frequency of data capture. If dependent upon aerial photography, this can be good for long-term studies, but not for capturing fluctuations between image capture dates. Satellite imagery can provide an opportunity for greater frequency, but often lower resolution.

Participatory process

Low opportunity for participation.

Connection with SDGs

Goal 2	Goal 11	Goal 15
Goal 3	Goal 12	Goal 16
Goal 4	Goal 13	Goal 17
Goal 6	Goal 14	

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b) References for Indicator based on the NbS projects from the CN database

Projects related to the assessment Water Security supported by Earth observation remote sensing, Big Data, and citizens data.

OPERAs
http://www.operas-project.eu
·Remote sensing algorithms to estimate evapotranspiration are available but often not at sufficient resolution, and do not provide predictions on upcoming water use.

OPPLA
Aquaval (ESP)
White Cart Water Project – Glasgow, UK
Waterberging Rijssen-Holte (NL)

Applied methods

For greater detail on applied and participatory methods for quantifying changes in air temperature related to NBS please see: Water Quality - Applied/Participatory Review

References

Metric references

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ENVIRONMENTAL INDICATORS - CORE

CONNECTING NATURE

Inundation risk for critical urban infrastructures (probability)

Applied/Participatory Review

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Description

Probability of a reduction of inundation risk for critical urban infrastructures based on more applied and participatory hydraulic modelling and GIS assessment.

Methodology

Metrics are based on the quantification of infrastructure that has a reduced risk of flooding due to NBS implementation. Ultimately, this relates to a reduced economic cost of flooding, or increased health & wellbeing of communities due to reduced stress levels associated with flooding or risk of flooding. It should be noted that, if NBS is poorly designed or well-designed but poorly constructed, it has the potential to lead to increased local flooding risk for some areas.

Level of expertise

Expertise required is very much based on the complexity of the data requirements of the model. Very basic models exist that require very low levels of expertise and are ideal for use as community engagement tools. To maximise the value of participatory approaches, experience of managing such projects is beneficial.

Data collection

Cost

If open source tools are used, cost can be very low. Cost increases if software purchase/registration is required, or consultancy service to process data. Participatory processes will have a cost too. The cost will depend on the level of engagement.

Effort

Similarly to the level of expertise required, effort is directly related to the data requirements of the simulation software. If the simulation software requires considerable data input and this is not freely available, effort for preparation can be considerable. However, if data is available, or data input is basic, the effort required can be low.

Data availability

Baseline data to support simulation is generally a necessity, although basic simulation tools can derive data from open source mapping data (e.g. digital terrain models).

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Scientific solid evidence

Robustness of evidence depends upon the level of precision of the simulation software and the data analysed. Typically, simulations requiring the most basic data input are associated with the least precise results. This is not always the case, however, and model validation (either through real-world testing or validation against other models) is recommended.

Extended methodology

Evaluation is typically based on simulation of storm events with hypothetical NBS components implemented to assess overall impact of flood risk to local infrastructure. Such models can be tested and supplemented by real-world data on stormwater management performance (Johannessen et al. 2019). Such monitoring is advisable after NBS installation to ensure that NBS design, construction and performance corresponds to that included in the simulation. For applied methods to evaluate stormwater management performance see metrics reviews Rainfall storage (water absorption capacity of NBS) and Flood peak reduction/delay.

Numerous simulation models exit, examples of commonly used models for such evaluation include:

- the EPA's Storm Water Management Model (SWMM) (Rossman 2015)
- OSTRICH-SWMM (Macro et al. 2019)
- SWMM-based TOPSIS multi-criteria decision analysis tool (Xu et al. 2017)
- the Landscape Green Infrastructure Design model, L-GriD (Zellner et al. 2016)
- Long-Term Hydrologic Impact Assessment (L-THIA) model (Lim et al. 2001)
- City Catchment Analysis Tool (CityCAT) (Pregnolato et al. 2016)

The models differ in relation to level of input necessary, and thus the level of expertise required for use. Typically, the models requiring more basic input also have less precision in relation to results. Comparative reviews of the performance of some of these models have been carried out in relation to the balance between data requirement and confidence in results and the need for validation (Bhaduri et al. 2001; Darabi et al. 2019).

Geographical scale

Simulations are typically carried out on catchment scales identifying flood risk areas under different climate scenarios. Local impacts can also be modelled to assess impacts on storm sewer systems and local flood risk areas.

Temporal scale

Monitoring methods can be adopted for short-term snapshots associated with single extreme events. They can also be adapted for long-term strategic simulations in relation to city-wide rollout programmes over long time periods and changes in flood risk with future climate change predictions.

Participatory process

Opportunities are available for a participatory process, particularly in relation to stakeholder decision-making (Voinov and Gaddis 2008; Voinov et al. 2016; Gray et al. 2018) and or data-gathering through ICT-enabled citizen observatories (When et al. 2015). Involving stakeholders through active participation can increase the legitimacy of risk processes, public acceptance, commitment, and support with respect to decision-making processes (Inam et al. 2017).

Earth observation/remote sensing/modelling

Metrics for this indicator are generally associated with simulation/modelling and are less orientated towards applied and participatory methods. A review of earth observation and remote sensing methodologies, including those adopted by past and current EU research and innovation projects can be found in: Inundation risk for critical urban infrastructures (probability) – Earth observation/Remote Sensing Review

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These tools are typically used to compare the impact on infrastructure risk of centralized and distributed green infrastructure solutions (Damodaram et al., 2010; Loperfido et al., 2014), or to compare green with grey infrastructure solutions (Freni et al., 2010; Lucas and Sample, 2015), to support decision-making processes. However, they can also be used as a predictive evaluation tool following NbS implementation. Examples of their use can include assessment of specific NbS solutions such as green roofs (Johannessen et al. 2019) or rainwater harvesting systems (Palla et al. 2017), and also more general NbS implementation (Zellner et al. 2016).

Multiple criteria decision-making storm simulation tools can also facilitate participatory approaches, empowering stakeholders to make decisions about their local environment and promoting deeper understanding of the local environment (Voinov and Gaddis 2008; Voinov et al. 2016; Gray et al. 2018), or ground-truthing real world performance compared to simulation outputs (When et al. 2015). Fieldwork data can be collected through interviews with inhabitants and very detailed mapping can be carried out to clearly identify elements at risk. Information collected at the household level should concern: 1) socio-economic data, 2) information on the property, 3) flooded houses and 4) strategies of risk reduction. This local knowledge is an important tool to obtain accurate data useful for understanding flood hazard and vulnerability patterns. It provides quantitative data at the household level that can be used to complement conventional GIS and remote sensing data.

Although the participatory approach allows improving on the analysis of satellite images, it has some limitations. The local population can give inaccurate information, especially in terms of hazard mapping and spatial perception. However, if using neighbourhood scale paper maps, handheld GPS and mobile SIG, the accuracy of mapping can be increased. So, the integration of local knowledge together with remote sensing can improve data, for example when satellite images are covered by clouds, and also yield new or more accurate information in terms of hazard intensity, exposure and location of key infrastructures. This mixed approach is an alternative to the use of expensive high-resolution satellite images, when financial resources are scarce or when images are not available on the study area. Thus, this approach could be replicated for different risks in other contexts.

Connection with SDGs

Goal 1	Goal 8	Goal 14
Goal 3	Goal 9	Goal 15
Goal 4	Goal 10	Goal 16
Goal 6	Goal 11	Goal 17
Goal 7	Goal 13	

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Original reference for indicator

Eklipse; Pregnolato et al., 2016

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Reduction in flood-risk by nature-based solutions simulation can be used to:

- Support the development of strategic plans for NbS implementation to reduce flood risk and comply with Flood Risk Management;
- Predict the impact of individual NbS projects;
- Quantify the predicted impact of implemented NbS;
- Promote stakeholder engagement in NbS planning;
- Support the leveraging of finances necessary for delivering NbS projects.

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ENVIRONMENTAL INDICATORS - CORE

CONNECTING NATURE

Inundation risk for critical urban infrastructures (probability)

Earth Observation/Remote Sensing Review

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Description

Probability of a reduction of inundation risk for critical urban infrastructures based on earth observation and remote sensing approaches.

Methodology

Advances in remote sensing technology and new satellite platforms such as ALOS sensors widened the application of satellite data. One of the many fields that these technologies can be applied is to validate flood inundation models. For a long time, flood extent from flood inundation models were validated using ground-truth surveys which was not very reliable. Different studies have extracted flood extent from satellite images available for flood events occurring in particular periods.

Level of expertise

There a semi-automatic method for flood mapping, based only on free satellite images and open-source software. The proposed method is suitable to be applied by the community involved in flood hazard management, not necessarily experts in remote sensing processing. Multispectral satellite data acquired by MODIS, Proba-V, Landsat, and Sentinel-2 and synthetic aperture radar (SAR) data collected by Sentinel-1 can be used to detect flooded areas using different methodologies (e.g., Modified Normalized Difference Water Index, SAR backscattering variation, and supervised classification).
Much of this freely available data is available with the first level of atmospheric or radiometric calibration, allowing their use by different types of users and not only experts in remote sensing processing. An example of a user-friendly data portal is the Worldview service for the visualization of MODIS products or the G-Pod service of European Space Agency (ESA), which allows the on-line processing of ENVISAT and Sentinel-1 SAR data (Berger et al., 2012; EOSDIS 2019; Li et al., 2016; Moel et al., 2009; Notti et al., 2018; Wulder et al., 2012). In addition, free GIS plugins allow the downloading and processing of free multispectral satellite images. The availability of these resources is useful for the management of natural hazard effects. However, expertise will be needed in order to improve and manually refine the automatic mapping using free ancillary data such as the digital elevation model-based water depth model and available ground truth data.

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Scientific solid evidence

There are some limitations/barriers to the reliability of the evidence generated. This includes the expense associated with the most high-resolution satellite images when financial resources are scarce, or when images are not available on the study area. In addition, some areas can be covered with clouds causing a partial loss of information. The presence of dense urban areas and forests also affect both SAR and multispectral based flood mapping and requires a more-complex data processing which is not straightforward to accomplish with a user-friendly approach. High spatial resolution is a key factor when mapping floods in dense urban areas, and it is one of the limitations of the free of charge satellite data approach. These services provide rapid mapping products that can be affected by uncertainty and are not always validated. Maps of flooded areas produced by official authorities and based on bespoke aerial photos and field surveys are more accurate, although they are time-consuming and require higher costs to be generated. Based on experience, however, on-demand high costs, high resolution data and field surveys are often necessary to ensure reliability of evidence.

Extended methodology

That can then be compared with the flood extent derived from the flood extent obtained for the annual rainfall using HEC-HMS and HEC-RAS. Based on the flood extent, it is possible to develop, demonstrate and validate an information system for flood forecasting, planning and management using remote sensing data with the help of Flood Hazard Maps for different return periods (10, 20, 50 and 100 years). This supports assessment of the population vulnerability and physical vulnerability of the lowest administrative division subjected to floods.
Most of the time non-structural measures like flood forecasting, proper early warnings and conducting awareness programs among the flood affected community can be very effective. Modelling of watersheds with modern technology makes this easy. Application of GIS and remote sensing technology to map flood areas will make it easy to plan non-structural measures which reduce the flood damages and risks involved. It will be a great benefit to communities to implement a flood management program.

Data collection

Cost

Precise flood mapping and modelling are essential for flood hazard assessment, damage estimation and sustainable urban planning to properly manage flood risk. In such a context, satellite remote sensing is currently a low-cost tool that can be profitably exploited for flood mapping (Notti et al., 2018).
In recent years, the availability of free satellite data significantly increased in terms of type and frequency, allowing the study of many natural and human-made processes at low cost and has boosted research in many fields (Klein et al., 2017; Li et al., 2016; Notti et al., 2018). This includes the production of flood maps at low cost around the world. The frequent passes of satellites and the availability of rapid processing chains allowed the development of services providing automatic and quasi-real time flood mapping such as, for example, the Copernicus Emergency Management Service (EMS) performed by the European Union, the Global Flood Detection System and the NASA Global Flood Mapping System.
The Sentinel satellite constellation of the Copernicus program of the European Union provides synthetic aperture radar (SAR) and multispectral data with global coverage, high-frequency pass, and high spatial resolution. Other examples of free remote sensing programs are Landsat, which has provided data since 1972, and the MODIS daily satellites giving multispectral images.

Effort

Effort is generally associated with the level of automation of the data processing. Greater effort is required if automated data is refined or ground-truthed.

Data availability

In order to obtain land use map over the study area, high resolution satellite images available on Google Earth® can be used.

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Free available remote sensing data include e.g. Rain Measurement Mission satellite precipitation data, Digital Elevation Model (DEM), Geographic Informational System (GIS), Hydrological model (Hydrologic Engineering Centre's Hydraulic Modelling System: HEC-HMS) and Hydraulic model (Hydrologic Engineering Centre's River Analysis System: HEC-RAS). However, there are some limitations in accuracy due to the coarse resolution of the precipitation and DEM data. The Rain Measurement Mission generated a global estimation of precipitation based on remote sensing observation. This algorithm, also known as Multi-Satellite Precipitation Analysis (TMPA), has high spatial (0.258) and temporal (3h) resolution, and is widely used in hydrological modelling, especially in data sparse regions. The result of flood modelling based on remote sensing rainfall data will be useful for developing regional flood early-warning and flood mitigation systems in flood hazardous areas.
Flood mapping based on remote sensing is divided into three main steps:

1. The detection of the flooded area, which can be performed using a manual or a semi-automatic mapping approach:

a) manual mapping which consists of the direct visual interpretation of the images (SAR amplitude or colour combinations of multispectral bands). In this case, the flooded areas were drawn manually directly on the georeferenced satellite images in QGIS software;

b) with the semi-automatic approach, which can help to produce an automatic flooded area map in raster format. The map can be extracted from SAR or multispectral satellite data using different methodologies such as band index, supervised classification or backscattering difference. In this step, an empirical threshold to detect flooded areas can be used; for this reason, it is not a fully automatic approach.

2. A possible improvement and refinement of manual and automatic detection which could be made using a cloud mask and permanent water body (from ancillary data or pre-flood images). Thus, additional information should be considered such as (a) water depth model derived from DEM, e.g., Shuttle Radar Topography Mission (SRTM) and ASTER, can be also used to estimate flood-prone areas (b) hillshade and aerial photos to detect the geomorphological features, and (c) ancillary data such as georeferenced photos or documents found on the web to have ground information about the flooded area extent.

The location of different land use categories (infrastructures, agricultural area, water bodies, etc.) and each house should be further photo-interpreted and digitized in Google Earth. Then Global mapper 15® can be used for the rapid conversion of the KML files into shapefiles with the reference system UTM. Finally, the preliminary database can be imported in ArcGIS 10® where a unique identification number can be attributed for each house affected (being in risk) by flooding. The flood extents for particular years can be obtained by comparing a reference high resolution satellite image before the flood and after it obtained in Google Earth using its historical satellite dataset. The Google Earth high-resolution imagery archive remains a largely unexploited resource for the analysis and description of the Earth's land surface. The high-resolution images (2.5 m resolution) used in this analysis come from Digital Globe's (e.g. Quick Bird—Ikonos) satellites. However, in some cases some areas can be covered with clouds causing a partial loss of information.

Geographical scale

Can be applied at various geographical scales, but is most commonly applied at a catchment scale.

Temporal scale

Can be applied over various temporal scales. Analysis of past extent can be a challenge thought if high resolution data is unavailable and reliable records are lacking.

Participatory process

To assess flood risk at a neighbourhood level, accurate data on flood extent, exposure and vulnerability is required. One of the possible and useful ways to obtain these data is a combination of remote sensing data and local knowledge through participatory processes. Further detail can be found on participatory processes in Inundation risk for critical urban infrastructures (probability) - Applied/Participatory Review.

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These data allow the creation of an improved final version of flooded area maps, manually drawn, both for the semi-automatic and manual approaches.

3. The flood map validation. This step is performed only when official flood maps or field survey maps are available. These maps should be used to evaluate the quality of the flooded area maps and in particular the performance of semi-automatic mapping (flood ratio and not flood ratio).

In addition, water storage data from the GRACE satellite or soil moisture data from ASCAT can be used to derive flood indicators. Each remote sensing technique for flood mapping presents advantages and drawbacks that must be evaluated on a case-by-case basis.

b) References for Indicator based on the NbS projects from the CN database

IMPRESSIONS (Impacts and risks from high-end scenarios: strategies for innovative solutions)
http://www.impressions-project.eu/
·Mapping land use, ecosystem functions, and ecosystem services using cutting-edge remote sensing and machine learning techniques
·A coordinated effort to integrate and analyse a higher quantity and quality of CO_2 and CH_4 data, from in situ and remote sensing observations encompassing atmosphere, land and oceans.
·Remote sensing of forestry

OPERANDUM (2018 – ongoing)
(OPEn-air laboRAtories for Nature baseD solUtions to Manage environmental risks) design and development of the Natural based solutions planned for the Italian OAL: introduce a novel-vegetated sand dune in the complex land- marine environment of the north Emilia-Romagna coastline to reduce storm surge and related coastal erosion; install herbaceous perennial deep rooting plants as coverage of earth embankments for the mitigation of flood risk and salt wedge intrusion in the Po delta
https://www.operandum-project.eu/the-project/

OPPLA (https://oppla.eu)

The project in this regard selected from the OPPLA data base:
·Wetlands to reduce flood risks in Aarhus (DK)
·De Doorbrak (NL)
·Urban hybrid dunes in Barcelona (ESP)
·Natur in grauen Zonen (DE)
·Ljubljana Region: Dealing with flood risk and mobility challenges (SLO)
·SUDS (SUstainable Drainage Systems) (UK)
·Embankments against flooding in Kristlandstad (SE)

Connection with SDGs

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Applied methods

For more applied and participatory approaches to assessment of reduction of flood risk see: Supporting/increasing biodiversity conservation - Applied Participatory Review.

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Original reference for indicator

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ENVIRONMENTAL INDICATORS - CORE

CONNECTING NATURE

Public green space distribution

Applied/Participatory Review

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Description

Measure of the distribution of public greenspace (total surface or per capita) and categories (i.e. street trees, residential gardens, school green areas, parks) using more applied and participatory approaches as an index to increase quality/quantity of green/blue existing, restored and new NBS with a high degree of multifunctionality (informed by ES Valuation e.g. includes cultural ES value, needs of residents, socio-economics etc) and adapted to the type of urban area (e.g. size of urban area/landscape structure).

Methodology

Public greenspace in cities contributes to quality of life in terms of environmental services and social and psychological services. Public greenspace distribution can therefore be an important factor for making a city sustainable.

Level of expertise

Expertise in relation to mapping and modelling will be necessary. Also expertise in leading participatory processes would be of value to maximise the quality of outputs.

Data collection

Cost

Some map datasets and satellite imagery are freely available online, but higher resolution images and more comprehensive data needed for network-based measures potentially can involve a licence fees/higher costs. Costs for GIS specialists if not available in-house. Participatory GIS can also involve costs in relation to designing a portal, hosting the webpage, generating engagement, and analysing data.

Effort

The level of effort involved would be dependent on the scale and amount of data to be analysed, the level of automation of data processing, and the level of expertise already available.

Data availability

Aerial photography and satellite imagery data is increasingly available but the quality and resolution can still be variable. Participatory data can be obtained in the form of already available data from local authorities, land managers, and non-government organisations, or generated through participatory engagement processes with organisations and individuals.

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Scientific solid evidence

Accuracy will be influenced by the resolution of satellite imagery and the complexity of metrics used to quantify distribution. Using more applied and participatory approaches as a sense check can strengthen the evidence generated.

Extended methodology

Decisions on where to create greenspace/NBS should be based on criteria related to maximising the equitability of distribution, focusing on areas lacking greenspace and in areas where ES valuation identifies greatest benefit/need.
Whilst it is possible to physically map greenspaces across cities, this tends to be a laborious and expensive process. As such, typically, public greenspace distribution would be measured through a mapping exercise that interrogates aerial photography and/or satellite imagery in a GIS environment (e.g. QuickBird satellite imageries analyses). This can be combined with census data to determine demographics in relation to population distribution (de la Barrera et al. 2016).
Such methods provide very basic insight into the distribution of greenspace in relation to population patterns. Supplementing these with methods to categorise urban greenspace (e.g. differentiating street trees, residential gardens, school green areas, parks, etc) and including variables that cover socio-economic, geographic and administrative aspects can provide greater evidence for supporting equality in urban greenspace distribution. Participatory approaches provide an opportunity for generating such data and/or ground-truthing the results from remote sensing data analyses. This includes the use of public participation GIS to map greenspaces overlooked by automated methods, and the use of public knowledge to categorise landuse types (Rall et al. 2019). Mears and Brindley (2019) provide a comprehensive review of metrics for assessing the equity of greenspace in urban areas. Within this process, they highlight the importance of generating comparable data across cities and projects, and the importance of incorporating the neighbourhood as experienced by residents as accurately as possible.

Geographical scale

Typically carried out over a city-scale but can be assessed at a local level also.

Temporal scale

Depending on the data available and the purpose of the exercise, could produce a current snapshot or a temporal view of change. Analysing past change can be a challenge if historical data of suitable resolution is not available.

Participatory process

It may be possible to validate greenspace type and distribution using a PPGIS type citizen science exercise and/or workshops with stakeholder groups holding tacit knowledge.

Earth observation/remote sensing/modelling

Spatial modelling/mapping is typically required but participatory and applied processes are possible to supplement this and enhance the level of confidence in the resulting maps. For more pure earth observation and remote sensing approaches, including those used on past and current EU projects, see indicator guidelines: Public green space distribution – Earth observation/Remote Sensing Review

Connection with SDGs

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Data on public greenspace distribution generated in these ways can be used to:

- Quantify the benefits of nature-based solution project in terms of improving the distribution of public greenspace;
- Support the planning of new nature-based solution greenspace initiatives;
- Underpin other indicators that require an understanding of greenspace distribution as a foundation.

References

Original reference for indicator

Eklipse

Metric references

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ENVIRONMENTAL INDICATORS - CORE

CONNECTING NATURE

Public green space distribution

Earth Observation/Remote Sensing Review

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Description

Distribution of public greenspace (total surface or per capita) and categories (i.e. street trees, residential gardens, school green areas, parks) as an index to increase quality/quantity of green/blue existing, restored and new NbS with a high degree of multifunctionality (informed by ES Valuation e.g. includes cultural ES value, needs of residents, socio-economics etc) and adapted to the type of urban area (e.g. size of urban area/landscape structure)

Methodology

Typically, public greenspace distribution would be measured through a mapping exercise, interrogating satellite imagery in a GIS environment (e.g. QuickBird satellite imageries analyses). This can be combined with census data to determine demographics in relation to distribution.

Level of expertise

Expertise in relation to mapping and modelling will be necessary. However, an increasing number of sensors, RS data products, processing algorithms, software and tools are available for the assessment of urban green space availability. Selecting an applicable data source and the method to process data is a complicated process which needs expert knowledge. Cost, time, expertise, and technical properties of remote sensing data are factors in this process. Thus, the assessment should be made by experts engaged in the NbS project who have expertise not only in RS, but also in urban planning, forestry, landscape ecology, regional planning. Each of them will then assess all built and land cover type combinations.

Data collection

Cost

The land surveying of urban green space have enormous costs and also are very time consuming. Therefore, urban green space mapping using satellite images to have a time series and to be careful with high speed and cost is less. It should be noted, that the choice of a higher density point cloud increases data costs and data volume, which also demands for more sophisticated processing algorithms. Costs for GIS specialists if not available in-house.

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Scientific solid evidence

Level of evidence generated is influenced by the resolution of satellite imagery and the complexity of metrics used to quantify greenspace distribution. There have been several notable recent studies in this field (Van De Voorde, 2016; Foster and Dunham, 2015; Taylor et al., 2011; Mitchell et al., 2011). One of them compares the quantity of green space derived from the European land cover dataset Coordination of Information on the Environment (CORINE) and from the British Ordnance Survey's master map (OSMM). They analyse their separate association with measures of mortality and morbidity at census ward level for the cities of York, Exeter, Edinburgh and Glasgow. They find that indicators based on the CORINE land cover tend to detect lower levels of green space exposure as the dataset mainly depicts the largest UGS. Interestingly, this does not affect the measured associations with the risk of mortality, suggesting a size effect in the mechanisms by which UGS influence health. Another survey compares land use percentage obtained with publicly available high-resolution aerial photography data (Google Earth in Brisbane; Microsoft Bing Maps in Sapporo), surveyed land use type in the field (visual estimation) and city supplied datasets. They find that informal UGS land use types are more sensitive to data selection than formal ones. There is also research which compares maps of urban forest cover derived from user-generated data (PhillyTreeMap) to the one obtained from the Pennsylvania Geospatial Data Clearinghouse (using remote sensing methods). Their results show effects of census block demographic profiles on the completeness of PhillyTreeMap coverage: population density, housing vacancy, median home value, and percentage of white residents have positive statistically significant effects.
These last three studies also show an emerging trend in UGS studies to embrace the digital turn in spatial data production and replace traditional data provision by governmental agencies and cartographic centres by data brought about by the Internet and social media such as Google Earth (Taylor et al., 2011), Google Street View (Seiferling et al., 2017).
The vegetation cover can be derived from satellite imagery (QuickBird). This sensor system comprises four spectral bands in the visual and near-infrared spectra (ground resolution of 2.4 m) and one panchromatic band (0.6 m ground resolution).
·The structure-type classification system is exclusively based on structural parameters (length, width, height and coverage of the surface) in turn encourages the automatic categorization of parks (and other elements of UGI) structures by using remote-sensing techniques and data.
Some studies analyse availability of urban green space based on the mapping of land covers of cities using Landsat images and a random forest classifier running on Google Earth Engine. Then they calculated the availability and accessibility of urban green spaces using the land cover maps and gridded population data.

Effort

The level of effort involved would be dependent on the scale and amount of data to be analysed, the level of automation of data processing, and the level expertise already available. Integrating remote sensing data and point-of-interest (POI) data (including location-rich semantic information) has been successfully applied in the identification of social functions of urban lands, but none were focused on a detailed and complete social functional map of UGS. Moreover, spatial patterns or distribution densities derived from the POI data have been extracted into feature vectors and then combined with physical properties derived from remote sensing data to improve the accuracy of land use identification.

Data availability

There is great debate regarding the reliability and use of data approaches to quantify and track the changes, trends, and patterns of UGS over long periods. Owning to the increasing availability of image data from multiple sources, the quantification of spatiotemporal patterns for green space frequently relies on remote sensing. However, data such as Lidar and high-resolution images are still not easily accessible for many regions or users due to the high costs of data acquisition. Moreover, it is usually impractical to provide full coverage of extensive metropolitan areas, with limited data available over long periods. With the advantages of global availability, repetitive data acquisition, and long-term consistency, Landsat series satellites have become the best compromise to overcome these limitations.

Geographical scale

At various geographical scales.

Temporal scale

At various temporal scales.

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Extended methodology

De la Barrera et al. (2016) propose the following indicators for measuring greenspace distribution:
·Aggregation index of greenspaces (Municipal scale)
·Share of blocks served by greenspace > 0.5 ha (Local scale)
·Share of population served by greenspace > 0.5 ha (Local scale)

Table 1 shows indicators then used to measure quantity and quality of GS (according to de la Barrera et al., 2016).

Table 1
Description of the proposed indicators.

Indicators	Name	Scale
Quantity of GS	GS per inhabitant	Municipal
	GS per built-up area	Municipal
	GS per impervious cover	Municipal
	GS per bare soils	Municipal
	GS per vegetation cover	Municipal
Quality of GS	Mean size of GS (±SD)	Municipal
	Shape index of GS (±SD)*	Municipal
	Vegetation cover on GS (mean ± SD)	Municipal
	Vegetation cover on GS per inhabitant (mean ± SD)	Municipal
Spatial distribution and accessibility to GS	Aggregation index of GS*	Municipal
	Share of blocks served by GS > 0.5 ha	Local
	Share of population served by GS > 0.5 ha	Local

Remote sensing imagery has been widely adopted for population estimation in cities. Major techniques for population estimation by remote sensing include dasymetric mapping, regression models and geostatistical models (Joseph et al., 2012). There are various studies on greenspace accessibility which analyse the accessibility of urban parks using Euclidean distance or based on GIS network analysis. In order to calculate how many of the total population have access to green space, serving as the first index for evaluation. The analysis is composed of three steps:
·First, a Landsat image is classified to land cover using semi-automatic classification on the Quantum GIS platform, for further disaggregating population data. The population layer is a census tract map for particular year. Such aggregate data doesn't reflect the actual distribution, and its accuracy cannot meet the higher resolution analysis. To match the population data with physical elements, Landsat imagery is used. The Semi-Automatic Classification Plugin of QGIS provides an interactive way to search, display and download Landsat 8 images.

Participatory process

The land cover classification either with low resolution or high-resolution images do not always completely represent the actual land cover in the city. However, it may be used in the future as a starting point for producing more accurate land cover maps by using two high resolution images. The validation of results on the ground as well as the participation of urban planner and policymakers is also essential.

Connection with SDGs

Goal 3	Goal 10	Goal 15
Goal 4	Goal 11	Goal 16
Goal 8	Goal 13	Goal 17
Goal 9	Goal 14	

Applied methods

For more applied and/or participatory approaches please see: Public green space distribution - Applied/Participatory Review

References

Metric references

a) From the literature review:

Atiqul Haq SM. (2011) Urban green spaces and an integrative approach to sustainable environment. Journal of Environmental Protection.;2:601–608. 10.4236/jep.2011.25069

Badiu, D.L., Iojă, C.I., Pătroescu, M., Breuste, J., Artmann, M., Niță, M.R., Grădinaru, S.R., Hossu, C.A. and Onose, D.A. (2016) Is urban green space per capita a valuable target to achieve cities' sustainability goals? Romania as a case study. Ecological indicators, 70: 53-66.

Comber, A., Brunsdon, C., & Green, E. (2008) Using a GIS-based network analysis to determine urban green space accessibility for different ethnic and religious groups. Landscape and Urban Planning, 86(1): 103–114.

Daniels B, Zaunbrecher BS, Paas B et al. (29018) Assessment of urban green space structures and their quality from a multidimensional perspective. Science of the Total Environment 615 (2018) 1364–1378. https://doi.org/10.1016/j.scitotenv.2017.09.167

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Moreover, it allows semi-automatic supervised classification of remote sensing images, providing tools to expedite the creation of ROIs, the pre-processing phases (image clipping, Landsat conversion to reflectance), the classification process, and the post processing phases (accuracy assessment, land cover change). Using this plugin, the image is classified into four land cover classes (built-up, water, vegetation, and soil).
Secondly, a population distribution map is created using dasymetric mapping technique. Dasymetric mapping means using ancillary data to disaggregate coarse resolution population data to a finer resolution (Eicher and Brewer 2001). The land cover map can be derived from Landsat imagery to disaggregate the population. In the meantime, by converting the census map to a 30m×30m cell raster, it achieves spatial down-scaling population simulation.
The third step is to identify the ratio of service population based on ArcGIS network analysis. A network service area is a region of the case of NBS that encompasses all accessible streets. Service areas created by network analysis are converted to a raster and overlay with the disaggregated population distribution raster to identify how many people are within the service area, and figure out the areas short of accessibility.
The green space ratio is the most commonly used metric to refer to the availability of UGS (Atiqul Hag, 2011) within a neighbourhood. It consists of calculating the amount (number and/or acreage) of UGS within a city or its sub-parts to provide an aggregate (or per neighbourhood) picture of provision to a certain number of residents, i.e. potential users (Nicholls, 2001) as well as potential UGS congestion (Sister et al., 2010; Van Herzele and Wiedemann, 2003).
The proposed procedure is based on measures of urban green space location and characteristics derived from two classical types of data, Landsat imagery and official cadaster-based map, and the voluntary geographical information provided by OpenStreetMap (OSM). Landsat and OSM, being available in many places, should allow for generalisation and transfer while the cadaster-based map is supposed to reflect the kind of institutional information available at local scale with most accurate details about formal UGS.
Provision of and access to UGS are examined with respect to the spatial distribution of the four indicators discussed earlier in the literature section, namely (i) availability, (ii) fragmentation, (iii) privatisation and (iv) accessibility.

Davies, Z.G., Edmondson, J.L., Heinemeyer, A., Leake, J.R. and Gaston, K.J. (2011) Mapping an urban ecosystem service: quantifying above-ground carbon storage at a city-wide scale. Journal of applied ecology, 48(5): 1125-1134.
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The indicators are computed as follows:

·(i) The availability index is measured by the share of land dedicated to urban green space per area, i.e. total UGS cover A divided by the reference surface.

·(ii) The fragmentation index is measured by the ratio of the total perimeter of UGS, P over their total area A. The fragmentation ratio P/A gives an indication of fragmentation with a higher value if the number of green parcels increases for a given total surface. It is also related to the shape of polygons, with lower values corresponding to a shape closer to a circle and larger values corresponding to elongated shapes.

·(iii) The privatisation index is measured by the ratio of private (denoted G for 'gardens') to total UGS cover (A), i.e. G/A.

·(iv) The accessibility index is measured by the average distance, per neighbourhood, from each cell to the nearest public UGS through the road network. The calculation is unweighted.

One of the common options is identifying UGS with Landsat. The Landsat 8 satellite image covering the European region can be downloaded from the Landsat Viewer website.

Santos et al. (2016) proposed a methodology based on 3D measure and analysis of green urban areas at the city scale. Two products are proposed: (1) measuring current vegetation cover at ground level through object-oriented classification of WorldView-2 imagery; and (2) estimating potential green cover at rooftop level using 3D data obtained by LiDAR sensor.

An Aggregation Index (AI) can be used to get a reference of how clustered public greenspaces are in a city. An AI of 100 indicates GS are adjacent to each other and 0 that GS is dispersed (FRAGSTATS - http://www.umass.edu/landeco/research/fragstats/fragstats.html).

The following data sources have been used to estimate the distribution of greenspace in Romania (Badiu et al., 2016):

Data on the surface of UGS used in the analysis.

No.	Data source	Extraction approach/data type	Year	Urban green categories considered
1.	Aerial images	Extraction of UGS using ArcGIS 10.1	2008	Street trees, cemeteries, institutions' gardens, public residential gardens, school green area, parks, urban forests, squares, industrial green spaces, commercial green spaces, sports grounds
2.	TEMPO Database (National Institute of Statistics)	Statistical data	2008	The surface of green spaces in cities—parks, institutions' gardens, residential gardens, squares, sports grounds
3.	Environmental Protection Agencies	Statistical data	2008	All green categories as a whole
4.	Urban Atlas	Urban green surface	2010	Green urban areas, sports and leisure facilities

Using multiple correspondence analyses on four UGS categories: street trees, residential gardens, school green areas and parks; and variables that cover socio-economic, geographic and administrative aspects, factors influencing the surface of UGS per capita at the city level can be identified. Multiple linear regression models can be used to explore the influence of independent variables such as landscape, citizens education level, period when cities were founded etc. These can influence surface of UGS and explain patterns and variation of greenspace distribution.

Collating landcover characteristics using GIS and characterising above-ground vegetation by maximum height e.g. Herbaceous Vegetation and Shrub (mean height typically <2 m), Tall Shrub (mean height generally 2–5 m) and Tree (trees >5 m tall), it is possible to indicate biomass and calculate distribution of greenspace and estimate carbon storage (Davies et al., 2011). This type of metric can be used to inform ES valuation and estimate whether a type of NbS could be used/is needed in an area to increase, for instance, carbon storage.

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Oh & Jeong (2007) argue that indices such as total park (or greenspace) area, park area per capita and number of parks does not reflect their distribution within a city, which could be aggregated at the outer limits, restricting access for some residents.
The distribution of urban parks/greenspaces instead should be assessed in terms of the population density of residential areas, land use, and development density through GIS network analyses. Network analysis can be used to provide the boundaries of 'service areas' of parks/greenspaces, where citizens can access them within a given distance/time through actual routes. Urban park/greenspace service indices can be formulated with a population number and floor area within the service area of parks. Service indices consider the benefits to the surrounding population according to the spatial location of parks compared to conventional indices that rely on area ratio per capita. Therefore, the service area ratio and the service population ratio (which reflect the area and population serviced through footpaths based on the location of the parks) is deemed a more effective indicator of park/greenspace distribution. By synthesizing census data, land uses, and development density based upon actual locations, the assessment method can help understand the spatial distribution of urban parks/greenspaces more accurately.

b) References for Indicator based on the NbS projects from the CN database

Naturvation (2017 – ongoing)
From the NATURVATION database on the value and benefit assessment methods
·remote sensing together with distributed lag nonlinear models used to assess the risk of death due to heat as an effect of distance to green and blue space (input data: Metrological, NVDI, distance to green and blue infrastructure)

·a framework using satellite images, remote sensing and statistical modelling to compute accessibility of parks and green space dependent on economic and population data (input data: percentage of green cover in a city, population density, GDP per capita, City land area, Per capita green space provision, Aggregation index; output data: Effects of and between the different types of in data)

PLUREL
(Peri-urban Land Use Relationships - Strategies and Sustainability Assessment Tools for Urban-Rural Linkages)
www.plurel.net
·remote sensing and GIS for sustainable urban development science to provide geo-referenced information on the shape, size and distribution of different land-use classes of the urban environment
The main application areas of these technologies in urban growth research within the project can be defined as follows:

- Mapping of environmental parameters (base data important for urban climate, access to and distribution of open space, calculation of sealed surfaces).

References:

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ENVIRONMENTAL INDICATORS - CORE

CONNECTING NATURE

Recreational value of blue-green spaces

Applied/Participatory Review

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Description

This indicator represents a quantification of the number of visitors/recreational activities within a greenspace or blue-green space in order to evaluate, or measure an increase in, recreational benefits as a result of NbS. Examples of features and activities that can attract visitors to NbS include features such as large trees, benches, education days, and communication zones for picnicking.

Methodology

The most basic measure for this indicator is increase/decrease in the number of visitors to a blue-green space before and after a change in how it is designed or managed. This data can be captured through a variety of methods including interviewing locals on likelihood of visiting the space (Coldwell and Evans 2018) and monitoring visitor numbers through physical counts or visitor profiling in relation to specific pursuits (Cope et al. 2000; Cessford and Muhar 2003).

Level of expertise

Some expertise is needed for the design of the evaluation (e.g. survey method, question selection). Once decided though, a low level of expertise is required for carrying out the survey or carrying out counts. Similarly, data analysis can require low expertise if basic inventories or correlations are required.

Data collection

Cost

Can be relatively low cost, particularly if citizen scientists/volunteers are used for data collection.

Effort

Effort is associated with the level of survey. Larger sample sizes/local community survey require a much greater effort than simple counts of visitors. Assessment of the characteristics of blue-green space is relatively low effort for all but the largest blue-green spaces.

Data availability

Some sites might collect visitor data. Typically, amenity characteristics are not recorded formally, however, some data might be held on websites for more formal sites.

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Scientific solid evidence

Robustness of evidence is very much based on the design of the questionnaire and the sample size of respondents. Visitor number count robustness can be a challenge due to the difficulty in capturing visitor numbers at some sites.

Extended methodology

Whilst these basic quantifications have a direct relevance to numbers of visitors, they do not necessarily provide information on the causal link between the features or activities available at a park and the presence of visitors (e.g. visitors might be there due to proximity). The most typical practice for assessing the recreational value of blue-green spaces is through generating direct feedback from users and/or local communities. This is generally done in the form of questionnaires applied to the visiting or neighbouring population to identify perceptions in relation to blue-greenspace characteristics (Kabisch and Haase 2014; Colley and Craig 2019). The majority of questionnaire techniques have focused on a single aspect of greenspace use, for example physical activity (Schipperijn et al. 2013; Akpinar 2016) or health (Akpinar et al. 2016).

Attempts have been made to quantify the 'offer' of the blue-green space by capturing a measure of the features and activities available. This has been done by classifying spaces according functional, physical characteristics considered to be associated with the attractiveness of a space (Sugiyama et al 2010; Brown et al. 2014; Kimpton 2017) Examples of characteristics used to measure blue-green space attractiveness in the Sugiyama et al. (2010) and Kimpton (2017) studies include:

- Presence of walking paths
- Shade, water features
- Irrigated lawn
- Lighting
- Birdlife
- Type of surrounding roads
- Being adjacent to a beach or river
- BBQs & Tables

Geographical scale

Analysis is performed on a single site scale and can comprise sites ranging from very large parks and open spaces to micro-scale pocket parks. Typically, replication across sites is used for comparative purposes as city-wide assessment is possible, although generally spatial modelling methods would be applied for this to minimise effort required.

Temporal scale

Evaluation methods can be adopted for short-term snapshots associated with a change in management. They can also be adapted for long-term evaluation of sites as the 'offer' changes and matures, as the accessibility of a site changes, or as the demand on a site changes.

Participatory process

Good opportunities for participation through which communication of the benefits of an NbS approach can be delivered. This can be achieved both through the questionnaire process and involving citizen science in data collection. Methods of amenity characterisation can also encourage stakeholders to consider what they would like in their local blue-green space and give a broader view of what is possible.

Earth observation/remote sensing/modelling

For greater detail on earth observation, remote sensing and/or modelling approaches, including those used on past and current EU projects, see indicator guidelines:
Water quality – Earth observation/Remote Sensing Review

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- Buildings
- Dog Enclosure
- Place Managers (e.g. kiosk operators)
- Formal Sport Features
- Informal Sport Features
- Lighting
- Playground Features
- Public Transport Stop
- Seating

When applying an NbS approach to evaluation, evaluation criteria should cover characteristics associated with economic, social, health & wellbeing, environmental and ecological benefits (Faivre et al. 2017).
Surveys can be questionnaire based, directly interacting with blue-green space users or local residents (Akpinar 2016), or using online spatial mapping participatory processes (Brown et al. 2014). A combination of the number of visitor metrics and attractiveness of 'offer' metrics can generate the most useful data in relation to value of NbS interventions and promotion of learning for NbS delivery in other blue-green spaces.

Evaluation of recreational value of blue-green space can be used to:

- Ensure that changes related to NbS implementation has a positive impact on visitors;
- Ensure that green-blue spaces are providing a broad offer in terms of attractiveness for communities;
- Support the design of green-blue spaces to ensure they are providing a NbS offer in terms of social, economic and environmental benefits.

Connection with SDGs

Goal 3	Goal 10	Goal 15
Goal 4	Goal 11	Goal 16
Goal 5	Goal 13	Goal 17
Goal 9	Goal 14	

References

Original reference for indicator

Eklipse; Kabisch and Haase (2014)

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ENVIRONMENTAL INDICATORS - CORE

CONNECTING NATURE

Recreational value of blue-green spaces

Earth Observation/Remote Sensing Review

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Description

This indicator represents a quantification of the number of visitors/recreational activities within a greenspace or blue-green space in order to evaluate, or measure an increase in, recreational benefits as a result of NbS. Examples of features and activities that can attract visitors to NbS include features such as large trees, benches, education days, and communication zones for picnicking. This presents a description of the earth observation and remote sensing approaches to this indicator.

Methodology

Direct contribution of earth observation / remote sensing tools for the assessment of the cultural value of blue and green spaces of NbS in cities was not identified through review. However, these tools could be used as an indirect way for mapping Land Use/Land Cover (LULC).

Level of expertise

Knowledge and experience on the topic are needed. As such, the Sentinel Application Platform requires advanced expert sensing data, including derived knowledge.

Data collection

Cost

The spatial structure of impervious-vegetated mix is heterogeneous at much finer scales in the urban landscape than elsewhere. As a result, for a long time, conventional methods of mapping urban vegetation have relied on a visual interpretation of aerial images and fieldwork. More recently, very high resolution (VHR) satellite remote sensing systems (IKONOS, QuickBird, GeoEye, RapidEye, WorldView, Pleiades) have been developed that are capable of providing imagery with similar detail to aerial photography, and they offer opportunities to overcome the lack of reliable and reproducible information on urban vegetation across large areas. However, the disadvantage of VHR satellites is their narrow swath and therefore limited coverage of the Earth's surface. Also, VHR satellites are commercially oriented services, and the data cost is relatively high. One of the most recent sources of information on land cover, including UGS, is Sentinel-2A (S2A), a high-resolution optical Earth observation mission. Although it has coarser spatial resolution than the VHR satellites, it offers higher spectral resolution and is provided free of charge.

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Scientific solid evidence

It can be difficult to link earth observation/remote sensing metrics to solid evidence due to the lack of a participatory aspect to the cultural value of specific features. Also, the finescale resolution of some greenspace features of cultural value makes identification from anything less than high resolution images unreliable. Combining participatory assessment of cultural value and mapping of greenspace features can increase the reliability of evidence generated.

Extended methodology

Based on remotely sensed data, image classification is an important process for that since high-resolution remote sensing technology provides strong support for the monitoring methods and evaluation indicators of urban environment. A basic modelling approach currently emerging uses aerial photography to quantify NbS quality. For example Greencity Watch urban green classification index use park features as a way of classifying park quality: https://www.greencitywatch.org/researchanddevelopment
Image classification can also be important in the investigations for green spaces. Through visual interpretation based on remote-sensing imagery from Google Earth, different transects in cities can be established radiating from the city centre to edge. In each transect, different quadrats can be delineated as the study quadrat in order to illustrate the findings.
The methodology proposed by De Ridder et al. (2004) help to analyse and visualise selected indicators for the possible enhancement of green infrastructure on different scale-levels (from street canyon to urban regions) in European cities by using GIS and remote sensing techniques.
The diversity and quality of urban green spaces (UGS) and human well-being are tightly linked, and UGS provide a wide range of ecosystem services (e.g., urban heat mitigation, storm water infiltration, food security, physical recreation). Analyses and inter-city comparison of UGS patterns and their functions requires not only detailed information on their relative quantity but also a closer examination of UGS in terms of quality and land use, which can be derived from the land cover composition and spatial structure. There is some research which presents an approach to UGS extraction from newly available Sentinel-2A satellite imagery, provided in the frame of the European Copernicus program (Kopecká et al., 2017).

Sentinel missions are part of the Copernicus program (previously called GMES), a joint initiative of the European Commission and European Space Agency to establish a European capacity for the provisioning and use of information for environmental monitoring and security applications.

Effort

The presented case studies showed the possibilities of semi-automatic extraction of UGS classes from e.g. Sentinel-2A data that may improve the transfer of scientific knowledge to local urban environmental monitoring and management.

Data availability

There a variety a data freely available e.g. Sentinel Application Platform (SNAP) is a platform for processing remote data up to city scale. Not ultra-fine scale. vegetation indices. As a tool, can be used for quantifying metrics from RS / satellite data up to city scale. However, it requires advanced expert sensing data, including derived knowledge. Not ultra-fine scale.
Another example is Coordination of Information on the Environment (CORINE) which focus on Global land use classification can be applicable as a tool comprising of global NDVI estimates from remotely sensed data, can be incorporated into other metrics. However, it can be applicable only to regional scale not to neighbourhood scale which reduce usefulness for city scale due to resolution.

Geographical scale

Analysis at various geographical scales is possible.

Temporal scale

Analysis over various temporal scales is possible, although lack of availability of historical high resolution data can be limiting.

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They investigate and map the spatial distribution of UGS in three cities in Slovakia: Bratislava, Žilina and Trnava. Supervised maximum likelihood classification was used to identify UGS polygons. Based on their function and physiognomy, each UGS polygon was assigned to one of the fifteen classes, and each class was further described by the proportion of tree canopy and its ecosystem services. The results document that the substantial part of UGS is covered by the class Urban greenery in family housing areas (mainly including privately-owned gardens) with the class abundance between 17.7% and 42.2% of the total UGS area.
The presented case studies showed the possibilities of semi-automatic extraction of UGS classes from Sentinel-2A data that may improve the transfer of scientific knowledge to local urban environmental monitoring and management.
Greenery in different elements of UGI, e.g. sports facilities, such as football pitches or aqua parks, increases the recreational potential of a city. However, the recreational opportunities of urban ecosystems also vary with social criteria, including accessibility, penetrability, safety, privacy and comfort.

b) References from literature review:

Breuste J et al. (2015) Special Issue on Green Infrastructure for Urban Sustainability. In: Journal of Urban Planning and Development, 141(3), n.p. Online (15.2.17): https://www.researchgate.net/publication/278665439.
Brown, G., Schebella, M. F., & Weber, D. (2014). Using participatory GIS to measurephysical activity and urban park benefits. Landscape and Urban Planning, 121,34–44.
Dennis, M.; James, P. (2016) User participation in urban green commons: Exploring the links between access, voluntarism, biodiversity and well being. Urban For. Urban Green., 15, 22–31.
De Ridder et al. (2004): An integrated methodology to assess the benefits of urban green space. In: Science of the Total Environment 334-335, 489-497. Online (15.2.17):
https://www.researchgate.net/profile/Christiane_Weber2/publication/8211761_Integrated_methodology_to_ass ess_the_benefits_of_urban_green_space/links/00b49526772578934c000000/Integrated-methodology-to-assess- the-benefits-of-urban-green-space.pdf.
Herold, M., Liu, X., & Clarke, K. C. (2003). Spatial metrics and image texture for mapping urban land use. Photogrammetric Engineering & Remote Sensing, 69(9), 991–1001.
Kopecká M, Szatmári D, Rosina K (2017) Analysis of Urban Green Spaces Based on Sentinel-2A: Case Studies from Slovakia. Land 2017, 6, 25; doi:10.3390/land6020025
Nikolaidou, S., Klöti, T., Tappert, S., & Drilling, M. (2016). Urban Gardening and Green Space Governance: Towards New Collaborative Planning Practices. Urban Planning, 1(1), 5-19. https://doi.org/10.17645/up.v1i1.520
Vargas-Hernández J.G., Pallagst K., Zdunek-Wielgołaska J. (2018) Urban Green Spaces as a Component of an Ecosystem. In: Dhiman S., Marques J. (eds) Handbook of Engaged Sustainability. Springer, Cham. https://doi.org/10.1007/978-3-319-53121-2_49-1

Participatory process

The variety of research indicates the emerging forms of collaboration, partnerships, and governance patterns that involve public and private sectors and increase participation by civil society actors. Cooperation amongst several interested groups and the collective reinvention of public urban spaces increase these spaces' accessibility for multiple users and actors, as well as presenting possibilities for alternative and diversified uses and activities. This might underline the hypothesis that future cities will be governed in less formalised ways, and that urban forms will be created through spontaneous, temporary, mobile, and adaptive negotiation processes.

Connection with SDGs

Goal 3	Goal 10	Goal 15
Goal 4	Goal 11	Goal 16
Goal 5	Goal 13	Goal 17
Goal 9	Goal 14	

Applied methods

For more applied and participatory metrics for this indicator please see : Recreational value of blue-green spaces - Applied/Participatory Review

References

Original reference for indicator

Eklipse; Kabisch and Haase (2014)

Metric references

a) References for Indicator based on the NbS projects from the CN database

No particular project was found to illustrate the use of RS and EO for the purpose of analysis of the Recreational value of blue-green spaces of NbS in cities.

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ENVIRONMENTAL INDICATORS - CORE

CONNECTING NATURE

Cultural value of blue-green spaces

Applied/Participatory Review

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Description

A measure of the number of cultural events/number of people involved to evaluate the cultural benefits of blue-green spaces using applied methods.

Methodology

The most basic measure for this indicator is counting an increase/decrease in the number of events promoting cultural benefits held in a blue-green space. This can be carried out before and after a change in how the blue-green space is designed or managed to assess the net benefit of a new NbS initiative. Cultural benefits are some of the non-material benefits of ecosystems, including providing opportunities for recreation, physical activity, socializing, and restoring capacities (Chen et al. 2019).

Level of expertise

Some expertise is needed for the design of the evaluation (e.g. survey method, question selection). Once decided though, a low level of expertise is required for carrying out the survey or carrying out counts. Similarly, data analysis can require low expertise if basic inventories or correlations are required.

Data collection

Cost

Can be relatively low cost, particularly if citizen scientists/volunteers are used for data collection.

Effort

Effort is associated with the level of survey. Larger sample sizes/local community demographic surveys require a much greater effort than simple counts of visitors. Counts of organised cultural events in blue-green space is relatively low effort but informal events might require greater effort to capture.

Data availability

Data on organised events is usually collected by most managed blue-green spaces. Data on attendees is also often available. Data on informal events is typically harder to obtain and demographic data on attendees is also often lacking. As such, establishing a baseline before any NbS intervention is important in relation to quantifying the impact of any changes to cultural events.

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Scientific solid evidence

Robustness of evidence is very much based on the design of the questionnaire and the sample size of respondents. Event counts are straightforward and robust, but without the additional data on attendees and demographics, the value of the data is limited. Visitor number counts and demographic data robustness can be a challenge due to the difficulty in capturing representative visitor numbers at some sites.

Extended methodology

In addition to the basic information on number of events, additional detail can be captured in relation to how well attended events were. This can be captured by counting the numbers of attendees through ticket sales, ticket collection on the day of the event, sign-in processes or monitoring visitor numbers through physical counts or visitor profiling in relation to specific pursuits (Cope et al. 2000; Cessford and Muhar 2003).
Whilst these basic quantifications have a direct relevance to numbers of visitors or events, they do not always provide information on the causal link between the events at a park and the presence of visitors (e.g. visitors might be there due to proximity), or the demographics of visitors attracted to the events. The most typical practice for capturing such information is through generating direct feedback from users and/or local communities. This is generally done in the form of questionnaires (Schipperijn et al. 2013; Kabisch and Haase 2014; Akpinar 2016). Questionnaire sampling protocol should be delivered in such a way as to ensure that responders are representative of the attendees at an event (Kabisch and Haase 2014). Sampling procedures can be designed in a way to compare the demographics of attendees with the demographics of the surrounding neighbourhood or city to ensure that cultural events are being delivered that are attractive to all. Analysis of local/regional socio-demographic data to compare to event attendee data is generally done using interrogation of city social datasets such as the number of inhabitants, number of immigrants, and number of individuals aged ≥65 years (Kabisch and Haase 2014). This enables insight into how urban green-blue spaces are supporting socio-environmental justice in cities (Kabisch and Haase 2014; Snaith 2015; Cronin-de-Chavez et al. 2019).

Geographical scale

Analysis is performed on a single site scale and can comprise sites ranging from very large parks and open spaces to micro-scale pocket parks. Typically, replication across sites is used for comparative purposes. City-wide replication would involve substantial effort as remote sensing data is not an option for quantifying attendees or events.

Temporal scale

Evaluation methods can be adopted for short-term snapshots associated with a change in management. They can also be adapted for long-term evaluation of sites as the events 'offer' changes, as the local demographics of a site changes, or as the demand on a site changes.

Participatory process

Good opportunities for participation through which communication of the benefits of an NbS approach can be delivered. This can be achieved both through the questionnaire process and involving citizen science in data collection. Capturing data on types of cultural events and demographics of attendees can also encourage community members to input information to blue-greenspace managers about the type of events that would be most attractive.

Earth observation/remote sensing/modelling

For earth observation, remote sensing and/or modelling approaches, including those used on past and current EU projects, see indicator guidelines:
Cultural value of blue-green spaces – Earth observation/Remote Sensing Review

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A combination of the number of events/visitor metrics and the demographics of attendees can generate the most useful data in relation to the popularity and inclusivity of cultural events, and thus the ‘value’ of the NbS interventions.

Evaluation of cultural value of blue-green space can be used to:

- Monitor the value of cultural events in relation to visitor numbers;
- Assess that changes related to NbS implementation have a positive impact on visitors in relation to attending cultural events;
- Ensure that changes related to NbS implementation promote socio-environmental justice.

Connection with SDGs

Goal 1
Goal 2
Goal 3
Goal 4
Goal 5
Goal 8
Goal 9
Goal 10
Goal 11
Goal 12
Goal 13
Goal 14
Goal 15
Goal 16
Goal 17

References

Original reference for indicator

Eklipse; Kabisch and Haase (2014)

Metric references

Akpinar, A (2016) How is quality of urban green spaces associated with physical activity and health? Urban Forestry & Urban Greening 16, 76-83.
Cessford, G and Muhar, A (2003) Monitoring options for visitor numbers in national parks and natural areas. Journal for Nature Conservation 11(4), 240-250.
Chen, X, de Vries, S, Assmuth, T, Dick, J, Hermans, T, Hertel, O, Jensen, A, Jones, L, Kabisch, S, Lanki, T, Lehmann, I, Maskell, L, Norton, L and Reis, S (2019) Research challenges for cultural ecosystem services and public health in (peri-)urban environments. Science of The Total Environment 651(2), 2118-2129.
Cope A, Doxford, D and Probert, P (2000) Monitoring Visitors to UK Countryside Resources: the Approaches of Land and Recreation Resource Management Organisations to Visitor Monitoring. Land Use Policy 17(1), 59–66.
Cronin-de-Chavez, A, Islam, S and McEachan, RRC (2019) Not a level playing field: A qualitative study exploring structural, community and individual determinants of greenspace use amongst low-income multi-ethnic families. Health & Place 56, 118-126.
Kabisch, N. and Haase, D., 2014. Green justice or just green? Provision of urban green spaces in Berlin, Germany. Landscape and Urban Planning, 122, pp.129-139.
Schipperijn, J, Bentsen, P, Troelsen, J, Toftager, M and Stigsdotter, U (2013) Associations between physical activity and characteristics of urban green space. Urban Forestry and Urban Greening 12, 109-116.
Snaith, B. (2015) The Queen Elizabeth Olympic Park: Whose Values, Whose Benefits? Unpublished Doctoral thesis, City, University of London.

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ENVIRONMENTAL INDICATORS - CORE

CONNECTING NATURE

Cultural value of blue-green spaces

Earth Observation/Remote Sensing Review

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Description

A measure of the number of cultural events/number of people involved to evaluate the cultural benefits of blue-green spaces using earth observation, remote sensing and modelling approaches.

Methodology

There is no real direct contribution of earth observation/remote sensing tools for the assessment of the cultural value of blue and green spaces of NbS in cities. However, these tools could be used in an indirect way for mapping Land Use/Land Cover (LULC) as a background layer for mapping and presenting indicator results.

Level of expertise

Not relevant.

Data collection

Cost

Not relevant generally. However, cost implications may occur when using RS as an indirect way of mapping Land Use/Land Cover (LULC). When providing support for monitoring methods and evaluation indicators of urban environment and for the investigations of green spaces (visual interpretation based on remote-sensing imagery from Google Earth, different transects in cities can be established radiating from the city centre to edge), the use of analysed spatial data can increase costs. However, the use of open access satellite imagery can reduce the cost of this.

Effort

Not relevant.

Data availability

Visual interpretation based on remote-sensing imagery from Google Earth, for establishing different transects in cities radiating from the city centre to edge, are free for download from these websites:
·http://glovis.usgs.gov/
·http://www.escience.cn/people/feiyunZHU/Dataset_GT.html
·http://openremotesensing.net
http://freegisdata.rtwilson.com

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Scientific solid evidence

Not relevant.

Extended methodology

When using of remotely sensed data, image classification is an important process as high-resolution remote sensing technology can provide strong support for the monitoring methods and evaluation indicators applied in the urban environment.

It also can be important for the investigation of attributes of green spaces. By using visual interpretation based on remote-sensing imagery from Google Earth, different transects in cities can be established radiating from the city centre to edge. In each transect, different quadrats of e.g. 450 × 450 m can be delineated as the study quadrat as a framework for illustrating findings.

b) References for Indicator based on the NbS projects from the CN database

No particular project was found to illustrate the use of RS and EO for the purpose of analysis of the cultural value of blue and green spaces of NbS in cities.

Geographical scale

City, city district

Temporal scale

Not relevant.

Participatory process

Not relevant.

Connection with SDGs

Goal 1	Goal 8	Goal 13
Goal 2	Goal 9	Goal 14
Goal 3	Goal 10	Goal 15
Goal 4	Goal 11	Goal 16
Goal 5	Goal 12	Goal 17

Applied methods

For greater detail on applied and participatory methods for quantifying cultural value of greenspace please see: Cultural value of blue-green spaces - Applied/Participatory Review

References

Original reference for indicator

Eklipse; Kabisch and Haase (2014)

Metric references

a) References from literature review:

Wu C.-D., McNeely E., Cedeno-Laurent J., Pan W.-C., Adamkiewicz G., Dominici F., Lung S.-C.C., Su H.-J., Spengler J.D. (2014) Linking student performance in Massachusetts elementary schools with the "greenness" of school surroundings using remote sensing. PLoS ONE. doi: 10.1371/journal.pone.0108548.

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ENVIRONMENTAL INDICATORS - CORE

CONNECTING NATURE

Connectivity of urban green and blue spaces (structural and functional)

Earth Observation/Remote Sensing Review

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Description

Earth observation/remote sensing indicators and tools for measuring the potential for green or blue areas to amplify the structural and functional connectivity and multifunctionality of other urban green/blue areas.

Methodology

One of the major impacts of urbanization is the fragmentation of open spaces into smaller and more isolated patches. Increased fragmentation of green in urbanized areas can reduce intra- and inter-species connectivity and lead to a loss of biodiversity (Kettunen et al., 2007). Fragmentation of green areas and distance between habitat patches is thus an important factor in determining biodiversity.

Level of expertise

The measure of the physical connectedness of the vegetation across a landscape, sometimes referred to as the 'structural vegetation connectivity' will typically be measured using remote sensing methods. It differs from 'ecological connectivity' which will usually be measured through on-ground observations and analysis. "Hyperspectral" sensors can have more than 200 bands and can provide a wealth of information to help, for example, identify specific species. Processing such datasets requires special expertise and satellite-based hyperspectral sensors are not yet common.

Data collection

Cost

Historically, RS data have often been expensive and hard to use, but changes over the last decade have resulted in massive amounts of global data being available at no cost, as well as significant (if not yet complete) simplification of access and use.

Effort

RS data/techniques make the findings of ES studies more relevant, more appropriate to urban planning, and useful for guiding sustainable development in these areas (Tavares et al., 2019). There are many sources to access such data (see Figure below). However, there are several limitations that include inconsistent metadata, data access, intellectual property and privacy considerations.

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Scientific solid evidence

The potential for satellite remote sensing to provide key data has been highlighted by many researchers, offering repeatable, standardized and verifiable information on long-term trends in biodiversity indicators and characteristics of connectivity and fragmentation. As concluded by a variety of research (listed in the references), remote sensing permits one to address questions on scales inaccessible to ground-based methods alone, facilitating the development of an integrated approach to natural resource management, where biodiversity, pressures to biodiversity and consequences of management decisions can all be monitored. Remote sensing (RS)—taking images or other measurements of Earth from above—provides a unique perspective on what is happening within the urban landscape and thus plays a special role in green infrastructure analysis, environmental monitoring as well as biodiversity and conservation applications. The periodic repeat coverage of satellite-based RS is particularly useful for monitoring change and so is essential for understanding trends, and also provides key input into assessments of vegetation, connectivity and conservation management.

Extended methodology

A Green Infrastructure approach, linking parks and other green spaces, is therefore considered essential for the preservation of biodiversity and to counter further habitat fragmentation (EEA, 2010). Fragmentation and isolation of urban green spaces can be described by means of spatial metrics, i.e. quantitative measures of spatial pattern that were originally developed by landscape ecologists to examine the link between the spatial patterning of ecosystem types in natural landscapes and ecological processes (Turner, 1989, 1990). Many metrics have been developed for characterizing patterns in landscapes and were later implemented in the spatial analysis program FRAGSTATS by McGarigal and Marks (1995), which today is a commonly used quantitative tool in the field of landscape ecology.
For instance, in the study of Van de Voorde et al. (2010) various spatial metrics available in FRAGSTATS were calculated to describe fragmentation and isolation of open and dense vegetation patches in the Brussels Capital Region, mapped from high resolution Quickbird data.

Satellite remote sensing measurements, on the other hand, are widely accessible, and offer a relatively inexpensive and verifiable means of deriving complete spatial coverage of environmental information for large areas at different spatial and temporal resolutions in a consistent manner, holding great potential for tracking changes in ecosystem functions.
Satellite remote sensing is, however, associated with intrinsic limitations, which include length, data processing, time capacity, etc. Integrated use of multiple remote sensing sources and increased remote sensing capacity can help overcome many of these known challenges, as long as data and product requirements are clearly identified: the prioritization of new satellite missions associated with freely accessible data for scientific use might indeed be facilitated by the formulation of clear, consensual demands from ecosystem researchers.

Data availability

Availability of lidar data is quite limited, and although radar data are more widely available it may be expensive and its use is less intuitive than the interpretation of optical images. Free software exists to do supervised and unsupervised classification, for example, https://www.orfeo-toolbox.org/ and http://www.dpi.inpe.br/spring/. One additional very useful tool is the Rapid Land Cover Mapper (http://lca.usgs.gov/lca/rlcm/), which provides a very simple way of visually mapping Land Use/Land Cover and change; it is free though requires ArcGIS ArcMap software.
And, increasingly, the open source R statistical software (http://www.r-project.org) is being used for image analysis, and many classification techniques and other geo- statistical models can be easily applied to images using existing user-supplied "packages".

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Fragmentation can be described by the total number of patches and by summary statistics characterizing the frequency distribution of patch size (expressed in hectares), including mean patch size, median patch size, standard deviation of patch size and coefficient of variation. Isolation of open and dense patches can be described by two indicators: the Euclidean nearest neighbor distance of a patch to other patches of the same type, and the proximity index.

Satellite imagery is the fastest method for data collection for urban planning. Since the first development of satellite imagery, many studies have investigated extracting various types of vegetation information. Johansen & Phinn (2006) combined IKONOS and Landsat ETM+ data in order to map structural parameters and the species composition of vegetation. Dennison et al. (2010) used GeoEye-1 high spatial resolution satellite data to map canopy mortality caused by a pine beetle outbreak. Gašparović et al. (2018) used WorldView-2, RapidEye, and PlanetScope data to detect urban vegetation based on land cover classification. Kranjčić et al. (2018, 2019) used Sentinel-2 data to visualize bark-beetle-damaged forests in Croatia, and Wessel et al. (2018) tested object-based and pixel-based methods on Sentinel-2 imagery for two forest sites in Germany. They stated that Sentinel-2 data had high potential for applied forestry and vegetation analysis. Friedel et al. (2017) used unsupervised machine learning to map landscape soils and vegetation components from satellite imagery. Tsai et al. (2018) used machine learning classification in order to map vegetation and land use types. As seen from the abovementioned literature, a lot of work has been done with remote sensing and machine learning to extract vegetation information and measure the potential for green or blue areas to amplify the connectivity and multifunctionality of other urban green/blue areas.

Many studies highlighted landscape fragmentation which was caused by rapid urbanization and has resulted in an immense amount of damage to the ecological system. Taking city districts as study areas, Guo et al. (2018) distinguished the vital patches and corridors for landscape connectivity maintenance through morphological spatial pattern analysis (MSPA), the probability of connectivity (PC), and the least-cost path analysis.These methods are mostly adopted and combined from the existing research about landscape modeling and can be divided into two parameters: the resistance value and the distance threshold.

Geographical scale

Remotely sensed data are inherently suited to provide information on urban vegetation and land cover characteristics, and their change at various geographical scales. However, the higher resolution required, the more expensive would be the RS data needed. In some cases, it would be better to use images provided by drones, but in this case permissions for survey mapping will be required and depends on the local and national/government regulations.

Temporal scale

Remotely sensed data are inherently suited to provide information on urban vegetation and land cover characteristics, and their change over time, at various temporal scales. Analysis of past change can be challenging if historical data of sufficient resolution is unavailable.

Participatory process

Participatory processes can be used to support data analysis. For further information on this see: Connectivity of urban green and blue spaces (structural and functional) - Applied/Participatory Review.

Connection with SDGs

Goal 3	Goal 10	Goal 15
Goal 4	Goal 11	Goal 16
Goal 8	Goal 13	Goal 17
Goal 9	Goal 14	

Applied methods

For more applied and participatory approaches to assessing connectivity, please see: Connectivity of urban green and blue spaces (structural and functional) - Applied/Participatory Review.

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In order to get a species-specific result, some focal species should be selected whose biological characteristics and habitat types are assumed to represent most of the habitats in the city being studied (umbrella species). The result of such studying can show the different habitats and corridors for such species. Then, the results of simulated scenarios can be used to obtain the final landscape pattern. Based on this study, one can propose a paradigm of ecological network identification of multiple species, which may contribute to landscape modeling and greenspace planning.

Landscape connectivity, the opposite of landscape fragmentation, describes the facilitating or impeding effect of the landscape on the dispersal of species among habitats. It is used to evaluate the ecological service function of a certain landscape by quantifying landscape patterns from a macro point of view. In recent decades, an interdisciplinary field called landscape ecology has proposed new methods to understand how landscape patterns influence ecological processes, for instance, biodiversity and the warmer microclimate-heat island effect.

The high-resolution remote sensing images (RS-images) can be used to extract land cover information. Image processing should be performed using ENVI (Harris Geospatial, Boulder, CO, USA) and eCognition (Trimble, Westminster, CA, USA), which can extract meaningful information from remote sensing image. Before classification, images have to be segmented. The scale parameter refers to the threshold of the heterogeneity variation allowed in the segmentation process (Dekavalla & Argialas, 2018). Scale parameter will affect the accuracy and efficiency of the extraction process. Multiscale segmentation was used to fix this problem. It is the foundation procedure of object-based image analysis (OBIA) to convert discrete pixels of RS-images into a homogeneous image object. Depending on the required land-cover categories (green space, agriculture land, built-up area, transportation area, and water), the segmentation scale parameter and the hierarchical relationship were identified according to their characteristics after several attempts to obtain a satisfactory result.

Difficulties in pixel-based classification caused by increasing satellite resolution led to the development of OBIA (Blaschke 2010). By identifying spectral and spatial information (the normalized difference vegetation index, geometry, brightness, texture, neighborhood attributes), adjacent pixels are grouped into multipixel objects (Aplin et al. 1999).

References

Metric references

a) References from literature review:

Aplin P, Atkinson P M, Curran P J (1999) Per-field classification of land use using the forthcoming very fine spatial resolution satellite sensors: Problems and potential solutions. Adv. Remote Sens. GIS Anal., 219–239.

Blaschke, T. (2010) Object based image analysis for remote sensing. ISPRS J. Photogramm. Remote Sens., 65, 2–16.

Datt, B. (1998) Remote sensing of chlorophyll a, chlorophyll b, chlorophyll a + b, and total carotenoid content in eucalyptus leaves. Rem. Sens. Environ. 66, 111–121. http://dx.doi.org/10.1016/S0034-4257(98)00046-7.

Dekavalla M., Argialas D. (2018) A Region Merging Segmentation with Local Scale Parameters: Applications to Spectral and Elevation Data. Remote Sens. 10(12), 2024; https://doi.org/10.3390/rs10122024

Dennison, P.E.; Brunelle, A.R.; Carter, V.A. Assessing canopy mortality during a mountain pine beetle outbreak using GeoEye-1 high spatial resolution satellite data. Remote Sens. Environ. 2010, 114, 2431–2435.

EEA – European Environment Agency (2010) Assessing biodiversity in Europe — the 2010 report. Copenhagen. doi:10.2800/42824

Friedel MJ, Buscema M, Vicente LE, Iwashita F, Kogavicente A (2017) Mapping fractional landscape soils and vegetation components from hyperion satellite imagery using an unsupervised machine-learning workflow. Int. J. Digit. Earth , 11, 670–690. [Google Scholar] [CrossRef]

Gašparović, M.; Dobrinić, D.; Medak, D. Urban vegetation detection based on the land-cover classification of Planetscope, Rapideye and Wordview-2 satellite imagery. In Proceedings of the 18th International Multidisciplinary Scientific Geoconference SGEM, 30 June–9 July 2018. [Google Scholar]

Geary, R., 1954. The contiguity ratio and statistical mapping. Inc. Stat. 5, 115–146.

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For this reason, the K-nearest neighbor method can be adopted in order to obtain the land-cover categories by creating the following spectral characteristics: normalized difference vegetation index, standard deviation, maximum difference, brightness, length/width, roundness, and aspect ratio.

Landscape metrics, for example, the L-Z complexity method (Li et al. 2009) and mean patch shape fragmentation index can be developed to quantify landscape fragmentation. Landscape fragmentation processes can be classified into perforation, subdivision, shrinkage, and attribution, which can also be measured. However, these studies evaluate the overall landscape fragmentation without locating where fragmentation is taking place. According to the definition of landscape fragmentation, fragmentation will bring two results: one is the decrease in patch area, and the other is the increase in patch number. In other words, the mean patch area will decrease.

Table 1. Remote-sensing based indices for the effectiveness and health of green (Wellmann et al., 2018)

Type of Index	Index Name	Abbreviation	Reference
Vegetation Indices	Vegetation fractions	Frac	(Haase et al., 2019)
	Normalized difference vegetation index	NDVI	(Tucker, 1979)
	Green NDVI	gNDVI	(Gitelson et al., 1996)
	Red edge normalized difference vegetation index	reNDVI	(Gitelson and Merzlyak, 1994)
	Vegetation health index	VHI	(Lausch et al., 2018) (Kogan, 1990, 1997)
	Vegetation condition index	VCI	(Kogan, 1995)
	Temperature condition index	TCI	(Singh et al. 2003)
Combination of methods	satellite remote sensing with on-the-ground observations	-	(Lotze-Campen and Lucht, 2001) (Haase et al., 2019)
Statistical Indices	Principal component analysis	1st component 2nd component 1st and 2nd component	(Jolliffe, 2002)

Gitelson, A.A., Kaufman, Y.J., Merzlyak, M.N. (1996) Use of a green channel in remote sensing of global vegetation from EOS-MODIS. Rem. Sens. Environ. 58,289–298. http://dx.doi.org/10.1016/S0034-4257(96)00072-7.
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Therefore, the mean patch area can be used to quantify the fragmentation.
The RS-image can be clipped into grids (size = 1 km × 1 km) using the Fishnet tool in ArcGIS. The area and number of patches in each grid can be summarized, then the mean patch area can be calculated to indicate its landscape fragmentation. Note: No single approach is sufficient to monitor the complexity and multidimensionality of health of green and VH over the short to long term and on local to global scales (as stated by Haase et al., 2019; Lausch et al., 2018; Wellmann et al., 2017). Rather, every approach has its pros and cons, making it all the more necessary to link approaches. It is possible to realize within the frameworks proposed in the above mentioned publications and by reflecting crucial requirements for coupling approaches and integrating additional monitoring elements to form a multisource vegetation health monitoring network (MUSO-VH-MN) as suggested by Lausch et al. 2018. Thereby it is important to have in mind, that when it comes to linking the different approaches, data, information, models or platforms in a MUSO-VH-MN, big data with its complexity and syntactic and semantic heterogeneity and the lack of standardized approaches and VH protocols pose the greatest challenge. Therefore, Data Science with the elements of (a) digitalization, (b) semantification, (c) ontologization, (d) standardization, (e) Open Science, as well as (f) open and easy analyzing tools for assessing VH are important requirements for monitoring, linking, analyzing, and forecasting complex and multidimensional changes in health of green and VH.

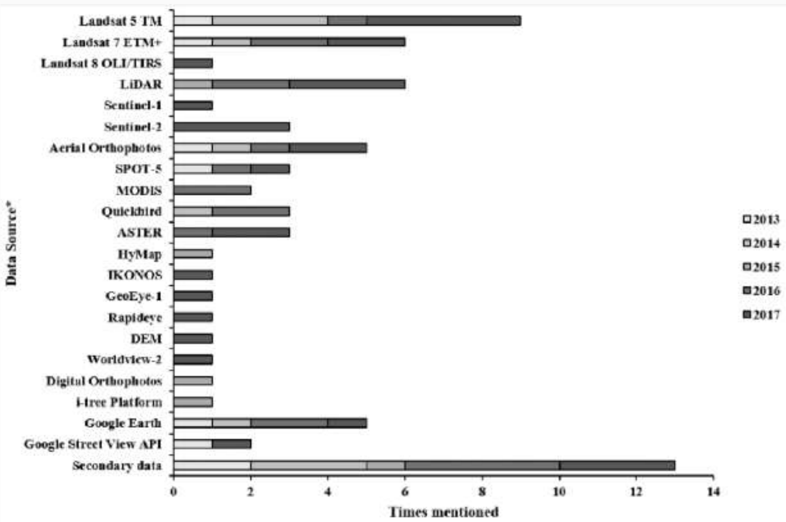

Figure 3. Identification of data source used by the authors, separated by year (2013–2017). * Abbreviations mentioned in the data source axis stands for TM, thematic mapper; ETM+, enhanced thematic mapper plus; OLI/TIRS, operational land imager/thermal infrared sensor; SPOT, satellite pour l'observation de la Terre; MODIS, moderate-resolution imaging spectroradiometer; ASTER, advanced spaceborne thermal emission and reflection radiometer; DEM, digital elevation model; API, application programming interface.

Source: Tavares et al., (2019)

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Table 2. Statistical indicators that have been tested for the quantification of spectral plant trait variations (Wellmann et al., 2017).

Type	Name	Formula	Reference
GLCM ***Stats group***	GLCM mean	$\mu_i = \sum_{i,j=0}^{N-1} i(P_{i,j})$	(Haralick et al., 1973)
	GLCM variance	$\sigma_i^2 = \sum_{i,j=0}^{N-1} P_{i,j}(i-\mu_i)^2$	(Haralick et al., 1973)
	GLCM correlation	$\sum_{i,j=0}^{N-1} P_{i,j}\left[\frac{(i-\mu_i)(j-\mu_j)}{\sqrt{(\sigma_i^2)(\sigma_j^2)}}\right]$	(Haralick et al., 1973)
GLCM ***Contrast group***	GLCM homogeneity	$\sum_{i,j=0}^{N-1}\frac{P_{i,j}}{1+(i-j)^2}$	(Haralick et al., 1973)
	GLCM contrast	$\sum_{i,j=0}^{N-1} P_{i,j}(i-j)^2$	(Haralick et al., 1973)
	GLCM dissimilarity	$\sum_{i,j=0}^{N-1} P_{i,j}\lvert i-j\rvert$	(Haralick et al., 1973)
GLCM ***Orderliness group***	GLCM entropy	$\sum_{i,j=0}^{N-1} P_{i,j}(-\ln P_{i,j})$	(Haralick et al., 1973)
	GLCM angular second moment	$\sum_{i,j=0}^{N-1} P_{i,j}^2$	(Haralick et al., 1973)
Spatial Autocorrelation	Geary's *C*	$C = \frac{n-1}{2\cdot\left(\sum_i\sum_j w_{ij}\right)}\cdot\frac{\sum_i\sum_j w_{ij}(x_i-x_j)^2}{\sum_i (x_i-\bar{x})^2}$	(Geary, 1954)
	Moran's *I*	$I = \frac{n\cdot\sum_i\sum_j w_{ij}(x_i-\bar{x})(x_j-\bar{x})}{\left(\sum_i\sum_j w_{ij}\right)\cdot\sum_i (x_i-\bar{x})^2}$	(Moran, 1950)
Descriptive Statistics	Standard Deviation	$\sigma = \sqrt{\frac{\sum(x-\overline{x})^2}{N}}$	
	Coefficient of Variation	$CV = \frac{\sigma}{\mu}$	(Datt, 1998)

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Wessel M, Brandmeier M, Tiede D (2018) Evaluation of Different Machine Learning Algorithms for Scalable Classification of Tree Types and Tree Species Based on Sentinel-2 Data. Remote Sens. , 10, 1419. [Google Scholar] [CrossRef]

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b) References for Indicator based on the NbS projects from the CN database

Green Surge (Green Infrastructure and Urban Bio- diversity for Sustainable Urban Development and the Green Economy)
www.greensurge.eu
One of the project tasks was "Identification, description and quantification of the full range of urban green spaces". In this regard, the research was based on remote sensing results in combination with relevant case studies field observation.
Cvejić R., Eler K., Pintar M., Železnikar Š., Haase D., Kabisch N., Strohbach M. (2015) A typology of urban green spaces, ESS provisioning services and demands. GREEN SURGE project report.
Weeks J.R. (2010). Defining urban areas. In: Remote sensing of urban and suburban areas. Rashed T., Jürgens C. (eds.). Springer, Dordrecht, Heidelberg, London, New York: p. 33-45.

IMPRESSIONS (Impacts and risks from high-end scenarios: strategies for innovative solutions)
http://www.impressions-project.eu/
·Mapping land use, ecosystem functions, and ecosystem services using cutting-edge remote sensing and machine learning techniques

OpenNESS (Operationalisation of Natural Capital (NC) and Ecosystem Services (ES)
http://www.openness-project.eu
·Use of such indicators as vegetation health and functional diversity in applying of remote sensing techniques.
Smith A., Berry P., Harrison P. Sustainable Ecosystem Management. OpenNESS Synthesis Paper.

OPPLA
(https://oppla.eu)
·Growing with green ambitions. Case study of Leipzig
An important lesson is that mapping should be combined with in situ green space monitoring of, for example, vegetation biomass. This would add value to remote sensing data and improve the capacity to assess ecosystem services provided by urban green space such as carbon dioxide removal. In addition, data were only available for 2012. An account based on a time series of land cover and land use would help city planners to better understand to what extent urban green infrastructure is under pressure.
Banzhaf, E., Kollai, H., Kindler, A. (2018b). Mapping urban grey and green structures for liveable cities using a 3D enhanced OBIA approach and vital statistics. Geocarto International. DOI: 10.1080/10106049.2018.1524514.

Naturvation (2017 – ongoing)
From the NATURVATION database on the value and benefit assessment methods for urban NBS:
·remote Sensing and LIDAR data used to estimate vegetation volume and NVDI. A 3D NVDI as constructed by multiplying the NVDI with the vegetation volume. Measured temperatures was modelled using Maximum Likelihood as a function of NVDI, 3D NVDI, distance to green / blue areas and built-area volume (input data: Remote images (1 m resolution), LIDAR data, temperature measurements; output data: temperature).
·a set of modelled GIS and remote sensing parameters used to model temperature as an effect of greenness, aerosols, buildings. Likely the method needs to be calibrated for each city/town separately (input data: GIS data of buildings, Landsat data; NVDI & AH CHRIS/PROBA satellite images, ASTER image data; output data: temperature).
·remote sensing for ES matrix – the ES matrix approach is an easy-to-apply concept based on a matrix linking spatially explicit biophysical landscape units to ecological integrity, ecosystem service supply and demand. By linking land cover information from, e.g. remote sensing, land survey and GIS with data from monitoring, statistics, ecosystem service supply and demand can be assessed and transferred to different spatial and temporal scales. The ES matrix approach is a quick and simple way to get an overall spatially-explicit picture of the ES in case study areas (input data: land cover and land use data (GIS) (incl. Additional biotic and abiotic information (e.g. land use intensity, soil quality, climate data); output data: ES provision capacity per land use class (0-5 values & biophysical units).
Banzhaf, E., Kollai, H. (2015) Monitoring the Urban Tree Cover for Urban Ecosystem Services-The Case of Leipzig, Germany. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 40(7), 301.
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Davis et al. (2016) Combined vegetation volume and "greenness" affect urban air temperature, Applied Geography, 71, 106–114
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ENVIRONMENTAL INDICATORS - CORE

CONNECTING NATURE

Connectivity of urban green and blue spaces (structural and functional)

Applied/Participatory Review

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Description

A more applied and participatory focus to measuring the potential for green or blue areas to amplify the connectivity and multifunctionality of other urban green/blue areas.

Methodology

Connectivity of landscapes can be evaluated in terms of:

- Structural connectivity – relating to the spatial configuration of patches, without considering the movement of individual organisms among these patches (Ioja et al. 2014) and
- Functional connectivity – relating to the ability of organisms to move among patches (Tischendorf and Fahrig 2000).

Both types of connectivity can be quantified using metrics that span different ranges of scale and complexity.

Level of expertise

Expertise in mapping and interrogation of data using GIS software is typically required. Level of expertise required is greater with increasing complexity of software processing.

Data collection

Cost

Cost is related to the data input requirements and the processing costs for specialist GIS analysis. Costs can be reduced if in-house expertise is available and if citizen scientists/volunteers are used for data collection.

Effort

Effort is generally associated with the scale of spatial analysis and the data input requirements. Once data is inputted, data analysis can be relatively low effort. Keeping databases updated can require additional effort.

Data availability

Aerial photography data is widely available, although resolution of open access data can represent a barrier depending on the scale of investigation. Open access land use mapping can also be available for urban areas. Data on the habitat suitability and spatial scales associated with connectivity can be missing for many groups/species in urban areas.

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Scientific solid evidence

Robustness of evidence for structural connectivity tends to be based on the methodology used to identify and characterise urban greenspace, the scale of resolution of the data, and the age of the data in relation to current state. If up-to-date data from reliable sources is used, calculation of distances using GIS mapping provides solid evidence. For functional connectivity, the robustness of data tends to be correlated with the level of understanding in relation to the spatial dynamics of the target group or activity, and the suitability of habitat.

Extended methodology

Structural connectivity is measured by the proximity of blue-green spaces and the infrastructure matrix that these form across a city. These are typically measured through a blue-green space mapping exercise that orientates and measures distribution and proximity on a city or regional level (Zhang et al. 2019). Typically, such mapping is done using the interrogation of satellite imagery and or land use maps. Examples of methodologies for such mapping include STURLA (Hamstead et al 2016) and FRAGSTATS (Saura and Torné 2009). The outputs from such exercises are usually represented through green infrastructure network maps that provide a planning tool for protecting existing blue-green spaces and opportunity maps for identifying priority areas for enhancing structural connectivity (Carlsen et al. 2011; Zhang et al. 2019).
Participatory processes are also possible using internet-based public participation GIS (PPGIS) surveys to map functional aspects of urban blue-green space (Kahila-Tani et al. 2016; Brown et al 2018a; Brown et al. 2018b) and map underused/unmapped microspaces (Crowe et al. 2016).
Functional connectivity is measured in relation to the ability of the landscape to support the movement of organisms through it (Peer et al. 2011). There has been a particular focus on functional connectivity in relation to urban biodiversity (Hess and Fischer 2001; Opdam 2006; Ahern 2007) because of the impact that fragmentation and the reduction in the number and area of natural habitats has on the ability of many species to persist (Fletcher et al. 2018).

Geographical scale

Analysis is generally performed on a city-wide or regional scale. Local connectivity analysis is also possible.

Temporal scale

Evaluation methods can be adopted for short-term snapshots associated with a change in land use, or strategic connectivity planning. Production of strategic maps can, however, represent a baseline for long-term evaluation of change in connectivity.

Participatory process

Opportunities are available for participation. This can be in the form of mapping greenspaces using internet-based public participation GIS (PPGIS), assessing habitat suitability for target species and activities, or surveying for presence/absence/movement of species.

Earth observation/remote sensing/modelling

Spatial modelling forms the foundation of this indicator. For earth observation, remote sensing and/or modelling approaches, including those used on past and current EU projects, see indicator guidelines: Connectivity of urban green and blue spaces (structural and functional) – Earth observation/Remote Sensing Review

Connection with SDGs

Goal 3
Goal 4
Goal 8
Goal 9
Goal 10
Goal 11
Goal 13
Goal 14
Goal 15
Goal 16
Goal 17

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The predominance of grey infrastructure in urban areas can represent a physical barrier to the movement of many species. These barriers can occur to the extent that urban development can exclude many species (McKinney 2006). Similarly to biodiversity, lack of blue-green space connectivity can also present a barrier to the movement of humans through urban areas (Ioja et al. 2014), particularly in relation to the use of active transport (Giles-Corti et al. 2010) and physical activity (Davison and Lawson 2006). Thresholds for connectivity differ between different species/groups. For some, connectivity must represent linear physical connections, for other species, 'stepping stones' of suitable habitat over appropriate spatial scale represent sufficient functional connectivity (Vergnes et al. 2012). Similar patterns are also reported for human activities associated with blue-green space (Wineman et al. 2014; Peschardt et al. 2012). This means that, for both biodiversity and human functional connectivity, it is vital to have an understanding of the spatial dynamics of connectivity of relevance to your target group and activity (e.g. for humans - active transport; for biodiversity – foraging, colonisation, etc) in order to set threshold values.

Methods for measuring connectivity are therefore based on the spatial thresholds for the group and activity of interest. The most basic method to achieve this is to use Geographical Information Systems (GIS) to apply buffer areas to mapped blue-green spaces that are known to be suitable for the target group and activity.

A more complex, but potentially more realistic approach is to combine distance data with data on the spatially heterogeneous impedance of the landscape matrix (i.e. a measure recognising that some non-target landuse types might be more permeable than others) (Hargrove et al. 2004). By adopting such an approach, it is possible to measure potential connectivity corridors using least-cost path tools using GIS software combined with gravity models and graph theory (Kong et al. 2010).

Conefor software in ArcMap can be used to calculate the integral index of connectivity (IIC). This represents a method for combining the distance between patches with the threshold dispersal distance of a certain species (Saura and Torné, 2009). Such a tool enables evaluation of functional connectivity and provides a suitable metric for landscape conservation planning (Pascual-Hortal and Saura, 2006).

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Original reference for indicator

Eklipse; Ioja et al., 2014

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Another example of a method for capturing functional connectivity is the use of habitat suitability models (HSM) utilising remote sensed vegetation data to map landcover composition and species distributions across cities (Bellamy et al. 2017).

In general, the biggest barrier to the delivery of such mapping tends to be a lack of understanding of the spatial dynamics (in relation to what constitutes functional connectivity) for the target groups (LaPoint et al. 2015). Applied methods to study the spatial dynamics of target groups, and to assess the permeability of different habitat types by direct observation, can strengthen the validity of mapped data.

Evaluation of blue-green space structural and functional connectivity can be used to:

- Underpin green infrastructure and biodiversity spatial planning;
- Prioritise sites for interventions;
- Assess that impacts of NBS projects on pre-existing green networks;
- Promote active transport initiatives.

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ENVIRONMENTAL INDICATORS - CORE

CONNECTING NATURE

Supporting/increasing biodiversity conservation

Applied/Participatory Review

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Description

Measure net change in individual (native) species numbers, functional richness, vegetation cover, conservation priority species in area affected by NBS using more applied and participatory methods.

Methodology

Biodiversity generates a wide range of benefits to society (ecosystem services) therefore its conservation is essential to achieving Sustainable Development Goals (SDGs) and to meet the United Nations Convention on Biodiversity (CBD) Aichi Biodiversity Targets. Measuring net changes to biodiversity to monitor gains or losses as a consequence of NBS can be undertaken using various methodologies, involving either primary observations of species or assessments of habitat extent/quality as a proxy for biodiversity value.

Level of expertise

Professional ecological consultants and scientific/ecological expertise are needed to design and implement and/or support citizen scientists monitoring schemes and data analysis (depending on the scheme or whether an existing scheme is adopted). If identification of target species is not straightforward, expertise can be required for the monitoring also.

Data collection

Cost

Variable. Consultancy costs would depend on the scale of the NBS project. If there are existing biodiversity monitoring schemes in place, implementation for a specific project could be relatively low, set-up costs for new schemes could be high.

Effort

Hiring professional consultants would involve the lowest effort. Co-ordinating citizen science projects can be more onerous but can also be lower effort for more substantial data than delivering the monitoring in-house.

Data availability

Using existing monitoring schemes can be a very effective mechanism for identifying long-term patterns. However, where such schemes don't exist, there may be a need to develop new programmes to capture the baseline data needed prior to the NBS intervention to capture change.

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Scientific solid evidence

ad-hoc, unstructured recording can restrict scientific value but can catalyse community engagement. Structured, systematic monitoring programmes, including citizen science, can be an important mechanism for ascertaining population trends over time.

Extended methodology

Counts of species (species richness) have commonly been used as a surrogate for measuring biodiversity for conservation at local and broader scales, and taxa are often categorized according to rarity/local conservation concern (see The Royal Society, 2003 for a framework for measuring biodiversity for conservation). Measurements of population sizes of individual species (abundance), particularly umbrella species (Roberge and Angelstam 2004) (species which if protected, indirectly protect many other species comprising the ecological community of their habitat), can be a more sensitive indicator of change. However, collecting the data on the population dynamics of single species can be resource intensive. Adopting participatory/citizen science approaches can provide a mechanism to reduce resource intensity but can, typically, only be applied to relatively easy to identify species. Selecting appropriate metrics will depend on the objectives of the study, and whether direct measurement is required, or whether a proxy/surrogate measurement may be sufficient. Typically, extrapolations are made from collecting a stratified random sample. Repeat surveys must be undertaken to monitor change against a baseline survey. Analytical techniques will be related to sampling strategies (i.e. diversity or species quality indices, multivariate modelling, etc).
Pocock et al. (2015) have developed a checklist of priority attributes for developing a biodiversity monitoring programme that includes 25 attributes that range from elemental to aspirational. This can be used as a checklist to clarify objectives and justify investment in resources and provides an excellent resource for local authorities or city stakeholders wanting to establish monitoring programes.

Geographical scale

Typically more local or project scale but can be used to capture data at city scale. Scale is typically related to recorded networks and their scale.

Temporal scale

Can provide a snapshot or site inventory/baseline from which changes can be measured over time with repeated surveys. Long-term data can be generated if formal monitoring programmes are established.

Participatory process

Such monitoring schemes offer great opportunities for citizen participation. This can be a mechanism to increase the scale and extent of the monitoring, and to increase community engagement with, and awareness of, urban biodiversity.

Earth observation/remote sensing/modelling

For further information on modelling and remote sensing approaches, and examples of their use in past and current EU projects, see indicator guidelines:
Supporting/increasing biodiversity conservation – Earth observation/Remote Sensing Review

Connection with SDGs

Goal 2
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The National Biodiversity Network (James, 2007) has an online handbook which provides comprehensive guidance on running a biological recording scheme that could potentially be used for site assessment, land-use planning and environmental policy development. The Natural History Museum (NHM) has a guide for specifically developing citizen science recording schemes (Tweddle, 2012).

The Wildlife Trust Biodiversity Benchmark provides a framework to achieve continual biodiversity enhancement and protection on landholdings by developing an action plan, recording the baseline (PEA - habitats & species), and conducting periodic monitoring to assess performance against targets.

Examples of citizen science projects that could be applied to NBS projects:

Glasgow's buzzing - community bee recording project in partnership with Buglife, creating and enhancing wildflower meadows across the City, carrying out invertebrate surveys (sweep nets of parks before/after meadow creation/enhancement) and raising community awareness of biodiversity (Bairner, 2016)

Urban butterfly project - recording butterflies in urban greenspaces 3 times during spring/summer to measure species/abundance using iRecord Butterflies app

RSPB Big Garden Birdwatch/Big Schools Birdwatch – annual snapshot of bird diversity

NHM Bioblitz – community bioblitz, typically a 24 hour census, recording as many species as possible.

When selecting species to target for evaluation of benefits, there are generally to strategies: selecting species that are local, national or international conservation priority species, and selecting representative umbrella species that are indicators of high biodiversity. When selecting umbrella species, it is generally advisable to select a range of species that are representative of a range of taxa (Sattler et al. 2014) and ensure that there is a local focus to this selection in terms of species associated with site of high biodiversity (Caro 2010).

Key drivers include:

- Assisting local authorities to evaluate their progress in urban biodiversity conservation (for example against Aichi/national/local biodiversity targets);
- Ensuring NBS contributes positively to biodiversity conservation;
- Serving as a public platform upon which biodiversity awareness raising exercises can be launched.

References

Original reference for indicator

UnaLab

Metric references

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Urban Butterfly Project https://butterfly-conservation.org/sites/default/files/urban-butterfly-project-recorders-pack.pdf

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ENVIRONMENTAL INDICATORS - CORE

CONNECTING NATURE

Supporting/increasing biodiversity conservation

Earth Observation/Remote Sensing Review

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Description

Measure net change in (native) species numbers, functional richness, vegetation cover, conservation priority species in area affected by NBS using Earth Observation and Remote Sensing approaches

Methodology

It is important to foster research and monitoring of biodiversity to determine the best assemblages of species to achieve the most efficient NBS, including the optimization of multiple economic, ecological and social benefits and exploration of trade-offs created by NBS. This can be achieved by collection of new data in the field and the use of remote sensing to gather comprehensive data on additional benefits, to complement existing data and observation.

Level of expertise

Expertise in mapping and interrogation of data using GIS software is typically required. Level of expertise required is greater with increasing complexity of software processing.

Typical “multi-spectral” sensors with 4 to 20 carefully selected and well-calibrated bands provide a great deal of information, and adding more bands can help with specific issues. “Hyperspectral” sensors can have more than 200 bands and can provide a wealth of information to help, for example, identify specific species.

Processing such datasets requires special expertise and satellite-based hyperspectral sensors are not yet common. Other sensor types include radar and lidar which actively emit electromagnetic energy and measure the amount that is reflected—these sensors are useful for measuring surface height as well as tree canopy characteristics and surface roughness.

Lidar is generally more precise than radar and ideal for measuring tree height. Radar is particularly useful where cloud cover is a problem (for instance, in the biodiversity-rich tropical rainforests) because it penetrates clouds.

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Scientific solid evidence

Remote sensing has been increasingly contributing to timely, accurate, and cost-effective assessment of biodiversity-related characteristics and functions during the last years. Various studies have demonstrated how satellite remote sensing can be used to infer species richness. However, most relevant studies constitute individual research efforts, rarely related with the extraction of widely adopted Convention on Biological Diversity (CBD) biodiversity indicators (Petrou et al., 2015). Furthermore, systematic operational use of remote sensing data by managing authorities remains limited. The monitoring with CBD related indicators can be facilitated by remote sensing.

Numerous studies using RS data to measure biodiversity-related properties are presented in the literature, covering a broad range of applications, study areas, data and methods. However, most studies are rarely explicitly connected to any widely adopted biodiversity indicator that could be extracted through them directly or indirectly. Instead, various indicators have been used by individual studies, resulting in numerous incompatible monitoring systems (Feld et al. 2009). Furthermore, despite the increasing availability of RS data, the connection between variables measured by RS and indicators required by the biodiversity and policy-making community is still poor (Secades et al. 2014). Thus, a link of RS approaches to a common set of indicators would be highly beneficial.

There are a number of recent remote sensing approaches able to extract related properties that exist for each headline indicator. Methods cover a wide range of fields, including: habitat extent and condition monitoring; species distribution; pressures from unsustainable management, pollution and climate change; ecosystem service monitoring; and conservation status assessment of protected areas.

There are some advantages and limitations of different remote sensing data and algorithms. By virtue of the large spatial coverage, information-rich character, and high temporal resolution, remote sensing technology has been widely used in UGS research (Chen et al., 2018). At the end of the 20th century, low/medium spatial resolution remote sensing products began to be applied to the identification of vegetation types (Mucina, 2010).

Data collection

Cost

Free from Internet sites, or up to $600/image with very high resolution. Landsat data sets can be downloaded for free from the Global Land Cover Facility.

Among all the sensors used in remote sensing of biodiversity, the most commonly used and first civilian sensor is Hyperion (Hyperion Sensor EO-1 (Earth Observing-1) of NASA, which is controlled by the EROS (Earth Resources Observation and Science) at a fairly low cost to the general public. Other sensors include CHRIS (Compact High Resolution Imaging Spectrometer) of EEA, PROBA (Project for On-Board Autonomy) and FTHSI (Fourier Transform Hyperspectral Imager) of US Air Force Research Lab.

Similar to the case with fine spatial resolution imagery, hyperspectral imagery is also an underutilized resource and due to its high cost problem, is putting it out of reach for research ecologists, predominantly those in e.g. developing countries. As an overlay to create habitat patches, spatial patterns should be generated from high-resolution image data. Moderate-resolution sensors such as TM, SPOT, and IRS are used to delineate road systems and cover larger areas more quickly and cheaply.

These high-resolution photos and digital sensors, typically 1–4 metres in resolution are air photos, IKONOS, and QuickBird. Images from these sensors allow direct spatial recognition of the spatial patterns and require less spectral contrast between the species and the surrounding landscape.

Drawbacks to these sensors include the high image cost per unit area and the substantially larger volume of data required to cover a project area. In most cases, regional or national projects with high-resolution data sets are not practical at this time because of cost and time required for analysis.

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Recent developments in remote sensors offer an excellent opportunity to explore various aspects of different vegetation types. With the many advantages of new remote sensors, combining the advantages of different sensors optimized for vegetation features has attracted a significant amount of research interest and has enabled researchers to propose many promising new techniques for the identification of various vegetation types. For example, using high temporal resolution remote sensing images together with vegetation phenological features can achieve more accurate identification of vegetation types (Yan et al. 2018; Senf et al. 2015). Utilizing the 3D structures provided by LiDAR imagery in combination with the hundreds of narrow spectral bands provided by hyperspectral (HS) imagery can enable the identification of more vegetation types (Xia et al. 2018; Alonzo et al. 2014) However, although there has been much research that involved combining multi-source data sets or adopting better classification methods, these are still unable to identify different social function types of UGS.

Extended methodology

Biodiversity includes multiscalar and multitemporal structures and processes, with different levels of functional organization, from genetic to ecosystemic levels. One of the most widely used methods to infer biodiversity is based on taxonomic approaches and community ecology theories. However, gathering extensive data in the field is difficult due to logistic problems, especially when aiming at modelling biodiversity changes in space and time, which assumes statistically sound sampling schemes. In this context, airborne or satellite remote sensing allows information to be gathered over wide areas in a reasonable time.

Most of the biodiversity maps obtained from remote sensing have been based on the inference of species richness by regression analysis. Estimating compositional turnover (β-diversity) might add crucial information related to relative abundance of different species instead of just richness. Presently, few studies have addressed the measurement of species compositional turnover from space.

Effort

Satellite remote sensing offers smart solutions for biodiversity monitoring and to prepare conservation strategies with less effort. Due to the availability of multi-date, multi-resolution, multi-sensor datasets, it has become possible to acquire huge detail on the earth's surface without making time-consuming field visits. Since high spatial resolution datasets can acquire very fine details over small areas at a regular interval of time, this information will provide the basis for regional scale monitoring of biodiversity. Thus, remote sensing plays an important role in assisting environmentalists to characterize and map biologically rich zones, generating information on changes in biodiversity, alteration and distribution in species diversity.

Data availability

Availability of lidar data is quite limited, and although radar data are more widely available it may be expensive and its use is less intuitive than the interpretation of optical images. The most cost-effective satellite sensors for distinguishing a smaller number of habitat classes are Landsat TM and ETM+), ASTER, and SPOT XS, with a 0–30-metre resolution. Landsat data time series (Landsat 5 TM and Landsat 7 ETM+) offer a cost-effective resource for large- scale reef surveys and for detecting large changes in coral or seagrass extent over time. If the habitat patches have already been mapped, IKONOS data can be used to measure small changes in patch location and boundary.

Geographical scale

At various geographical scales. Satellite remote sensing technology in the last decade has empowered interdisciplinary research at regional and local scale with high temporal resolution in order to provide information about changes in species distribution, habitat degradation and fine-scale disturbances of forests.

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There are novel techniques to measure β-diversity from airborne or satellite remote sensing proposed by Roccini et al. (2017), mainly based on:

- multivariate statistical analysis,
- the spectral species concept,
- self-organizing feature maps,
- multidimensional distance matrices,
- Rao's Q diversity.

Each of these measures addresses one or several issues related to turnover measurement.
High temporal resolution remote sensing images together with vegetation phenological features can achieve more accurate identification of vegetation types. Yan et al. (2018) integrated object-based classification data with vegetation phenological information derived from multi-temporal WorldView-2 images to identify grass and tree types. Senf et al. (2015) found that adding phenological patterns captured by multi-seasonal Landsat imagery can better discriminate shrublands and woodlands that would otherwise be a challenging task in single-date Landsat imagery.

Moreover, utilizing the 3D structures provided by LiDAR imagery in combination with the hundreds of narrow spectral bands provided by hyperspectral (HS) imagery can enable the identification of more vegetation types. Xia et al. (2018) constructed an ensemble classifier to integrate HS and LiDAR data, and used it to identify several tree types and three grass types. Alonzo et al. (2014) used a crown-level integration of HS and LiDAR data to identify 29 common tree species in urban regions.

Drone mapping is described as a tool for monitoring ecosystem restoration. Plant communities with different plant cover and species composition reflect spectral bands in different rates and this information reflects state and disturbances of mire ecosystems (peatlands). Usage of drones gives higher resolution data compared to other remote sensing options, and is suitable for plant community level monitoring, but at the same time there is a trade-off between spatial resolution and mapping area.

Temporal scale

At various temporal scales.

Participatory process

It is today possible to integrate remote sensing data and in situ observations to monitor several essential biodiversity variables such as habitat structure and phenology.

In this context, municipalities should explore the possibilities of launching citizen science projects and consider the possibility in general that within cities, local knowledge on biodiversity and ecosystem services may reside in many different groups within civic society. Here, we can face the challenges related to scaling, boundaries, locally adapted indicators and scoring which can be met by each municipality developing their interpretation of what scale and what boundary is the most appropriate, what definitions to use, and what set of sub-indicators may best reflect the local ecological and cultural context. However, there are some challenges that are not easily addressed at the municipal level and need input from the research community.

Connection with SDGs

Goal 2	Goal 8	Goal 13
Goal 3	Goal 9	Goal 14
Goal 4	Goal 10	Goal 15
Goal 6	Goal 11	Goal 16
Goal 7	Goal 12	Goal 17

Applied methods

For more applied and participatory methods please see: Supporting/increasing biodiversity conservation - Applied/Participatory Review

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Various indicators are used to assess the status and trends of components of biodiversity, measure pressures, and quantify biodiversity loss at the level of genes, populations, species, and ecosystems, at various scales (Butchart et al. 2010; EEA 2012; Petrou et al. 2015). Several sets of such indicators have been proposed by organizations, scientists, and policy makers (EEA 2012; Feld et al. 2009; Petrou et al., 2015; Strand et al. 2007). They can be either directly measured or calculated using statistical models and may have a global, regional, or national applicability.

Among the most widely adopted sets are the ones proposed by the United Nations (UN) Convention on Biological Diversity (CBD), aiming at monitoring the progress towards the achievement of the defined targets at global scale (AHTEG 2011). Further efforts include the definition of more directly measured variables, to enhance indicator extraction, such as the Essential Biodiversity Variables (EBV) proposed by the Group on Earth Observations Biodiversity Observation Network (GEO BON) (Pereira et al. 2013).

Although in-situ campaigns are the most accurate way of measuring certain aspects of biodiversity, such as the distribution and population of plant and animal species, in many cases, they have proven particularly costly, time demanding, or impossible (Buchanan et al. 2009; Gillespie et al. 2008).

Alternatively, remote sensing (RS) data from airborne or satellite sensors are increasingly being employed in biodiversity monitoring studies (Nagendra et al. 2013; Bergen et al. 2009). Offering repetitive and cost-efficient monitoring of large areas, RS data can provide precious information nearly impossible to be acquired by field assessment alone (Nagendra et al. 2001, 2013).

Recently, essential biodiversity variables (EBVs) were identified (Pereira et al., 2013) (Table 1) and defined as variables, or a group of linked variables, that allows quantification of the rate and direction of change in one aspect of the state of biodiversity over time and across space (Pettorelli et al., 2018).

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EBVs are planned to harmonise assessment of biodiversity monitoring at any scales, and to support the aims of the Convention on Biological Diversity and IPBES.

From the start, satellite remote sensing has been expected to be an important methodology for the derivation of EBVs, and indeed, satellite remote sensing EBVs (SRS-EBVs) have been conceptualised as the subset of EBVs whose monitoring relies largely or wholly on the use of satellite-based data (Luque S et al. 2018). Table 2 gives a summary of the different types of remote sensing data that is useful in biodiversity monitoring.

Table 1. Essential biodiversity variables and use of RS (based on Walters et al., 2013)

ESSENTIAL BIODIVERSITY VARIABLES	SPATIAL RESOLUTION SATELLITE IMAGERY WITH TYPE OF MEASUREMENT SCALES (INCLUDING AVAILABLE REMOTE SENSING SENSORS)	RELEVANCE AND RELATED INFORMATION FOR BIODIVERSITY
TEMPORAL PHENOLOGY METRICS	Low/coarser spatial resolution (Global Scale) (MODIS, AVHRR etc.)	Phenology types, Forest / Non Forest, Deforestation and Biomass burning.
HABITAT STRUCTURE, ECOSYSTEM EXTENT AND FRAGMENTATION	Medium spatial resolution (Regional Scale) (Landsat, IRS, SPOT etc.)	Forest type distribution and agricultural expansion
HABITAT TYPES AND STRUCTURES, AND ECOSYSTEM COMPOSITION BY FUNCTIONAL TYPE	High spatial resolution (Local scale) (IKONOS, QuickBird, Rapid Eye historic GeoEye, WorldView-2 etc.)	Species-level distribution, canopy diameters, stand-level analysis, individual tree detection, to differentiate species at a finer scale.
HABITAT TYPES AND STRUCTURES	Active remote sensing data	Habitat degradation monitoring by generation of 3D structures

Table 2. Remote Sensing Data Useful for Biodiversity Monitoring

REMOTE SENSING DATA	BIODIVERSITY MONITORING
COARSE SPATIAL RESOLUTION (MODIS, AVHRR)	Forest / Non Forest, Biomass burning studies at global scale.
MEDIUM SPATIAL RESOLUTION (LANDSAT, IRS, SPOT)	Indicators of overall species richness and diversity at regional scales, forest type distribution and agricultural expansion
HIGH TEMPORAL RESOLUTION DATA (MULTI SEASON DATA OR IMAGES CORRESPONDING TO SPECIFIC SEASONS)	Information on invasion species and other species of interest (e.g. using images acquired corresponding to critical phonological stages of flowering or leaf senescence

Nagendra H, Lucas R, Honrado JP, et al. (2013) Remote sensing for conservation monitoring: Assessing protected areas, habitat extent, habitat condition, species diversity, and threats. Ecol Indic 33:45–59
Nedkov S, Zhiyanski M, Dimitrov S, Borisova B, Popov A, Ihtimanski I, Yaneva R, Nikolov P, Bratanova- Doncheva S (2017) Mapping and assessment of urban ecosystem condition and services using integrated index of spatial structure. One Ecosystem 2: e14499. https://doi.org/10.3897/oneeco.2.e14499
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b) References for Indicator based on the NbS projects from the CN database

Green Surge
(Green Infrastructure and Urban Bio- diversity for Sustainable Urban Development and the Green Economy) www.greensurge.eu
One of the project tasks was "Identification, description and quantification of the full range of urban green spaces". In this regard, the research was based on remote sensing results in combination with relevant case studies field observation.
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EKLIPSE
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OpenNESS
Operationalisation of Natural Capital (NC) and Ecosystem Services (ES)
http://www.openness-project.eu
·Monitoring of results using GIS and/or remote sensing to help assess impacts on land cover.
·Use of such indicators as vegetation health and functional diversity in applying of remote sensing techniques.
Smith A., Berry P., Harrison P. Sustainable Ecosystem Management. OpenNESS Synthesis Paper.

OPPLA
Great number of projects.

PLUREL
(Peri-urban Land Use Relationships - Strategies and Sustainability Assessment Tools for Urban-Rural Linkages) www.plurel.net
·remote sensing and GIS for sustainable urban development science to provide geo-referenced information on the shape, size and distribution of different land-use classes of the urban environment
The main application areas of these technologies in urban growth research within the project can be defined as follows:

- Monitoring urban growth (area change, structures, land consumption, soil sealing
- Monitoring land cover/land-use changes (loss of agricultural area, wetland infringement, loss of areas important for biodiversity, spatial distribution of inner-urban green and open spaces and natural areas)
- Mapping of environmental parameters (base data important for urban climate, access to and distribution of open space, calculation of sealed surfaces).

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URBES
(Urban Biodiversity and Ecosystem Services) https://www.biodiversa.org/121
·Remote Sensing of Urban Ecology (EO sensors, modelling algorithms)
·spatial and remote sensing data analyses, mostly engaged in WP2: Case study conditions and co-design workshops for identifying local policy solutions and WP5: Resilient supply of ecosystem services.
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ENVIRONMENTAL INDICATORS - CORE

CONNECTING NATURE

Species diversity

Applied/Participatory Review

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Description

Changes in overall number of species/species diversity/biodiversity indices within area affected by NBS using more applied/participatory methods.

Methodology

Population counts for species or groups of species can provide an intuitive biodiversity metric which also has public resonance and the data can be used to populate indicators and measure progress towards conservation policy targets. Whilst survey of individual target conservation species and/or umbrella species can be of value in relation to specific conservation objectives, quantification of biodiversity indices can also have value in providing a more holistic insight into overall biodiversity and greater representation of a range of taxa (Buckland et al. 2005).

Level of expertise

Expertise needed for accurate monitoring of some species groups. Relatively straightforward data analysis based on the CBI calculation for example.

Data collection

Cost

Can be relatively low cost if organisations are already collecting suitable data. Also, if data is not available from external organisations, use of citizen science participatory methods can reduce costs for data gathering.

Effort

Data needs to be captured every 3 years for CBI. Effort varies for 3 Tracks of UBIF.

Data availability

Can use existing data and capture new data.

Geographical scale

Devised to measure change at a city level but could be scaled-down to a borough/neighbourhood/site level.

Temporal scale

Devised to measure change over time. Measures should be repeated at least every 3 years. Impossible to get historical data if no past survey was carried out.

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Scientific solid evidence

Depends of the quality of the data used and the representativeness of the index selected to overall biodiversity patterns. Raw data can characterise species spatial and temporal distributions but are generally limited because of the time/costs involved in the detailed level of data collection needed to accurately detect change.

Extended methodology

The City Biodiversity Index (CBI) (Chan et al 2014), was proposed to engage cities in the implementation of the Convention on Biodiversity's strategic plan for biodiversity. The CBI was intended to provide a benchmark of biodiversity conservation efforts of cities, it provides a self-assessment tool to monitor the progress of biodiversity conservation efforts against a city's baseline.
The first part of the framework involves a profile of the city, then 23 indicators are proposed that comprise 3 core components: 1) native biodiversity, 2) ES provided by biodiversity, and 3) governance and management of biodiversity. This framework could be used to undertake a full CBI self-assessment.
Alternatively, those indicators that directly measure biodiversity could be used, for example Indicator 3: native biodiversity in built-up areas (bird species), or Indicators 4-8 which include three 'core indicator' groups that are most surveyed worldwide – plants, birds and butterflies. Cities can select two additional taxonomic groups (for instance those where data is already held or target groups of local importance/conservation interest).
The data from the first year of implementing the Index provides the baseline for future monitoring. It is recommended that application of the Index take place every 3 years to allow sufficient time for the results of biodiversity conservation efforts (e.g. NBS implementation) to materialise. Example units of calculation are: number/abundance of native bird species per hectare. The net change in number of native species from the previous survey to the most recent survey is calculated as: total increase in number of species (as a result of re-introduction or restoration efforts, new species found, etc.) minus number of species that have gone extinct.

Participatory process

Data capture could include public participation and citizen science data collection. Such practices are widespread including using volunteer recording groups.

Earth observation/remote sensing/modelling

For further information on earth observation, modelling, and remote sensing approaches, and examples of their use in past and current EU projects, see indicator guidelines: Species diversity – Earth observation/Remote Sensing Review

Connection with SDGs

Goal 2	Goal 8	Goal 13
Goal 3	Goal 9	Goal 14
Goal 4	Goal 10	Goal 15
Goal 6	Goal 11	Goal 16
Goal 7	Goal 12	Goal 17

References

Original reference for indicator

UnaLab

Metric references

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Possible sources of data include agencies in charge of nature conservation/biodiversity (Wildlife Trusts, etc), city municipalities and urban planning agencies, biological records centres, nature groups, universities, etc.
The Urban Biodiversity Inventory Framework (UBIF 2017) offers an alternative 3 track methodology to collect species diversity information as follows: Track 1 - collating data from partners/stakeholders; Track 2 - presence/absence of surrogate species; Track 3 - relative abundance estimates of surrogate species. Track 1 requires the least additional resources but with limited scope for summary statistics, whereas Tracks 2 and 3 require increasing resources but generate increasingly detailed data e.g. comparing changes at a site over time.

The CBD agreed a set of 26 specific biodiversity indicators (2010 Biodiversity Indicators Partnership 2010), some of which reflect measures in the CBI (above) and others that could be extrapolated for use under this indicator:

- Trends in the abundance/distribution of selected species (e.g. birds/butterflies)
- Change in status of threatened and/or protected species (Red List species/species of European interest)
- Change in extent of habitats (e.g. vulnerable habitats/habitats of conservation importance)
- Coverage of protected areas (loss/gain of nationally/locally designated areas/sites)

Additional specific examples of general biodiversity measures typically undertaken by professional ecologists include:
The Defra Biodiversity Metric 0.2 (Natural England 2018) was developed to as a means of assessing changes in biodiversity value as a consequence of development or land-use change, primarily with the aim of quantifying biodiversity net-gain. It uses habitat as a proxy to measure biodiversity which is converted into measurable 'biodiversity units' according to the area of each habitat type. The metrics score different habitat types (e.g. woodland, grassland) according to their relative biodiversity value and adjusts this according to the condition and location of the habitat. Where new habitat is created or existing habitat is enhanced, then the associated risks of doing so are factored into the metric.

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It can be used to calculate losses and gains in biodiversity from actions. The metric sites within the 'mitigation hierarchy'. To apply the metric a site should be surveyed, mapped and divided into parcels of distinct habitat types present using a recognised habitat classification system.
The biodiversity 'value' of a habitat parcel is evaluated on the basis of its area and the relative 'quality' of its habitat (distinctiveness, condition, strategic significance, habitat connectivity). The calculation uses the scores and the area of the habitat to give a number of biodiversity units that represent the biodiversity value of that habitat parcel. The relative value in biodiversity units 'post development' is then deducted from the 'baseline' to give a value for the extent of change e.g. 'Net Gain'. Net loss would require improvement to development proposal to improve the number of biodiversity units obtained or, if there is no scope for additional on-site compensation or enhancement, off-site measures will need to be considered.

BREEAM UK Strategic Ecology Framework (SEF) is a new framework for evaluating, protecting and enhancing ecology in the built environment (Yates, Abdul & Buchanan, 2016). BREEAM credits for ecology (BREEAM 2014) provides a scoring system for assessing the ecological value of a site before and after development (Land Use and Ecology LE01 – LE06). Both protocols start with a Preliminary Ecological Appraisal (PEA) and evaluate and monitor how proposed schemes will benefit biodiversity. The credit system awards high scores to schemes that deliver ecological enhancement.

Key drivers for such biodiversity monitoring include:

- Assisting local authorities to evaluate their progress in urban biodiversity conservation (for example against Aichi/national/local biodiversity targets);
- Ensuring NBS contribute positively to biodiversity conservation;
- Creating a foundation for development of Local Biodiversity Strategies/Action Plans (see example of Lisbon, Portugal in MAES reference below)
- Serving as a public platform upon which biodiversity awareness raising exercises can be launched.

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ENVIRONMENTAL INDICATORS - CORE

CONNECTING NATURE

Species diversity

Earth Observation/Remote Sensing Review

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Description

Changes in species diversity/number of species within area affected by NbS using earth observation and remote sensing indicators

Methodology

It is important to foster research and monitoring of biodiversity to determine the best assemblages of species to achieve the most efficient NBS, including the optimization of multiple economic, ecological and social benefits and exploration of trade-offs created by NBS. This can be achieved by collection of new data in the field and the use of remote sensing to gather comprehensive data on additional benefits, to complement existing data and observation.

Level of expertise

Expertise in mapping and interrogation of data using GIS software is typically required. Level of expertise required is greater with increasing complexity of software processing.

Typical "multi-spectral" sensors with 4 to 20 carefully selected and well-calibrated bands provide a great deal of information, and adding more bands can help with specific issues. "Hyperspectral" sensors can have more than 200 bands and can provide a wealth of information to help, for example, identify specific species.

Processing such datasets requires special expertise and satellite-based hyperspectral sensors are not yet common. Other sensor types include radar and lidar which actively emit electromagnetic energy and measure the amount that is reflected—these sensors are useful for measuring surface height as well as tree canopy characteristics and surface roughness.

Lidar is generally more precise than radar and ideal for measuring tree height. Radar is particularly useful where cloud cover is a problem (for instance, in the biodiversity-rich tropical rainforests) because it penetrates clouds.

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Scientific solid evidence

Remote sensing has been increasingly contributing to timely, accurate, and cost-effective assessment of biodiversity-related characteristics and functions during the last years. Various studies have demonstrated how satellite remote sensing can be used to infer species richness. However, most relevant studies constitute individual research efforts, rarely related with the extraction of widely adopted Convention on Biological Diversity (CBD) biodiversity indicators (Petrou et al., 2015). Furthermore, systematic operational use of remote sensing data by managing authorities remains limited. The monitoring with CBD related indicators can be facilitated by remote sensing.

Numerous studies using RS data to measure biodiversity-related properties are presented in the literature, covering a broad range of applications, study areas, data and methods. However, most studies are rarely explicitly connected to any widely adopted biodiversity indicator that could be extracted through them directly or indirectly. Instead, various indicators have been used by individual studies, resulting in numerous incompatible monitoring systems (Feld et al. 2009). Furthermore, despite the increasing availability of RS data, the connection between variables measured by RS and indicators required by the biodiversity and policy-making community is still poor (Secades et al. 2014). Thus, a link of RS approaches to a common set of indicators would be highly beneficial.

There are a number of recent remote sensing approaches able to extract related properties that exist for each headline indicator. Methods cover a wide range of fields, including: habitat extent and condition monitoring; species distribution; pressures from unsustainable management, pollution and climate change; ecosystem service monitoring; and conservation status assessment of protected areas.

There are some advantages and limitations of different remote sensing data and algorithms. By virtue of the large spatial coverage, information-rich character, and high temporal resolution, remote sensing technology has been widely used in UGS research (Chen et al., 2018). At the end of the 20th century, low/medium spatial resolution remote sensing products began to be applied to the identification of vegetation types (Mucina, 2010).

Data collection

Cost

Free from Internet sites, or up to $600/image with very high resolution. Landsat data sets can be downloaded for free from the Global Land Cover Facility.

Among all the sensors used in remote sensing of biodiversity, the most commonly used and first civilian sensor is Hyperion (Hyperion Sensor EO-1 (Earth Observing-1) of NASA, which is controlled by the EROS (Earth Resources Observation and Science) at a fairly low cost to the general public. Other sensors include CHRIS (Compact High Resolution Imaging Spectrometer) of EEA, PROBA (Project for On-Board Autonomy) and FTHSI (Fourier Transform Hyperspectral Imager) of US Air Force Research Lab.

Similar to the case with fine spatial resolution imagery, hyperspectral imagery is also an underutilized resource and due to its high cost problem, is putting it out of reach for research ecologists, predominantly those in e.g. developing countries. As an overlay to create habitat patches, spatial patterns should be generated from high-resolution image data. Moderate-resolution sensors such as TM, SPOT, and IRS are used to delineate road systems and cover larger areas more quickly and cheaply.

These high-resolution photos and digital sensors, typically 1–4 metres in resolution are air photos, IKONOS, and QuickBird. Images from these sensors allow direct spatial recognition of the spatial patterns and require less spectral contrast between the species and the surrounding landscape.

Drawbacks to these sensors include the high image cost per unit area and the substantially larger volume of data required to cover a project area. In most cases, regional or national projects with high-resolution data sets are not practical at this time because of cost and time required for analysis.

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Recent developments in remote sensors offer an excellent opportunity to explore various aspects of different vegetation types. With the many advantages of new remote sensors, combining the advantages of different sensors optimized for vegetation features has attracted a significant amount of research interest and has enabled researchers to propose many promising new techniques for the identification of various vegetation types. For example, using high temporal resolution remote sensing images together with vegetation phenological features can achieve more accurate identification of vegetation types (Yan et al. 2018; Senf et al. 2015). Utilizing the 3D structures provided by LiDAR imagery in combination with the hundreds of narrow spectral bands provided by hyperspectral (HS) imagery can enable the identification of more vegetation types (Xia et al. 2018; Alonzo et al. 2014) However, although there has been much research that involved combining multi-source data sets or adopting better classification methods, these are still unable to identify different social function types of UGS.

Extended methodology

Biodiversity includes multiscalar and multitemporal structures and processes, with different levels of functional organization, from genetic to ecosystemic levels. One of the most widely used methods to infer biodiversity is based on taxonomic approaches and community ecology theories. However, gathering extensive data in the field is difficult due to logistic problems, especially when aiming at modelling biodiversity changes in space and time, which assumes statistically sound sampling schemes. In this context, airborne or satellite remote sensing allows information to be gathered over wide areas in a reasonable time.

Most of the biodiversity maps obtained from remote sensing have been based on the inference of species richness by regression analysis. Estimating compositional turnover (β-diversity) might add crucial information related to relative abundance of different species instead of just richness. Presently, few studies have addressed the measurement of species compositional turnover from space.

Effort

Satellite remote sensing offers smart solutions for biodiversity monitoring and to prepare conservation strategies with less effort. Due to the availability of multi-date, multi-resolution, multi-sensor datasets, it has become possible to acquire huge detail on the earth's surface without making time-consuming field visits. Since high spatial resolution datasets can acquire very fine details over small areas at a regular interval of time, this information will provide the basis for regional scale monitoring of biodiversity. Thus, remote sensing plays an important role in assisting environmentalists to characterize and map biologically rich zones, generating information on changes in biodiversity, alteration and distribution in species diversity.

Data availability

Availability of lidar data is quite limited, and although radar data are more widely available it may be expensive and its use is less intuitive than the interpretation of optical images. The most cost-effective satellite sensors for distinguishing a smaller number of habitat classes are Landsat TM and ETM+), ASTER, and SPOT XS, with a 0–30-metre resolution. Landsat data time series (Landsat 5 TM and Landsat 7 ETM+) offer a cost-effective resource for large- scale reef surveys and for detecting large changes in coral or seagrass extent over time. If the habitat patches have already been mapped, IKONOS data can be used to measure small changes in patch location and boundary.

Geographical scale

At various geographical scales. Satellite remote sensing technology in the last decade has empowered interdisciplinary research at regional and local scale with high temporal resolution in order to provide information about changes in species distribution, habitat degradation and fine-scale disturbances of forests.

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There are novel techniques to measure β-diversity from airborne or satellite remote sensing proposed by Roccini et al. (2017), mainly based on:

- multivariate statistical analysis,
- the spectral species concept,
- self-organizing feature maps,
- multidimensional distance matrices,
- Rao's Q diversity.

Each of these measures addresses one or several issues related to turnover measurement.
High temporal resolution remote sensing images together with vegetation phenological features can achieve more accurate identification of vegetation types. Yan et al. (2018) integrated object-based classification data with vegetation phenological information derived from multi-temporal WorldView-2 images to identify grass and tree types. Senf et al. (2015) found that adding phenological patterns captured by multi-seasonal Landsat imagery can better discriminate shrublands and woodlands that would otherwise be a challenging task in single-date Landsat imagery.

Moreover, utilizing the 3D structures provided by LiDAR imagery in combination with the hundreds of narrow spectral bands provided by hyperspectral (HS) imagery can enable the identification of more vegetation types. Xia et al. (2018) constructed an ensemble classifier to integrate HS and LiDAR data, and used it to identify several tree types and three grass types. Alonzo et al. (2014) used a crown-level integration of HS and LiDAR data to identify 29 common tree species in urban regions.

Drone mapping is described as a tool for monitoring ecosystem restoration. Plant communities with different plant cover and species composition reflect spectral bands in different rates and this information reflects state and disturbances of mire ecosystems (peatlands). Usage of drones gives higher resolution data compared to other remote sensing options, and is suitable for plant community level monitoring, but at the same time there is a trade-off between spatial resolution and mapping area.

Temporal scale

At various temporal scales.

Participatory process

It is today possible to integrate remote sensing data and in situ observations to monitor several essential biodiversity variables such as habitat structure and phenology.

In this context, municipalities should explore the possibilities of launching citizen science projects and consider the possibility in general that within cities, local knowledge on biodiversity and ecosystem services may reside in many different groups within civic society. Here, we can face the challenges related to scaling, boundaries, locally adapted indicators and scoring which can be met by each municipality developing their interpretation of what scale and what boundary is the most appropriate, what definitions to use, and what set of sub-indicators may best reflect the local ecological and cultural context. However, there are some challenges that are not easily addressed at the municipal level and need input from the research community.

Connection with SDGs

Goal 2	Goal 8	Goal 13
Goal 3	Goal 9	Goal 14
Goal 4	Goal 10	Goal 15
Goal 6	Goal 11	Goal 16
Goal 7	Goal 12	Goal 17

Applied methods

For more applied and participatory metrics please see: Species diversity - Applied/Participatory Review

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Various indicators are used to assess the status and trends of components of biodiversity, measure pressures, and quantify biodiversity loss at the level of genes, populations, species, and ecosystems, at various scales (Butchart et al. 2010; EEA 2012; Petrou et al. 2015). Several sets of such indicators have been proposed by organizations, scientists, and policy makers (EEA 2012; Feld et al. 2009; Petrou et al., 2015; Strand et al. 2007). They can be either directly measured or calculated using statistical models and may have a global, regional, or national applicability.

Among the most widely adopted sets are the ones proposed by the United Nations (UN) Convention on Biological Diversity (CBD), aiming at monitoring the progress towards the achievement of the defined targets at global scale (AHTEG 2011). Further efforts include the definition of more directly measured variables, to enhance indicator extraction, such as the Essential Biodiversity Variables (EBV) proposed by the Group on Earth Observations Biodiversity Observation Network (GEO BON) (Pereira et al. 2013).

Although in-situ campaigns are the most accurate way of measuring certain aspects of biodiversity, such as the distribution and population of plant and animal species, in many cases, they have proven particularly costly, time demanding, or impossible (Buchanan et al. 2009; Gillespie et al. 2008).

Alternatively, remote sensing (RS) data from airborne or satellite sensors are increasingly being employed in biodiversity monitoring studies (Nagendra et al. 2013; Bergen et al. 2009). Offering repetitive and cost-efficient monitoring of large areas, RS data can provide precious information nearly impossible to be acquired by field assessment alone (Nagendra et al. 2001, 2013).

Recently, essential biodiversity variables (EBVs) were identified (Pereira et al., 2013) (Table 1) and defined as variables, or a group of linked variables, that allows quantification of the rate and direction of change in one aspect of the state of biodiversity over time and across space (Pettorelli et al., 2018).

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EBVs are planned to harmonise assessment of biodiversity monitoring at any scales, and to support the aims of the Convention on Biological Diversity and IPBES.

From the start, satellite remote sensing has been expected to be an important methodology for the derivation of EBVs, and indeed, satellite remote sensing EBVs (SRS-EBVs) have been conceptualised as the subset of EBVs whose monitoring relies largely or wholly on the use of satellite-based data (Luque S et al. 2018). Table 2 gives a summary of the different types of remote sensing data that is useful in biodiversity monitoring.

Table 1. Essential biodiversity variables and use of RS (based on Walters et al., 2013)

ESSENTIAL BIODIVERSITY VARIABLES	SPATIAL RESOLUTION SATELLITE IMAGERY WITH TYPE OF MEASUREMENT SCALES (INCLUDING AVAILABLE REMOTE SENSING SENSORS)	RELEVANCE AND RELATED INFORMATION FOR BIODIVERSITY
TEMPORAL PHENOLOGY METRICS	Low/coarser spatial resolution (Global Scale) (MODIS, AVHRR etc.)	Phenology types, Forest / Non Forest, Deforestation and Biomass burning.
HABITAT STRUCTURE, ECOSYSTEM EXTENT AND FRAGMENTATION	Medium spatial resolution (Regional Scale) (Landsat, IRS, SPOT etc.)	Forest type distribution and agricultural expansion
HABITAT TYPES AND STRUCTURES, AND ECOSYSTEM COMPOSITION BY FUNCTIONAL TYPE	High spatial resolution (Local scale) (IKONOS, QuickBird, Rapid Eye historic GeoEye, WorldView-2 etc.)	Species-level distribution, canopy diameters, stand-level analysis, individual tree detection, to differentiate species at a finer scale.
HABITAT TYPES AND STRUCTURES	Active remote sensing data	Habitat degradation monitoring by generation of 3D structures

Table 2. Remote Sensing Data Useful for Biodiversity Monitoring

REMOTE SENSING DATA	BIODIVERSITY MONITORING
COARSE SPATIAL RESOLUTION (MODIS, AVHRR)	Forest / Non Forest, Biomass burning studies at global scale.
MEDIUM SPATIAL RESOLUTION (LANDSAT, IRS, SPOT)	Indicators of overall species richness and diversity at regional scales, forest type distribution and agricultural expansion
HIGH TEMPORAL RESOLUTION DATA (MULTI SEASON DATA OR IMAGES CORRESPONDING TO SPECIFIC SEASONS)	Information on invasion species and other species of interest (e.g. using images acquired corresponding to critical phonological stages of flowering or leaf senescence

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

b) References for Indicator based on the NbS projects from the CN database

Green Surge
(Green Infrastructure and Urban Bio- diversity for Sustainable Urban Development and the Green Economy) www.greensurge.eu
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EKLIPSE
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OpenNESS
Operationalisation of Natural Capital (NC) and Ecosystem Services (ES)
http://www.openness-project.eu
·Monitoring of results using GIS and/or remote sensing to help assess impacts on land cover.
·Use of such indicators as vegetation health and functional diversity in applying of remote sensing techniques.
Smith A., Berry P., Harrison P. Sustainable Ecosystem Management. OpenNESS Synthesis Paper.

OPPLA
Great number of projects.

PLUREL
(Peri-urban Land Use Relationships - Strategies and Sustainability Assessment Tools for Urban-Rural Linkages) www.plurel.net
·remote sensing and GIS for sustainable urban development science to provide geo-referenced information on the shape, size and distribution of different land-use classes of the urban environment
The main application areas of these technologies in urban growth research within the project can be defined as follows:

- Monitoring urban growth (area change, structures, land consumption, soil sealing
- Monitoring land cover/land-use changes (loss of agricultural area, wetland infringement, loss of areas important for biodiversity, spatial distribution of inner-urban green and open spaces and natural areas)
- Mapping of environmental parameters (base data important for urban climate, access to and distribution of open space, calculation of sealed surfaces).

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URBES
(Urban Biodiversity and Ecosystem Services) https://www.biodiversa.org/121
·Remote Sensing of Urban Ecology (EO sensors, modelling algorithms)
·spatial and remote sensing data analyses, mostly engaged in WP2: Case study conditions and co-design workshops for identifying local policy solutions and WP5: Resilient supply of ecosystem services.
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ENVIRONMENTAL INDICATORS - CORE

CONNECTING NATURE

Land use change and greenspace configuration

Applied/Participatory Review

STUART CONNOP (1), CAROLINE NASH (1), JACK ELLIOT (1), DAGMAR HAASE (2), DIANA DUSHKOVA (2)

(1) University of East London, United Kingdom
(2) Humboldt-Universität zu Berlin, Germany

Description

Records change in land use (e.g. from brownfield to green areas by adding vegetated brownfield to UGI resource) and accounting for configuration (e.g. individual gardens, groups of gardens and socio-economic factors impact on the utility of private gardens for native biodiversity conservation)

Methodology

Identifying urban land-use patterns is important for decision-makers to ensure sustainable development. Typical metrics for this indicator comprise the use of land use and land cover maps. These are typically obtained by classifying and modelling Remotely Sensed (RS) data, for example Landsat in a GIS environment (for more detailed information on remote sensing and earth observation approaches see Land use change and greenspace configuration - Remote Sensing Review).

Level of expertise

As this indicator is generally associated with remote sensing, GIS expertise and a familiarity with modelling are required. Supplementing this with local ground-truthed data requires expertise in habitat assessment and, potentially, participatory processes.

Data collection

Cost

Some map datasets and satellite imagery are freely available online, others involve a licence fee. Data on brownfield successional status could require ground-truthing by ecological survey. There would be costs associated with acquiring GIS software if not already available, and GIS specialists.

Effort

If in-house GIS specialists already exist, this should be a moderate effort exercise. Effort related to the addition of supplementary ground-truthed data would be associated with the availability of such data (i.e. whether it has to be carried out or just collated from existing surveys) and the amount of such data.

Data availability

Some land cover data will be already available, more in-depth data such as brownfield successional stage is unlikely to be readily available.

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Scientific solid evidence

Applied methods are used to support and supplement evidence generated through remote sensing metrics. As such, they should strengthen the evidence generated.

Extended methodology

Even with advances in RS, the ability to distinguish various urban land use types accurately using classification algorithms remains difficult due to the fine-scale heterogeneity of land cover types in urban areas (Pauleit & Duhme, 2000; Jia et al., 2018). Methods that combine RS and more applied approaches have been developed to establish a greater level of precision in relation to this micro-variation. For instance, Pauleit & Duhme (2000) used a combination of existing habitat inventory, mapping land cover, and units and types from aerial photographs to reproduce the fin-grained patterns of land covers in the city of Munich. This enabled delineation of distinct units (e.g. configurations of built-up and open spaces such as detached houses, hi-rise blocks, industrial areas, parks, agricultural lands etc) which were grouped into 24 urban land cover types (e.g. houses, factory block, roads, railways, lakes and ponds, woodlands, parks and green spaces, cemeteries, sports fields, etc). This enabled quantitative characterisation of physical features of units (% cover of sealed surfaces, vegetation, etc.) which was built into a GIS database. Environmental parameters (e.g. surface temperature, rainwater infiltration) were assigned to land covers to assess the likely environmental impacts of land cover changes, for instance rainwater infiltration. When considering land use change and greenspace configuration, it is important to consider how green (vegetated) urban brownfields can supplement urban green infrastructure by providing habitat, microclimate and recreational services (Mathey et al., 2015). Changes in their land use and physical structure as a result of urban planning decisions will impact ecosystem service provision. Development of brownfield sites can often have a negative impact on ecosystem service provision compared to their undeveloped state. As such, their consideration as a part of land use change indicators is not straightforward. Brownfield registers and Environmental Impact Assessments can provide source data regarding pre-development brownfield habitat structure/quality.

Geographical scale

This indicator is generally applied at a city-scale, but neighbourhood and site level assessments can also be made.

Temporal scale

Intended to record change over time, but the ability to assess past change would depend on availability and resolution of historical data. Once current data has been obtained, a baseline can be established from which future changes can be assessed.

Participatory process

Participatory processes are possible to supplement remote sensing data with ground-truthed data to avoid the pitfalls of the heterogeneity in land use of high-density urban areas. Citizen science and participatory GIS processes can be used for this.

Earth observation/remote sensing/modelling

This indicator is primarily assessed using remote sensing, earth observation and modelling methods. Participatory and applied processes can be used to supplement this data. For more detail on remote sensing, earth observation and modelling approaches, including those used on past and current EU projects, see indicator guidelines:
Land use change and greenspace configuration – Earth observation/Remote Sensing Review

Connection with SDGs

Goal 1
Goal 3
Goal 4
Goal 6
Goal 8
Goal 9
Goal 10
Goal 11
Goal 13
Goal 14
Goal 15
Goal 16
Goal 17

CONNECTING NATURE

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Parameters for habitat services provided by green urban brownfields can be based on successional stage typologies: brownfield with pioneer vegetation; with persistent ruderal vegetation; with ruderal tall herbaceous vegetation; with spontaneous wood; and three biodiversity parameters: structural diversity, specific plant and animal groups, regenerative functions. This information can be supplemented by modelling of microclimate regulation based on vegetation parameters can be done at site level (ENVI-met) and city level (HIRVAC-2D). Data relating to perception, acceptance and use of/forms of use of brownfields by residents can be collected by questionnaires. Scenario analysis can show how changes in land use can impact ecosystem services (e.g modelling future development proposals). These aspects should be integrated into analytical and evaluation algorithms when devising city strategies for brownfields to secure ecosystem services.
In terms of assessing the value of domestic gardens in relation to their ability to support biodiversity, several studies have developed methods for assessing/quantifying value. This includes methods for assessing value for urban birds (Daniels and Kirkpatrick 2006) and invertebrates (Smith et al. 2006). Goddard et al. (2010) present a comprehensive overview of a range of methods related to garden biodiversity.

Data on landuse change and greenspace configuration collected in these ways can be used to:

- Track landuse change on sites in relation to ecosystem service provision;
- Track trends in private garden use to monitor a substantial green infrastructure asset over which local authorities have little influence;
- Set targets for landuse change, for example recognising the highest quality brownfield sites for biodiversity and ecosystem service delivery and prioritising the beneficial reuse of brownfield sites with little environmental value.

References

Original reference for indicator

Eklipse

Metric references

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ENVIRONMENTAL INDICATORS - CORE

CONNECTING NATURE

Land use change and greenspace configuration

Earth Observation/Remote Sensing Review

STUART CONNOP (1), CAROLINE NASH (1), JACK ELLIOT (1), DAGMAR HAASE (2), DIANA DUSHKOVA (2)

(1) University of East London, United Kingdom
(2) Humboldt-Universität zu Berlin, Germany

Description

Records change in land use (e.g. from brownfield to green areas by adding vegetated brownfield to UGI resource) and accounting for configuration (e.g. individual gardens, groups of gardens and socio-economic factors impact on the utility of private gardens for native biodiversity conservation) using earth observation and remote sensing approaches.

Methodology

Use of remote sensing involves the application of multi-temporal datasets to quantitatively analyse the temporal effects of the land use changes as well as green space configuration. Due to the high degree of complexity of urban issues, GIS and remote sensing (RS) technologies have long been used to facilitate scientists to assess the overall state of urban environment, to manage the urban infrastructures and improve the efficiency and rationality of its spatial management.

Level of expertise

It is a challenge and a critical need to understand the methods for extracting useful information from the data, as well as to interpret the time-series signals correctly. We need to be able to interpret both slow variations due to gradual ecosystem transformations, and faster variations due to disturbances or other rapid events. Methods based on remote sensing theory, process modelling, and statistical data analysis will help developing this understanding.

Data collection

Cost

Remote sensing via satellite imagery is an excellent tool to study LULCC because images can cover large geographic extents and have a high temporal coverage. Remote sensing is also used to investigate historical LULCC and also provide data (e.g. ground truth) in areas that are inaccessible.
The major disadvantages of remote sensing include: the inability of many sensors to obtain data and information through cloud cover, distinct phenomena can be confused if they look the same to the sensor, the resolution of the satellite imagery may be too coarse for detailed mapping and for distinguishing small contrasting areas and very high-resolution satellite imagery are very expensive.

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Scientific solid evidence

During the last decades, geographic information systems (GIS), historical maps, aerial imagery, and remotely sensed images have proven very effective in studying land change dynamics. These tools have been widely used also on the city level to assess changes over time and to predict future scenarios based on long-term sets of observations. Agarwal et al. (2002) presented a framework to compare models of land use change with respect to scale (spatial and temporal), complexity, and their ability to incorporate space, time, and human decision making. Several different approaches have been developed to predict future land use transformations.

Extended methodology

A necessary prerequisite for the improvement of urban environment is rationality of its spatial management – the optimal division of urban spaces by their functional predestination. One of approaches suited to this is functional zonation of the city – a spatial management of basic types of activities – labour, household, recreational.
Using RS data VHR QuickBird optical images the territory of the city can be classified depending on the type of the activities of the population, which predetermine industrial, inhabited, recreation zones with their morphotypes. The map of functional zonation of the city allows the identification of the optimal level of distribution of ecologically unfavourable, neutral and favourable plots on the territory of the city analysed regarding the implemented NbS.
On the next stage the RS technics can be used to study the ecological state of ecologically favourable plots. Some studies have investigated whether it is possible, using WorldView-2 data and in the context of an urban park, to map canopy stress assumed to be associated with pollution. For instance, small urban parks can be studied using biogeochemical analysis of the tree canopy, field spectral reflectance measurements of tree leaves, simulated WorldView-2 multispectral data generated from the leaf spectra, and summer images of real WorldView-2 data. There is some evidence confirmed through the high correlation between spectral reflectance values and leaves' heavy metal pollution levels, which also confirmed the importance of creating GIS and RS enabled pollution control and monitoring system.

Despite these disadvantages, remotely sensed satellite data have been used to identify changes in a variety of aquatic and terrestrial environments including coastal, agriculture, forested, and urban areas. This is particularly true for remote regions, which are often inaccessible and therefore not easy to obtain the needed data using traditional methods (Fonji and Taff, 2014) LULCC researchers often use remotely sensed data to provide information on resource inventory and land use, and to identify, monitor and quantify changing patterns in the landscape.
There a lot of free and open source software for land monitoring, one of them is Collect Earth developed by the Food and Agriculture Organization of the United Nations (FAO). Built on Google desktop and cloud computing technologies, Collect Earth facilitates access to multiple freely available archives of satellite imagery, including archives with very high spatial resolution imagery (Google Earth, Bing Maps) and those with very high temporal resolution imagery (e.g., Google Earth Engine, Google Earth Engine Code Editor). Collectively, these archives offer free access to an unparalleled amount of information on current and past land dynamics for any location in the world. Collect Earth draws upon these archives and the synergies of imagery of multiple resolutions to enable an innovative method for land cover and land use change monitoring.

Effort

Remote sensing is the most resource-efficient method to monitor land cover and land uses changes, as well as impacts of climate change, which may be identified as glacier changes, changes in vegetation phenology or advance of new plant species to higher latitudes or elevations, for example. In addition to "traditional" satellite imagery to cover large areas we can also use advanced hyperspectral remote sensing data or laser scanning data for land change studies.

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b) References for Indicator based on the NbS projects from the CN database

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·Use of such indicators as vegetation health and functional diversity in applying of remote sensing techniques.
Smith A., Berry P., Harrison P. Sustainable Ecosystem Management. OpenNESS Synthesis Paper.

OPPLA
(https://oppla.eu)
·Growing with green ambitions. Case study of Leipzig
An important lesson is that mapping should be combined with in situ green space monitoring of, for example, vegetation biomass. This would add value to remote sensing data and improve the capacity to assess ecosystem services provided by urban green space such as carbon dioxide removal. In addition, data were only available for 2012. An account based on time series of land cover and land use would help city planners to better understand to what extent urban green infrastructure is under pressure.
Limitations of the mapping approach: Mapping accuracy: The UFZ team used a remote sensing based approach utilizing digital ortho photos. All remote sensing techniques map from above, and overlaid featured cannot be detected. As a consequence, GI features at ground level such as lawn/meadow and blue structures may be underestimated if covered by large trees and / or dominant shrubland.
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PLUREL (Peri-urban Land Use Relationships - Strategies and Sustainability Assessment Tools for Urban-Rural Linkages) www.plurel.net
·remote sensing and GIS for sustainable urban development science to provide geo-referenced information on the shape, size and distribution of different land-use classes of the urban environment
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- Monitoring urban growth (area change, structures, land consumption, soil sealing
- Monitoring land cover/land-use changes (loss of agricultural area, wetland infringement, loss of areas important for biodiversity, spatial distribution of inner-urban green and open spaces and natural areas)
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Andersson E, McPherson T, Kremer P, Frantzeskaki N, Gomez-Baggethun E, Haase D, Tuvendal M, Wurster D 2015 Scale and Context Dependence of Ecosystem Service Providing Units. Ecosystem Services 12, 157-164.
Baró F, Frantzeskaki N, Gómez-Baggethun E, Haase D 2015. Assessing the match between local supply and demand of urban ecosystem services in five European cities. Ecological Indicators 55, 146-158.
Hamstead Z A, Kremer P, Larondelle N, McPhearson T, Haase D 2016. Classification of the heterogeneous structure of urban landscapes (STURLA) as an indicator of landscape function applied to surface temperature in New York City. Ecological Indicators 70, 574-585.

Naturvation (2017 – ongoing)
From the NATURVATION database on the value and benefit assessment methods for urban NBS:
·a model based on remote sensing – MODIS NPP (Input data: allometric equations, net photosynthesis (PSNnet) data of 2010 provided by the MODIS, average growths in diameter of specific tree species, trees diameter at breast high), output data: Net primary productivity kg C per tree and year

Data availability

Fairly long time-series of Earth Observation data already exist for the whole area of the Earth. These time-series data make up an invaluable source of information for better understanding and management of our environment.
Remote sensing data is available from the USGS (http://glovis.usgs.gov) for free. ASTER GDEM is available from the Geospatial Data Cloud (http://www.gscloud.cn/) for free.
Costs of RS data of higher resolution is as follows (cost per sq.km of newly acquired imagery):
·Worldview 2, 50cm pan is about €30 / sqkm
·IKonos pan, 0.8-3m resolution is about €25 /sqkm
·Deimos -1, 22m res is 15c/sqkm
·Landsat, MODIS and MERIS sensors – free.
A high quality airborne lidar survey would be in the order of €450/sq.km.

Geographical scale

Method suitable for various geographical scales.

Temporal scale

Method suitable for various temporal scales, although availability of historical data can sometimes be a barrier to studying past trends.

Participatory process

A combination of remote sensing, field observations and focus group discussions is often suggested to be used to analyse the dynamics and drivers of LULC change. Supervised image classification can be applied to map LULC classes. In addition, focus group discussions and ranking can support to explain the drivers and causes linked to the land cover changes.
There is some research which has proposed the analysis of very-high-resolution satellite imagery with participatory mapping based on workshops and field surveys.

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·classification via remote sensing to determine tree species, LIDAR data to determine size of tree and allomeric equations to model above ground tree biomass (Input data: land cover (tree canopy %, spatial distribution of tree species), tree crown height, stem diameter (dbh), tree height, crown diameter & field surveys for tree data (# trees, tree location, stem diameter) (for calibration and validation); output data: above-ground carbon storage (biomass) (tC/ha, MtC, kg)
·deterministic model based on allomeric equations, LIDAR data and remote sensing to estimate tree carbon sequestration over the city (input data: remote sensing data, urban structure type data (e.g. green space, streets, low buildings with yards etc.), tree characteristics (tree height, crown width, crown base height, diameter at breast height (DBH))(from models); output data: aboveground carbon storage (kg C/building type, tC/ha, total tC)
·remote sensing together with distributed lag nonlinear models used to assess the risk of death due to heat as an effect of distance to green and blue space (input data: Metrological, NVDI, distance to green and blue infrastructure)
·modeling and detecting heat islands at different scales depending on a kernel smoothing and using remote sensing. Greenness and heat islands showed high correlation (input data: ASTER remote sensing images; output data: temperature in Kelvin).
·modeling the needs of green space for several ecosystem services, using GIS information, remote sensing and Pareto optimization (input data: GIS raster layers with information about green spaces; output data: air temperature.
·remote Sensing and LIDAR data used to estimate vegetation volume and NVDI. A 3D NVDI as constructed by multiplying the NVDI with the vegetation volume. Measured temperatures was modelled using Maximum Likelihood as a function of NVDI, 3D NVDI, distance to green / blue areas and built-area volume (input data: Remote images (1 m resolution), LIDAR data, temperature measurements; output data: temperature).
·a set of modelled GIS and remote sensing parameters used to model temperature as an effect of greenness, aerosols, buildings. Likely the method needs to be calibrated for each city/town separately (input data: GIS data of buildings, Landsat data; NVDI & AH CHRIS/PROBA satellite images, ASTER image data; output data: temperature).
·a framework using satellite images, remote sensing and statistical modelling to compute accessibility of parks and green space dependent on economic and population data (input data: percentage of green cover in a city, population density, GDP per capita, City land area, Per capita green space provision, Aggregation index; output data: Effects of and between the different types of in data)
·deterministic model, using remote sensing of greenness as well as surface sealing to estimate recreation supply (input data: Remote sensing data, NVDI & surface sealing; output data: Spatially normalized minimum of green space provision per person suggested by the city administration (m^2 per Block; m^2/m^2)
·remote sensing & satellite imagery and digital orthophotos together with Geographic Information Systems (GIS) used to develop a digital elevation model and a digital surface model (input data: qualitative and GIS data; output data: quality of life, tree coverage; spending time in city parks, gardens, and open spaces)
·remote sensing for ES matrix – the ES matrix approach is an easy-to-apply concept based on a matrix linking spatially explicit biophysical landscape units to ecological integrity, ecosystem service supply and demand. By linking land cover information from, e.g. remote sensing, land survey and GIS with data from monitoring, statistics, ecosystem service supply and demand can be assessed and transferred to different spatial and temporal scales. The ES matrix approach is a quick and simple way to get an overall spatially-explicit picture of the ES in case study areas (input data: land cover and land use data (GIS) (incl. Additional biotic and abiotica information (e.g. land use intensity, soil quality, climate data); output data: ES provision capacity per landuse class (0-5 values & biophyscial units).

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·variation and disturbances of different sensor characteristics are shown to offset.
·NDVI (Normalized Difference Vegetation Index is a dimensionless index that describes the difference between visible and near-infrared reflectance of vegetation cover and can be used to estimate the density of green on an area of land (Weier and Herring, 2000, Environmental Research, 2018) is calculated and transferred into a classified NDVI for more than one decade.
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Connection with SDGs

Goal 1
Goal 3
Goal 4
Goal 6
Goal 8
Goal 9
Goal 10
Goal 11
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Goal 17

Applied methods

For more applied and participatory approaches for quantifying greenspace distribution, please see: : Land use change and greenspace configuration - Applied/Participatory Review

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ENVIRONMENTAL INDICATORS - CORE

CONNECTING NATURE

Access to public amenities

Applied/Participatory Review

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(2) Humboldt-Universität zu Berlin, Germany

Description

Share of population with access to at least one type of public amenity (social welfare points, social meeting centres, restrooms, information displays, public telephones, rain shelters, drinking fountains) within 500m (% of people) using more applied and participatory methods. By incorporating these features into NBS schemes it may be possible to increase accessibility and reduce transport distances and vehicle use.

Methodology

Density of public amenities has been used as an indicator of compactness or urban sprawl (and less car use). Accessible local services and facilities can reduce travel, particularly by private cars and help ensure sustainable communities. It can also be viewed as an indicator of health/wellbeing and quality of life.

Level of expertise

Generally some GIS expertise is needed for mapping aspects.

Data collection

Cost

There would be costs associated with acquiring GIS software and GIS specialism, if it is not already available. There would be costs associated with the participatory processes for gathering data on public perceptions of accessibility if this needs to be gathered.

Effort

Compiling data on amenities and questionnaires regarding public perceptions of accessibility can be labour intensive depending on method adopted and level of engagement.

Data availability

Data can be obtained from sources such as Google maps, Yellow Pages, census data, postcode directories, city planning offices.

Geographical scale

Typically city-scale, but can be used over smaller scales (e.g. smaller administrative units).

Temporal scale

Most likely to be used to provide a snapshot or baseline to be measured against a future snapshot. Historical analysis can be carried out if past data/knowledge is available.

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Scientific solid evidence

The indicator is relevant to access to services, and can be linked to quality of the built environment. The CITYkeys scoring system allows for some subjectivity and does not explicitly account for quality of services or user acceptance. Density can be a perceived experience rather than an outcome of empirical calculations (Burton, 2000).
Data on access to public amenities collected in these ways can be used to:

- Quantify the benefits of NbS in terms of improving access to public amenities;
- Assess the distribution of key public amenities in relation to planning new greenspace;
- Prioritise public amenity delivery through NBS design.

Extended methodology

Public amenities are services/facilities which are provided by the government or town/city councils for the general public to use, with or without charge, for instance libraries, social welfare points etc (CITYkeys). Access to public amenities partially measures the mix and distribution of different facilities and uses in a city and the proximity of public services to the residential location of city dwellers.
CITYkeys defines this indicator as the extent to which public amenities are available within 500 m (presumably of residential areas). The metric recommended is a Likert scale of 1 to 5, as follows:
1.No amenities: no public amenities whatsoever are available (e.g. no basic nor additional).
2.Relatively few amenities: only few basic public amenities are available (e.g. a small park).
3.A reasonable number of amenities: basic public amenities are available including a few important amenities such as a park and a community centre.
4.A sufficient number of amenities: basic public amenities are widely available (e.g. open green spaces, public recreation) as well as many important public amenities (theatres).

Participatory process

If used, public perception questionnaires would be the main participatory process.

Earth observation/remote sensing/modelling

Some spatial modelling/mapping is generally required but participatory and applied processes are possible to supplement this. For more pure earth observation, remote sensing and/or modelling approaches, including those used on past and current EU projects, see indicator guidelines:
Access to public amenities – Earth observation/Remote Sensing Review

Connection with SDGs

Goal 3, Goal 4, Goal 5, Goal 7, Goal 9, Goal 10, Goal 11, Goal 13, Goal 16, Goal 17

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UnaLab

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5.Relatively many amenities: the area surrounding the project's central living area includes a wide variety of public amenities including numerous basic amenities (e.g. green spaces, public recreation facilities) as well as numerous important public amenities (e.g. theatres, zoos).
The evaluation could also take into account the type of amenities in terms of a relative value, i.e. the availability of public recreation is more important than the availability of drinking fountains.
Burton (2002) use the following metrics to measure mix of uses in cities and these could be applied for measuring accessibility of public amenities:
1.Number of key facilities for every 1000 residents
2.Ratio of residential to non-residential urban land (or multiplying the number of households by an average house footprint area of 35 m2 (this does not include garden area), and the total area of non-residential land)
3.Variation in the number of facilities per postcode sector: average standard deviation across all facilities.
4.Overall provision and spread of key facilities: variation in the number of facilities per postcode sector divided by the average number of facilities per sector.
The indicator which gives the most accurate `picture' of how mixed a city is in terms of uses is probably (4), and indicators (1) and (2) were considered probably the one most closely related to quality of life. The ratio of non-residential to residential land uses (2) may reflect the incidence of industrial or commercial land rather than the provision of amenities. The authors also suggest indicators that use the metric: % of postcode sectors containing fewer than two key facilities, contain four or more, six or more, etc.
Spatial accessibility to amenities generally refers to the ease with which amenities can be reached and may also measure quality of the amenities. Neighbourhood Spatial Accessibility measures accessibility at the neighbourhood level and can give a general view of accessibility patterns in cities (Hewko, 2001; Smoyer-Tomic et al., 2004). Potential indices outlined in Talen (1998) include:

- The container approach-summation of number of amenities available within a neighbourhood (or specified radius around neighbourhood residents)
- Minimum distance – distance residents have to travel to closest amenity of interest (e.g. library)
- Travel cost - distance residents have to travel to reach all facilities in a study area

Gravity potential – sum of, for all facilities, some function of facility attractiveness mitigated by distance.
The choice of metric can produce markedly different accessibility spatial patterns and therefore choice should be based on the purpose of the study. Type of distance measurement can have implications (e.g. Euclidean, network-based etc – see 'accessibility of greenspaces indicator for further detail). These approaches can be combined with a 'needs analysis' to determine Spatial Equity of amenities and whether there is an association between neighbourhood need and accessibility. 'Need' indicators can be variables related to socio-economic factors (i.e. % low income, % attached house, % transient etc). Spearman Rank Correlations can be used to assess the association of relative need and relative accessibility. Modelling using Local Indicators of Spatial Associations (LISA) and local Moran statistics and scatterplots can provide an indication of equitably distributed amenities (see Smoyer-Tomic et al., 2004 for details).
MacDonald et al. (2013) extracted data from a Scottish study on 'Transport, Housing and Wellbeing' related to public amenities and perceptions of accessibility, rated as 'very well-placed', 'fairly well-placed', 'not very well-placed', or 'not at all well-placed'. Amenities were mapped in GIS and both Euclidean and network buffers used to measure presence/absence of a selection of amenities within 800 m, 1000 m and 1200 m from respondents postcode. Subjective (perceptions) and objective (GIS measures) were cross tabulated using Kappa statistics in SPSS.

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ENVIRONMENTAL INDICATORS - CORE

CONNECTING NATURE

Access to public amenities

Earth Observation/Remote Sensing Review

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Description

Share of population with access to at least one type of public amenity (social welfare points, social meeting centres, restrooms, information displays, public telephones, rain shelters, drinking fountains, etc) within 500m (% of people) using earth observation and remote sensing methods. By incorporating these features into NBS schemes it may be possible to increase accessibility and reduce transport distances and vehicle use.

Methodology

Remote sensing imagery has been widely adopted for analysis of spatial inequalities in distribution and accessibility to public amenities in cities (Joseph et al., 2012). Major techniques for this include dasymetric mapping, regression models and geostatistical models (Jensen et al., 2004; Joseph et al., 2012), spatial visualization and overlay analysis with georeferencing and digitization (Borana and Yadav, 2017; Travland et. al., 2017).

Level of expertise

An increasing number of sensors, RS data products, processing algorithms, software and tools are available for the assessment of public amenities and urban green space availability. Selecting an applicable data source and the method to process data is a complicated process which needs expert knowledge.
Cost, time, expertise, and technical properties of remote sensing data are factors in this process. Thus, the assessment should be made by experts engaged in the NBS project who have expertise not only in RS, but also in urban planning, forestry, landscape ecology, regional planning. Each of them will then assess all built and land cover type combinations.

Data collection

Cost

The land surveying of urban green space can have enormous costs and is also generally very time consuming. Therefore, urban green space mapping using satellite images to have a time series is a faster and more cost-effective process. It should be noted that the choice of a higher density point cloud increases data costs and data volume.
This also requires more sophisticated processing algorithms.

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Scientific solid evidence

Theoretical frameworks used to explain the location of public services and amenities include central place theory, aspects of industrial location theory and spatial diffusion theory which are all described as normative theories being able to optimize with respect to defined criteria operating in prescribed environmental conditions (Rushton, 1979).

However, recent advancement in geospatial technologies has led to several applications in geographically orientated challenges, hence, the adoption of an effective decision tool like Geographic Information System (GIS), high resolution products of satellite remote sensing as well as the Global Positioning System (GPS) in solving the rather challenging task of optimal location for public amenities and facilities with respect to necessary criteria.

Today, cities worldwide are affected adversely by the problem of appropriate location of public facilities and amenities. They are either too far from their market zone or they are too congested in a particular location or hardly accessible by local citizens and in some cases, political consideration to the siting of these facilities dominate without given considerations to the necessary criteria for demands and public interest.

A number of studies have aimed to investigate the optimal determination of the locations of some public facilities in cities using geospatial techniques. A fusion of remote sensing, geographic information system (GIS) and GPS techniques have been explored by recent studies in this field (Ahmed, 2007; Borana and Yadav, 2017; Duncan et al., 2012; Johnson et al., 2004; Michael, 2008; Travland et. al., 2017). Together they provide strong evidence on distribution and access.

They underline the need for development of a Geodata base of existing public amenities and facilities, and the use of Euclidean-distance geometry to spatially analyse the appropriate locations with regards to the set of standard criteria.

Effort

While GIS techniques provide an efficient tool for inventory management and classification of different public amenities and facilities within an urban park and urban environment, remote sensing techniques facilitate their accurate and objective mapping. They can also be used to record temporal changes. These changes may cause a feature to change its class/category, shift its position, expand, shrink, or change its shape and are important to record and monitor for effective management. Technologies like remote sensing and GIS can be used effectively to develop an information system for efficient management of an urban park and conservation area.

Effort for achieving this is generally related to the accessibility of data and level of automation required for analysis.

Data availability

There is great debate regarding the reliability and use of data approaches to quantify and track the changes, trends, and patterns of UGS and public amenities over long periods. Owning to the increasing availability of image data from multiple sources, the quantification of spatiotemporal patterns for greenspace and public amenities frequently relies on remote sensing. However, data such as Lidar and high-resolution images are still not easily accessible for many regions or users due to the high costs of data acquisition. Moreover, it is usually impractical to provide full coverage of extensive metropolitan areas, with limited data available over long periods. With the advantages of global availability, repetitive data acquisition, and long-term consistency, Landsat series satellites have become the best compromise to overcome these limitations.

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According to existing studies, integrating remote sensing data and point-of-interest (POI) data (including location-rich semantic information) has been successfully applied in the identification of social functions of urban lands, but none were focused on a detailed and complete social functional map of UGS. Moreover, spatial patterns or distribution densities derived from the POI data have been extracted into feature vectors and then combined with physical properties derived from remote sensing data to improve the accuracy of land use identification.

Extended methodology

There are some studies on accessibility of public amenities where amenities services are shown with the help of the database management systems by using GIS and RS (Nilsson, 2014; Taylor et al., 2017). Research indicates that urban population today prefer more open, well designed, structured, and built amenities as opposed to wildland recreation areas (Johnson et al., 2004; Travland et. al., 2017). Thus, an urban park should offer a variety of facilities and amenities including playgrounds, ball fields, and walking trails to cater the needs of a multicultural society (Duncan et al., 2012; Travland et. al., 2017).

The spatial depiction of the public amenities and infrastructural facilities can be made quite user friendly with application of GIS. Some research analyses the accessibility of urban parks and public amenities using Euclidean distance or based on GIS network analysis. In order to calculate how many of the total population have access to the public amenities and estimate the provision of public amenities, Borana and Yadav (2017) suggest the analysis composed of three steps:

·the Location of Quietient technique and Gini coefficient can be used to determine the spatial concentration and deficiencies of the public amenities.

·Remote Sensing (RS) data and Geographical Information System (GIS) Technology can be used for mapping and visualisation of the public amenities.

·Lorenz Curve is used to examine the inequality in the distribution of public amenities in the study area.

Geographical scale

Can be applied at various geographical scales.

Temporal scale

Can be applied over various temporal scales.

Participatory process

Uneven distribution of public amenities indicates that the existing planning might not produce acceptable results in terms of balanced development of different municipal wards. Since a number of the amenities are provided by the government, their availability and distribution must be planned carefully. A participatory approach can be an effective mechanism for assessing and ensuring the even distribution of urban amenities in a city. The results of the analysis of access to public amenities can help policy-makers and municipal authorities in proper planning in the distribution of public amenities. Validation of results on the ground as well as the participation of urban planner and policy makers is also essential.

Connection with SDGs

Goal 3
Goal 4
Goal 5
Goal 7
Goal 9
Goal 10
Goal 11
Goal 13
Goal 16
Goal 17

Applied methods

For further information on more applied and participatory methods, please see:
Access to public amenities - Applied/Participatory Review

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

In doing so, the Landsat data and Survey of toposheets should be used. For georeferencing and subset of the study area ENVI software can be used. ArcGIS software is used for preparation of base map and visualisation of the public amenities in different municipal districts. The spatial data can be collected from field survey using GPS. The non-spatial data of the facilities can be collected from municipal departments. The Location Quotient method and Gini Coefficient with Lorenz curve can be used for analysis of different public amenities of municipal districts of the city.
The Location Quotient is a method for comparing a municipal ward's (district's) percentage share of a particular amenity with its percentage share of its population. The Location Quotient of different wards in a city with respect to a particular facility provides knowledge about the level of concentration of that facility in those wards.

Finally, the analysis results can show where are the disparity in the distribution of amenities in the municipal districts within the city.

b) References for Indicator based on the NbS projects from the CN database

Naturvation (2017 – ongoing)
From the NATURVATION database on the value and benefit assessment methods
·a framework using satellite images, remote sensing and statistical modelling to compute accessibility of parks, green space and public amenities dependent on economic and population data (input data: percentage of green cover in a city, population density, GDP per capita, City land area, Per capita green space provision, Aggregation index; output data: Effects of and between the different types of in data)

PLUREL
(Peri-urban Land Use Relationships - Strategies and Sustainability Assessment Tools for Urban-Rural Linkages) www.plurel.net
·remote sensing and GIS for sustainable urban development science to provide geo-referenced information on the shape, size and distribution of different land-use classes of the urban environment and provision of public amenities among different urban districts
The main application areas of these technologies in urban growth research within the project can be defined as follows:

- Mapping of environmental parameters (base data important for urban climate, access to and distribution of open space, calculation of sealed surfaces).

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References

Original reference for indicator

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Metric references

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ENVIRONMENTAL INDICATORS - CORE

CONNECTING NATURE

Blue space area

Applied/Participatory Review

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Description

Measure change in blue space (ponds, rivers, lakes) in urban area (%, hectares or ha/100k) due to NbS based on more applied and participatory methods.

Methodology

Measuring bluespace change in urban areas can provide an index representing:

- the degree of nature conservation, and
- improving public health and quality of life as they are directly related to the natural water circulation, environmental purification and the green/blue network.

More green and blue space also reduces vulnerability to extreme weather events like urban heat islands and flooding by heavy rainfall. Bluespace area can be used as an indicator of these environmental, social and economic benefits.

Level of expertise

Accessing the public datasets should be straightforward but likely some expertise in GIS needed, particularly for more comprehensive ILM methodology? (see Blue space area - Remote Sensing Review)

Data collection

Cost

Some map datasets and satellite imagery are freely available online, others involve a licence fee. Would be costs associated with acquiring GIS software if not already available, and GIS specialists

Effort

Would depend on the level of in-house expertise available and scale.

Data availability

There is existing greenspace map data available in the UK, and international satellite data available online, but may be variation in terms of spatial resolution.

Geographical scale

City-scale typically, but may be possible to use the data to monitor local-level changes in greenspace.

Temporal scale

Depending on the data available and the purpose of the exercise, could produce a current snapshot or a temporal view of change.

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Scientific solid evidence

Available greenspace datasets in the UK are pretty comprehensive and accurate, but there can be limitations for area i.e. >0.25ha depending on resources available. A weakness is it does not capture the quality/health of the green/bluespace which would influence ES benefits.

Extended methodology

Metrics outlined for greenspace area (Env55) are also generally applicable for bluespace. Green and blue space area information has typically been collected from high-resolution satellite images and then mapped and measured (area) in a GIS environment (see Env56-RS for more information).
An example comprises the Integrated Landscape Map (ILM) methodology that uses open-source, high spatial and temporal resolution data with global coverage (e.g. the OS Mastermap Greenspace layer and Sentinel S2A data (see link below)) to generate a composite spatial dataset that can classify land cover in a way that produces a more refined green/blue infrastructure map for cities (Dennis et al., 2018). This method has the capacity to include public and private green and blue spaces and overcomes some of the shortcomings of the large minimum mapping units of other datasets. It can be used to measure and represent the landscape qualities of urban environments. ILM provides uses a classification system involving seven thematic land use types coupled with five land cover values which can be used to more accurately investigate social-ecological relationships.
Participatory mapping GIS portals or mapping workshops can help supplement remote sensing approaches with ground-truthing and local knowledge. An example of this is the BlueHealth SoftGIS (BSGIS) tool (Geertman et al. 2009) that was used in the BlueHealth study programme (Grellier et al. 2017). Data on bluespace area collected in these ways can be used to:

- Quantify the distribution of bluespace across target areas;
- Support the equitable distribution of bluespace through urban planning for environmental, social and economic benefits;
- Provide underpinning data for other indicators such as ecosystem service mapping, stormwater management, biodiversity mapping, etc.

Participatory process

Citizen participation could be through a PPGIS tool such as GLOBE app.

Earth observation/remote sensing/modelling

This indicator is predominantly based on earth observation/remote sensing mapping techniques. For more detail on earth observation, remote sensing and modelling approaches, including those used on past and current EU projects, see indicator guidelines: Blue space area – Earth observation/Remote Sensing Review

Connection with SDGs

Goal 2	Goal 8	Goal 13
Goal 3	Goal 9	Goal 14
Goal 4	Goal 10	Goal 15
Goal 6	Goal 11	Goal 16
Goal 7	Goal 12	Goal 17

References

Original reference for indicator

Unalab

Metric references

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ENVIRONMENTAL INDICATORS - CORE

CONNECTING NATURE

Blue space area

Earth Observation/Remote Sensing Review

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Description

Measuring change in blue space (ponds, rivers, lakes) in urban area (%, hectares or ha/100k) due to NbS using earth observation/remote sensing and modelling approaches

Methodology

In order to characterise urban blue infrastructure and assess changes of different bluespace types over varying time periods different remote sensing techniques and GIS are used. The most common use of RS data is for the purpose of greenness identification (the indices and statistical indicators could be found in the Tables 1 and 2). Many of these metrics are equally applicable to bluespaces.

Level of expertise

Experience of working with large datasets related to remotely sensed, climatic and environmental parameters as well as their statistical analysis using tools is important. Knowledge of GIS techniques such as multi-criteria evaluation and sensitivity analysis are also desirable. Knowledge of ecosystem services is required and experience of their quantitative and/or spatial assessment is advantageous.

Data collection

Cost

Generally, average cost of a raw satellite image is approximately one dollar for each sq km. There are lots of considerations when purchasing imagery but in general satellite images are cheaper than aircraft, low resolution images are cheaper than high and old images are cheaper than new. To get some idea, you can look at the cost per sq.km of newly acquired imagery to get an idea of comparison:

- Worldview 2, 50cm pan is about €30 / sqkm
- IKonos pan, 0.8-3m resolution is about €25 /sqkm
- Deimos -1, 22m res is 15c/sqkm
- Landsat, MODIS and MERIS sensors – free.
- A high quality airborne lidar survey would be in the order of €450/sq.km.

There are a lot of ways to analyze cost (e.g. per pixel worldview is much the cheapest of the three listed above). Also note as price per km may be quoted but you will often be obliged to have minimum order of a few hundred sq.km – which may compare project costs back toward airborne if you are only interested in a small area.

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Scientific solid evidence

Currently, there is a variety of research focused on mapping of UGS, based on remote sensing data including the mapping of bluespace. With the capacity to differentiate land cover (LC) types at a large scale, remote sensing has been widely used for vegetation mapping in various environments. Satellite imagery has been adopted for the monitoring of vegetation both in urban and rural areas. The techniques applied for this can generally be equally applicable for bluespace areas. As with greenspace mapping, strength of evidence is based on the scale of bluespace analysed compare to the resolution of the satellite data and confidence of identifying bluespace compared to surrounding infrastructure. However, with suitable data, strong evidence can be provided.

Extended methodology

Remote sensing data has been the source of previously available ready-made European LC datasets such as CORINE Land Cover (CLC) and Urban Atlas (UA). The spatial detail of these datasets is, however, not sufficient for thorough evaluation of UGS. CLC has the minimum mapping unit of 25 ha, which can capture only the largest of greenspaces. However, many smaller patches 'hidden' in the urban fabric polygons are relevant too. The same principle applies to urban bluespaces with many spaces being overlooked by such datasets. UA data presents a significant improvement, mapping patches of at least 0.25 ha. Nevertheless, in spatially fragmented urban landscapes, smaller but frequently occurring patches of bluespace should be considered.

The limitation of UA data is that they are updated only on six-year basis and released with delay after the reference year (UA 2012 was made public in 2015). A recent study presented the spatial distribution and (mostly) functional classification of UGS in Sofia and Bratislava, based on recently available Sentinel-2A (S2A) multispectral satellite imagery, provided free of charge in the frame of European Copernicus Earth observation program (Vatseva et al., 2016).

Effort

The creation of a spatial dataset incorporating freely available remote sensing data and cartographic layers is a useful step towards a bluespace dataset for a wide range of uses for research, policy and practice. The effort of achieving this is related to the scale of area being analysed, availability of suitable data, and level of automation of analysis.
During the past decades, remarkable efforts have been made in developing various methods for the task of remote sensing image scene classification and distribution of urban green and blue spaces because of its important role for a wide range of applications, such as natural hazards detection, LULC determination, geospatial object detection, geographic image retrieval, vegetation mapping, provision of green and blue spaces, environment monitoring, and urban planning.

Data availability

Differs from country to country. An example of good practice includes the UK national mapping agency (Ordnance Survey) that has produced a fine-scale vector dataset of urban green and blue space using spatial data at the highest available resolution for the United Kingdom. The data are available under licence (OS Mastermap Greenspace Layer) as well as in open-access format (OS Open Greenspace Layer).
Copernicus Sentinel S2A (available since 2015) data were obtained from the Copernicus Scientific Data Hub (scihub.copernicus.eu/dhus).

Geographical scale

Remote sensing and geographic information system (GIS) provide powerful tools for mapping and analysis of UGS at various spatial and temporal scales.

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The target minimum mapping unit represented a five-fold improvement compared to UA, i.e. 500 sq. m. Moreover, given the short revisit time of Sentinel 2 (5 days in mid- latitudes once the second satellite of the mission, Sentinel-2B, is launched in 2016), the proposed method can deliver more frequent and timely information on UGS compared to UA. Fifteen different classes of UGS were mapped and quantified with this method.

Table 1. Remote-sensing based indices for the effectiveness and health of green and blue spaces (Wellmann et al., 2017)

Vegetation Indices	Vegetation fractions	Frac	(Haase et al., 2019)
	Normalized difference vegetation index	NDVI	(Tucker, 1979)
	Green NDVI	gNDVI	(Gitelson et al., 1996)
	Red edge normalized difference vegetation index	reNDVI	(Gitelson and Merzlyak, 1994)
	Vegetation health index	VHI	(Lausch et al., 2018) (Kogan, 1990, 1997)
	Vegetation condition index	VCI	(Kogan, 2001)
	Temperature condition index	TCI	(Singh et al., 2003)
Combination of methods	satellite remote sensing with on-the-ground observations	-	(Lotze-Campen et al., 2002) (Haase et al., 2019)
Statistical Indices	Principal component analysis	1st component 2nd component 1st and 2nd component	(Jolliffe, 2002)

Temporal scale

Remote sensing and geographic information system (GIS) provide powerful tools for mapping and analysis of UGS at various spatial and temporal scales. Analysis of past trends can be a challenge if historical data is not available in a suitable resolution.

Participatory process

The accuracy of the resulting classification derived from the RS can be improved by incorporating digitised landscape and environmental data available from local environmental NGOs (e.g. City of Trees etc.) or community groups, which served principally to correct misclassification.
Similarly, participatory approaches can also be vital to supplement quantity of bluespace data with quality assessments.

Connection with SDGs

Goal 2	Goal 8	Goal 13
Goal 3	Goal 9	Goal 14
Goal 4	Goal 10	Goal 15
Goal 6	Goal 11	Goal 16
Goal 7	Goal 12	Goal 17

Applied methods

For further detail on more applied and participatory methods, please see:
Blue space area -
Applied/Participatory Review

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Table 2. Statistical indicators that have been tested for the quantification of spectral plant trait variations (Wellmann et al., 2017).

Type	Name	Formula	Reference
GLCM *Stats group*	GLCM mean	$\mu_i = \sum_{i,j=0}^{N-1} i(P_{i,j})$	(Haralick et al., 1973)
	GLCM variance	$\sigma_i^2 = \sum_{i,j=0}^{N-1} P_{i,j}(i-\mu_i)^2$	(Haralick et al., 1973)
	GLCM correlation	$\sum_{i,j=0}^{N-1} P_{i,j}\left[\frac{(i-\mu_i)(j-\mu_j)}{\sqrt{(\sigma_i^2)(\sigma_j^2)}}\right]$	(Haralick et al., 1973)
GLCM *Contrast group*	GLCM homogeneity	$\sum_{i,j=0}^{N-1} \frac{P_{i,j}}{1+(i-j)^2}$	(Haralick et al., 1973)
	GLCM contrast	$\sum_{i,j=0}^{N-1} P_{i,j}(i-j)^2$	(Haralick et al., 1973)
	GLCM dissimilarity	$\sum_{i,j=0}^{N-1} P_{i,j}\lvert i-j\rvert$	(Haralick et al., 1973)
GLCM *Orderliness group*	GLCM entropy	$\sum_{i,j=0}^{N-1} P_{i,j}(-\ln P_{i,j})$	(Haralick et al., 1973)
	GLCM angular second moment	$\sum_{i,j=0}^{N-1} P_{i,j}^2$	(Haralick et al., 1973)
Spatial Autocorrelation	Geary's *C*	$C = \frac{n-1}{2\left(\sum_i\sum_j w_{ij}\right)} \cdot \frac{\sum_i\sum_j w_{ij}(x_i-x_j)^2}{\sum_i(x_i-\bar{x})^2}$	(Geary, 1954)
	Moran's *I*	$I = \frac{n \sum_i\sum_j w_{ij}(x_i-\bar{x})(x_j-\bar{x})}{\left(\sum_i\sum_j w_{ij}\right) \sum_i(x_i-\bar{x})^2}$	(Moran, 1950)
Descriptive Statistics	Standard Deviation	$\sigma = \sqrt{\frac{\sum(x-\overline{x})^2}{N}}$	
	Coefficient of Variation	$CV = \frac{\sigma}{\mu}$	(Datt, 1998)

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Metric references

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Dennis M, Barlow D, Cavan G. (2018) Mapping Urban Green Infrastructure: A Novel Landscape-Based Approach to Incorporating Land Use and Land Cover in the Mapping of Human-Dominated Systems. Land 2018, 7, 17; doi:10.3390/land7010017

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Ibrahim, I., A. Abu Samah, and R. Fauzi. 2014. Biophysical factors of remote sensing approach in urban green analysis. Geocarto International 29:807-818.

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The target minimum mapping unit represented a five-fold improvement compared to UA, i.e. 500 sq. m. Moreover, given the short revisit time of Sentinel 2 (5 days in mid- latitudes once the second satellite of the mission, Sentinel-2B, is launched in 2016), the proposed method can deliver more frequent and timely information on UGS compared to UA. Fifteen different classes of UGS were mapped and quantified with this method.
Dennis et al. (2018) presents a landscape approach, employing remote sensing, GIS and data reduction techniques to map urban green and blue infrastructure elements in a large U.K. city region. The method proposed by Dennis has three elements:

(1) the use of remote sensing and GIS techniques to combine measures of land use, land cover and associated landscape metrics in the characterisation of neighbourhoods according to census units;
(2) employing data reduction methods to identify common attributes of urban landscapes for the creation of meaningful typologies for social–ecological research;
(3) a demonstration of the merit of the approach through analysis of social–ecological relationships in a large urban conurbation.

The methodology presented by Dennis et al. (2018) demonstrates the possibility of integrating currently available land use data such as those published by the e.g. U.K. Ordnance Survey with a land cover classification derived from high-resolution satellite imagery. The resulting composite dataset exhibits the ability to capture landscape features (integrating land use and land cover), indices, and a related typology congruent with existing socio-geographic units (e.g. U.K. national census tracts). Use of the latter as spatial extents for processing and analysis is particularly advantageous given that they reflect statistical units at which population, socioeconomic and health-related data are regularly reported.
The primary use of recently available high-resolution remotely sensed data with global coverage (Sentinel 2A satellites), combined with a universally applicable classification scheme based on simple ecological stratification, highlights the potential of the method for work in other urban and human-dominated landscapes in a range of climates.
A novel composite spatial dataset covering the conurbation of Greater Manchester was achieved through a combination of remote sensing and GIS techniques that drew on the strengths of separately but freely available spatial data.

Kogan, F.N. (1990) Remote sensing of weather impacts on vegetation in non-homogeneous areas. International Journal of Remote Sensing, 11: 1405–1419. DOI: 10.1080/01431169008955102. (For more information on this paper, please contact the IDMP HelpDesk).
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Tucker, C. J. (1979) Red and photographic infrared linear combinations for monitoring vegetation. Remote Sens. Environ., 8, 127–150.

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The resulting dataset was then compared with other open-source and widely used datasets covering the same study area (Urban Atlas and Land Cover Map). The methodology may provide a useful template for developing refined green/blue infrastructure maps for other cities (Dennis et al. 2018).
Green and blue areas >0.25ha in a city can also be extracted from European Settlement Map 2016 at 10 metre resolution, and the total population of the city and number of inhabitants can be extracted from the EU 100m pop mosaic Global Human Settlement Layer (GHSL) and the best available input census data for a city (Pafi et al., 2016). This data can be used to estimate green/blue area in relation to population. Calculating the bluespace area (according to UnaLab, CITYkeys report): the total blue area in hectares in the city divided by one 100,000th of the city's total population, or blue area per capita in m2 (Pafi et al., 2016).
A variety of studies have demonstrated that the use of high-resolution data is effective in capturing total green and blue cover in greater detail than other available sources (LCM 2015, Urban Atlas 2012 and OS Mastermap Greenspace 2017 datasets used for comparison). Using available high-resolution, remote sensing images researchers can transform Earth observation data into useful information necessary for urban planning and decision making. The mapping method applied with the use of RS is well suited to provide reliable geoinformation based on satellite images and to produce high resolution maps of urban green and blue spaces in urban territories.
Quantifying the urban green and blue spaces using remote sensing data proves to be key in the transfer of scientific knowledge to the urban environmental monitoring and management. However, the quantity of greenery and blue spaces is often measured using aerial photography or remote sensing techniques. Such data offer little information on the quality of the landscape view from the ground level, and other attributes, which may be important in terms of generating positive health outcomes. Participatory approaches or combining indicators can be necessary to generate such data.

b) References for Indicator based on the NbS projects from the CN database

AMICA (Adaptation and Mitigation – an Integrated Climate Policy Approach)

http://www.amica-climate.net
One of the project tasks was Risk and Disaster management. In this regard it is based on:
·GIS data and tools for risk assessment and management as help for decision local and regional makers for planning and disaster preparedness,
·remote sensing data on impacts and damages and urgent needs in case of disasters (GMES),
·remote sensing of urban areas (Wilson et al. 2003) has revealed a patchwork of discrete heat islands related to the distribution and structure of buildings and streets, as well as areas with much lower temperatures associated with parks and green space (Yu & Hien 2006).
Charlesworth, S.M. 2010. A review of the adaptation and mitigation of global climate change using sustainable drainage in cities. Journal of Water and Climate Change, volume 1 (3): 165-180.
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Green Surge (Green Infrastructure and Urban Bio- diversity for Sustainable Urban Development and the Green Economy)
www.greensurge.eu
One of the project tasks was "Identification, description and quantification of the full range of urban green spaces". In this regard, the research was based on remote sensing results in combination with relevant case studies field observation.

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Cvejić R., Eler K., Pintar M., Železnikar Š., Haase D., Kabisch N., Strohbach M. 2015. A typology of urban green spaces, ESS provisioning services and demands. GREEN SURGE project report.
Spronken-Smith, R. A., and Oke, T. R. (1998). The thermal regime of urban parks in two cities with different summer climates. International Journal for Remote Sensing, 19, 2085–2107.
Weeks J.R. (2010). Defining urban areas. In: Remote sensing of urban and suburban areas. Rashed T., Jürgens C. (eds.). Springer, Dordrecht, Heidelberg, London, New York: p. 33-45.

OpenNESS - Operationalisation of Natural Capital (NC) and Ecosystem Services (ES)
http://www.openness-project.eu
·Monitoring of results using GIS and/or remote sensing to help assess impacts on land cover.
·Use of such indicators as vegetation health and functional diversity in applying of remote sensing techniques.
Smith A., Berry P., Harrison P. Sustainable Ecosystem Management. OpenNESS Synthesis Paper.

OPERAs
http://www.operas-project.eu
·Remote sensing algorithms to estimate evapotranspiration are available but often not at sufficient resolution, and do not provide predictions on upcoming water use.
·More experience needs to be gained in combining technologies and scales: direct mapping of soil moisture as done with in-situ, air- or space borne radar, crop water stress mapping by thermal infrared sensors or derived from crop vigour and/or modelling of the crop/soil/atmosphere continuum.

OPPLA
(https://oppla.eu)
Different projects from the database
·Growing with green ambitions. Case study of Leipzig
An important lesson is that mapping should be combined with in situ green space monitoring of, for example, vegetation biomass. This would add value to remote sensing data and improve the capacity to assess ecosystem services provided by urban green space such as carbon dioxide removal. In addition, data were only available for 2012. An account based on time series of land cover and land use would help city planners to better understand to what extent urban green infrastructure is under pressure.
Limitations of the mapping approach: Mapping accuracy: The UFZ team used a remote sensing based approach utilizing digital ortho photos. All remote sensing techniques map from above, and overlaid featured cannot be detected. As a consequence, GI features at ground level such as lawn/meadow and blue structures may be underestimated if covered by large trees and / or dominant shrubland.
Banzhaf, E., Arndt, T., Ladiges, J. (2018a): Potentials of urban brownfields for improving the quality of urban space. In: Kabisch, S., Koch, F., Gawel, E., Haase, A., Knapp, S., Krellenberg, K., Nivala, J., Zehnsdorf, A. (eds.) Urban transformations - Sustainable urban development through resource efficiency, quality of life and resilience. Future City 10 Springer International Publishing, Cham, pp. 221 – 232. https://doi.org/10.1080/02513625.2018.1487643.
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PLUREL (Peri-urban Land Use Relationships - Strategies and Sustainability Assessment Tools for Urban-Rural Linkages)
www.plurel.net
·remote sensing and GIS for sustainable urban development science to provide geo-referenced information on the shape, size and distribution of different land-use classes of the urban environment

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The main application areas of these technologies in urban growth research within the project can be defined as follows:

- Monitoring urban growth (area change, structures, land consumption, soil sealing
- Monitoring land cover/land-use changes (loss of agricultural area, wetland infringement, loss of areas important for biodiversity, spatial distribution of inner-urban green and open spaces and natural areas)
- Mapping of environmental parameters (base data important for urban climate, access to and distribution of open space, calculation of sealed surfaces).

References:

Herold, M., Hemphill J., Dietzel, C. & Clarke, K.C. (2005): Remote Sensing Derived Mapping to Support Urban Growth Theory. Proceedings URS2005 conference, Phoenix, Arizona, March 2005.

URBACT (European exchange and learning programme promoting sustainable urban development)

https://urbact.eu

·remote sensing (production of high spatial resolution, including the urban atlas, built-up areas, and air pollution) and so-called big data, a growing source of detailed data can now be used to compare and benchmark cities.

URBES (Urban Biodiversity and Ecosystem Services)

https://www.biodiversa.org/121

·Remote Sensing of Urban Ecology (EO sensors, modelling algorithms)

·spatial and remote sensing data analyses, mostly engaged in WP2: Case study conditions and co-design workshops for identifying local policy solutions and WP5: Resilient supply of ecosystem services.

Larondelle N, Haase D, Kabisch N 2014. Diversity of ecosystem services provisioning in European cities. Global Environmental Change 26, 119-129.

Larondelle N, Hamstead Z A, Kremer P, Haase D, McPhearson T 2014. Comparing urban structure-function relationships across cities: Testing a new general urban structure classification in Berlin and New York. Applied Geography 53, 427-437.

Andersson E, McPherson T, Kremer P, Frantzeskaki N, Gomez-Baggethun E, Haase D, Tuvendal M, Wurster D 2015 Scale and Context Dependence of Ecosystem Service Providing Units. Ecosystem Services 12, 157-164.

Baró F, Frantzeskaki N, Gómez-Baggethun E, Haase D 2015. Assessing the match between local supply and demand of urban ecosystem services in five European cities. Ecological Indicators 55, 146-158.

Hamstead Z A, Kremer P, Larondelle N, McPhearson T, Haase D 2016. Classification of the heterogeneous structure of urban landscapes (STURLA) as an indicator of landscape function applied to surface temperature in New York City. Ecological Indicators 70, 574-585.

Baró F, Palomo I, Zulian G, Vizcaino P, Haase D, Gómez-Baggethun E 2016. Mapping ecosystem service capacity, flow and demand for landscape and urban planning: a case study in the Barcelona metropolitan region. Land Use Policy 57, 405-417 https://doi.org/j.landusepol.2016.06.006.

EKLIPSE

Digital mapping (e.g., remote sensing, GIS) of the potential for NBS and status of implementation (Badiu et al., 2016; Giannico et al., 2016; Gómez-Baggethun and Barton, 2013).

Badiu, D.L., Iojă, C.I., Pătroescu, M., Breuste, J., Artmann, M., Niță, M.R., Grădinaru, S.R., Hossu, C.A., Onose, D.A., 2016. Is urban green space per capita a valuable target to achieve cities' sustainability goals? Romania as a case study. Ecol. Indic. 70, 53–66. doi:10.1016/j.ecolind.2016.05.044

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Gómez-Baggethun, E., Barton, D.N., 2013. Classifying and valuing ecosystem services for urban planning. Ecol. Econ. 86, 235–245. doi:10.1016/j.ecolecon.2012.08.019

Raymond et al. 2016. An impact evaluation framework to guide the evaluation of nature-based solutions projects.

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ENABLE (Enabling Green and Blue Infrastructure Potential in Complex Social-Ecological Regions)
http://projectenable.eu/partners/
·spatial and remote sensing data analyses, mostly engaged in WP2: Case study conditions and co-design workshops for identifying local policy solutions and WP5: Resilient supply of ecosystem services.

Nature4Cities* (2017 – ongoing)
· identifying the needs for observation and modeling of coastal areas and examination of the current contributions of remote sensing (space and airborne).
International Space Science Institute (ISSI) (2017) Monitoring the evolution of coastal zones under various forcing factors using space-based observing systems. White Paper on Observing and Modeling Coastal Areas.
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Naturvation (2017 – ongoing)
From the NATURVATION database on the value and benefit assessment methods for urban NBS:
· a model based on remote sensing – MODIS NPP (Input data: allometric equations, net photosynthesis (PSNnet) data of 2010 provided by the MODIS, average growths in diameter of specific tree species, trees diameter at breast high), output data: Net primary productivity kg C per tree and year
· classification via remote sensing to determine tree species, LIDAR data to determine size of tree and allomeric equations to model above ground tree biomass (Input data: land cover (tree canopy %, spatial distribution of tree species), tree crown height, stem diameter (dbh), tree height, crown diameter & field surveys for tree data (# trees, tree location, stem diameter) (for calibration and validation); output data: above-ground carbon storage (biomass) (tC/ha, MtC, kg)
· deterministic model based on allomeric equations, LIDAR data and remote sensing to estimate tree carbon sequestration over the city (input data: remote sensing data, urban structure type data (e.g. green space, streets, low buildings with yards etc.), tree characteristics (tree height, crown width, crown base height, diameter at breast height (DBH))(from models); output data: aboveground carbon storage (kg C/building type, tC/ha, total tC)
· remote sensing together with distributed lag nonlinear models used to assess the risk of death due to heat as an effect of distance to green and blue space (input data: Metrological, NVDI, distance to green and blue infrastructure)
· modeling and detecting heat islands at different scales depending on a kernel smoothing and using remote sensing. Greenness and heat islands showed high correlation (input data: ASTER remote sensing images; output data: temperature in Kelvin).
· modeling the needs of green space for several ecosystem services, using GIS information, remote sensing and Pareto optimization (input data: GIS raster layers with information about green spaces; output data: air temperature.
· remote Sensing and LIDAR data used to estimate vegetation volume and NVDI. A 3D NVDI as constructed by multiplying the NVDI with the vegetation volume. Measured temperatures was modelled using Maximum Likelihood as a function of NVDI, 3D NVDI, distance to green / blue areas and built-area volume (input data: Remote images (1 m resolution), LIDAR data, temperature measurements; output data: temperature).
· a set of modelled GIS and remote sensing parameters used to model temperature as an effect of greenness, aerosols, buildings. Likely the method needs to be calibrated for each city/town separately (input data: GIS data of buildings, Landsat data; NVDI & AH CHRIS/PROBA satellite images, ASTER image data; output data: temperature).
· a framework using satellite images, remote sensing and statistical modelling to compute accessibility of parks and green space dependent on economic and population data (input data: percentage of green cover in a city, population density, GDP per capita, City land area, Per capita green space provision, Aggregation index; output data: Effects of and between the different types of in data)

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· deterministic model, using remote sensing of greenness as well as surface sealing to estimate recreation supply (input data: Remote sensing data, NVDI & surface sealing; output data: Spatially normalized minimum of green space provision per person suggested by the city administration (m^2 per Block; m^2/m^2)
· remote sensing & satellite imagery and digital orthophotos together with Geographic Information Systems (GIS) used to develop a digital elevation model and a digital surface model (input data: qualitative and GIS data; output data: quality of life, tree coverage; spending time in city parks, gardens, and open spaces)
· remote sensing for ES matrix – the ES matrix approach is an easy-to-apply concept based on a matrix linking spatially explicit biophysical landscape units to ecological integrity, ecosystem service supply and demand. By linking land cover information from, e.g. remote sensing, land survey and GIS with data from monitoring, statistics, ecosystem service supply and demand can be assessed and transferred to different spatial and temporal scales. The ES matrix approach is a quick and simple way to get an overall spatially-explicit picture of the ES in case study areas (input data: land cover and land use data (GIS) (incl. Additional biotic and abiotica information (e.g. land use intensity, soil quality, climate data); output data: ES provision capacity per landuse class (0-5 values & biophyscial units).

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Burkhard B. F., Kroll, F. Müller, W. 2009. Wind horst Landscapes' capacities to provide ecosystem services – a concept for land-cover based assessments. Landscape Online, 15, 1-22.
Davis et al. 2016. Combined vegetation volume and "greenness" affect urban air temperature, Applied Geography, 71, 106–114
Karteris, M., Theodoridou, I., Mallini, G., Tsiros, E., and Karteris A. 2016. Towards a green sustainable strategy for Mediterranean cities: Assessing the benefits of large-scale green roofs implementation in Thessaloniki, Northern Greece, using environmental modelling, GIS and very high spatial resolution remote sensing data, Renewable and Sustainable Energy Reviews, 58, 510-525
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Neema et al. 2013. Multitype Green-Space Modeling for Urban Planning Using GA and GIS, Environment and Planning B: Planning and Design, 40, 447-473
Schreyer et al. 2014. Using Airborne LiDAR and QuickBird Data for Modelling Urban Tree Carbon Storage and Its Distribution-A Case Study of Berlin, Remote Sensing, 6(11), 10636-10655
Tigges et al. 2017. Modeling above-ground carbon storage: a remote sensing approach to derive individual tree species information in urban settings, Urban Ecosystems, 20(1), 91-111
Weng et al. 2011. Modeling Urban Heat Islands and Their Relationship With Impervious Surface and Vegetation Abundance by Using ASTER Images. IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, 49(10), 4080-4089

OPERANDUM (2018 – ongoing) (OPEn-air laboRAtories for Nature baseD solUtions to Manage environmental risks)
Mentioned in the Research provided by University of the Sunshine Coast, Institute of Remote Sensing and Digital Earth in order to:

- Contribute to a high resolution modeling of the estuarine and the coastal sea dynamics focusing on the Italian OAL.
- Contribute to build up present day and climate change scenarios for predicting and assessing storm surge, coastal erosion, salt wedge intrusion
- Contribute to the design and development of the Natural based solutions planned for the Italian OAL: introduce a novel-vegetated sand dune in the complex land- marine environment of the north Emilia-Romagna coastline to reduce storm surge and related coastal erosion; install herbaceous perennial deep rooting plants as coverage of earth embankments for the mitigation of flood risk and salt wedge intrusion in the Po delta

https://www.operandum-project.eu/the-project/

Think Nature platform
https://platform.think-nature.eu/resources?page=13

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

· remote sensing from urban gardens in Barcelona, Spain, including municipal 'allotment gardens' and 'civic gardens' emerging from bottom-up initiatives (identifying different urban gardens types regarding the ES values they provide, and specific garden characteristics including biophysical garden properties etc.

Langemeyer J., Camps-Calvet M., Calvet-Mir L., Barthel S., Gómez-Baggethun E. 2018. Stewardship of urban ecosystem services: understanding the value(s) of urban gardens in Barcelona. Landscape and Urban Planning. https://doi.org/10.1016/j.landurbplan.2017.09.013

UnaLab
·technical handbook takes the Key performance indicators as basis for detailed evaluation of NBS. One of them is leaf area index which can be measured using remote sensing.
https://www.unalab.eu/

URBAN Green-UP* (2017 – ongoing)
As based on Technical report by the Joint Research Centre (JRC), the European Commission's science and knowledge service and references below:
·Mapping the removal of PM10 and ozone by urban trees (Rome, one of the EnRoute city labs) as well as at regional level. They combined high resolution remote sensing data with measured pollutant concentrations to estimate the physical removal of pollutants by trees. A damage cost approach was used to estimate the monetary value associated to pollutant removal. The overall pollution removal accounted for 5123 and 19,074 t of PM10 and O3, respectively, with a relative monetary benefit of 161 and 149 Million euro for PM10 and O3, respectively.
·mapping and assessing the contribution of urban vegetation to microclimate regulation (a) Deriving a map of Land Surface Temperature based on Landsat 8 Data, using a methodology based on (Du et al. 2015); b) Aggregating Land types to assess the changes in average temperature (see Figure 12), c) Estimate the Influence of green cover on surface temperature index (Under development)
·mapping urban temperature using remote sensing information (split window algorithm), using the model for assessing urban temperature and the indicator for microclimate regulation
Du C, Ren H, Qin Q, Meng J, Zhao S. 2015. A Practical Split-Window Algorithm for Estimating Land Surface Temperature from Landsat 8 Data. Remote Sens. 7:
Fusaro L, Marando F, Sebastiani A, Capotorti G, Blasi C, Copiz R, Congedo L, Munafò M, Ciancarella L, Manes F. 2017. Mapping and Assessment of PM10 and O3 Removal by Woody Vegetation at Urban and Regional Level. Remote Sens. 9:
Wegmann M, Leutner BF, Metz M, Neteler M, Dech S, Rocchini D. 2017. A grass GIS package for semi- automatic spatial pattern analysis of remotely sensed land cover data. Methods Ecol Evol. doi: 10.1111/2041-210X.12827
Zulian, G., Thijssen, M., Günther, S. Maes, J. 2018. Enhancing Resilience Of Urban Ecosystems through Green Infrastructure (EnRoute). Progress report, EUR 29048 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-79-77697-7, doi:10.2760/958542, JRC110402)

Other sources
- multi-sensor multi time-series approach to detect urban land cover changes.
- Landsat, Sentinel and RapidEye data (2005–2017) are combined in a robust procedure.
- variation and disturbances of different sensor characteristics are shown to offset.
- NDVI (Normalized Difference Vegetation Index is a dimensionless index that describes the difference between visible and near-infrared reflectance of vegetation cover and can be used to estimate the density of green on an area of land (Weier and Herring, 2000, Environmental Research, 2018) is calculated and transferred into a classified NDVI for more than one decade.
- results show success of approach to detect small scale vegetation development.

Kabisch, N.; Selsam, P.; Kirsten, T.; Lausch, A.; Bumberger, J. 2019. A multi-sensor and multi-temporal remote sensing approach to detect land cover change dynamics in heterogeneous urban landscapes. Ecological Indicators, 99, 273-282. https://doi.org/10.1016/j.ecolind.2018.12.033

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ENVIRONMENTAL INDICATORS - CORE

CONNECTING NATURE

Soil sealing

Applied/Participatory Review

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(1) University of East London, United Kingdom
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Description

De-sealing, reusing sealed sites to reduce land take/soil sealing (with impermeable surfaces), and use of permeable materials and surfaces e.g. green roofs.

Methodology

Impermeable ground and modified ecosystems transform natural soil and alter important environmental processes (e.g. water cycle etc). Mapping impermeable surfaces provides an indicator of urban development e.g. densification/urban sprawl, and can aid assessments of drainage, urban heat island, biodiversity and health and wellbeing. The majority of soil sealing metrics would be based on an earth observation and/or remote sensing approach. However, other more applied and participatory methods are available.

Level of expertise

Data is generally added to background digital maps, so some expertise in GIS is needed.

Data collection

Cost

There are costs associated with satellite data, data processing and analysis but these depend on city access to resources. Greenspace factor assessment generally involves site visits. Participatory processing can help reduce mapping costs.

Effort

Potentially time-intensive depending on resolution or scale.

Data availability

There is existing satellite/map data available and pilot citizen science apps.

Geographical scale

City-scale typically, but may be possible to use the data to monitor local-level changes in greenspace if high-resolution imagery available.

Temporal scale

Can be used to provide a current snapshot or to look at trends but the RS section below suggests there may be a trade-off in the resolution of available historical data to map change in the past to now.

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Scientific solid evidence

Not typically a method for generating solid evidence. Tends to be more of a focus on generating an index to help quantify change.

Extended methodology

At a site or project level, a Green Space Factor score (between 0 and 1) can be calculated based on score assigned (by a planning authority) to any particular surface-cover type (e.g. asphalt, lawn, green roof etc). The area for each surface cover type is calculated and multiplied by its factor, and the overall total score is divided by the total area of the project. The project score can then be compared to targets set by local authorities. GSF can provide certainty for developers regarding expectations for urban greening for new developments. It can identify planning proposals with insufficient quantity and functionality of greening, encourage improvements in greening, and compare and evaluate proposals for a site. Examples are Malmo's Green Space Factor and Green Points system (Kruuse, 2011) and the London Urban Greening Factor (Grant, 2017).
Citizen Science: LandSense
https://lep.landsense.eu/Themes/Urban-Landscape-Dynamics/ is an EU project that aims to engage citizens in monitoring change in the urban landscape that can be integrated into local authorities databases to improve urban planning (Olteanu-Raimond et la., 2018). The LandSense Engagement Platform will become a marketplace where citizens can participate in Land Use and Land Cover (LULC) campaigns and can register new or reuse existing services. Citizens use a mobile app to validate current land use and add new information for land use changes (under the name PAYSAGES in France). Campaigns can be opportunistic or guided, and contributors would typically either: edit a feature, add new information about a feature, report of change or an error in existing data, take pictures of features depicted on the map (Olteanu-Raimond et la., 2018).
Data on soil sealing collected in these ways can be used to:

- Set targets for soil unsealing;
- Monitor changes in relation to loss of permeable surfaces;
- Linking to other indicators such as land use change and stormwater management;
- Support initiatives to improve soil health and promote groundwater recharge.

Participatory process

Lots of opportunity for community participation. The LandSense app provides a mechanism to engage citizen participation and update data.

Earth observation/remote sensing/modelling

Some spatial modelling/mapping is required but participatory and applied processes are possible to supplement this. For more greater detail on earth observation, remote sensing and modelling approaches, including those used on past and current EU projects, see indicator guidelines:
Soil sealing – Earth observation/Remote Sensing Review

Connection with SDGs

Goal 2	Goal 9	Goal 14
Goal 3	Goal 10	Goal 15
Goal 4	Goal 11	Goal 16
Goal 8	Goal 13	Goal 17

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Original reference for indicator

Connecting Nature Review

Metric references

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ENVIRONMENTAL INDICATORS - CORE

CONNECTING NATURE

Soil sealing

Earth Observation/Remote Sensing Review

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Description

De-sealing - reusing sealed sites to reduce land take/soil sealing (with impermeable surfaces), and use of permeable materials and surfaces e.g. green roofs

Methodology

The soil sealing level, or the percentage of impervious surfaces, is an important factor in environmental sciences. Surfaces of this type directly influence the natural water cycle and affect the energy balance of the area. The hydrological regime is influenced by the degree of soil sealing and the spatial pattern; the connectivity between impervious patches necessitates the implementation of remote sensing techniques. Impervious surfaces can also be treated as a reliable indicator of anthropopressure on the natural environment (Weng, 2011).

Level of expertise

There are many kinds of remote sensing data available, but to find out the best fitting ones needs expert knowledge. Expertise in mapping and interrogation of data using GIS software is typically required. Level of expertise required is greater with increasing complexity of software processing. Given the large number of remote sensing data available, it is difficult to select the appropriate one because each satellite has different revisit times, ordering requirements, delivery schedules, pixel resolutions, sensors, and costs.

Data collection

Cost

Despite the potential of high-resolution image data to map sealed surfaces at a high level of spatial detail, the limited footprint, high cost and time intensive processing of such images hampers their use at a regional or nationwide scale. In addition, the limited historical archive of high-resolution image data restricts their use for spatio-temporal monitoring. For mapping sealed surface cover for larger areas or for studying changes in sealed surface cover over a significant period of time, medium resolution remote sensing data seem therefore more suited. If cost is no object the best procedure, and that which provides the most flexibility in end products, is to purchase a digital tape or CD and process the image on one's own system.

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Scientific solid evidence

If appropriate pixel and/or sub-pixel classification is carried out, a high level of evidence can be generated. Error factors can also be calculated based on sample areas.

Extended methodology

Monitoring of the soil sealing level is an important issue where urban sprawl is concerned (Pabjanek et al., 2016). Sensing and measuring soil sealing can be carried out on a municipal scale from digital cartography, multi-temporal aerial photography and satellite images from Landsat and Spot, provided by NASA or national remote sensing plans (Garcia and Perez, 2016). Mapping sealed surface cover for larger areas or for studying changes in sealed surface cover over a significant period of time are most effectively measured with medium resolution remote sensing data.

The identification, analysis, measurement and evaluation of soil loss through sealing can then be obtained from various remote sensing techniques: spectral bands, Principal Component Analysis, tasselled cap, Normalised Difference Built-up Index (NDBI) (Zha et al., 2003), Normalised Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI) etc. NDBI has been shown to be the most effective methodology for the densest sectors of cities, but greater precision and reliability of sealed surfaces can be obtained from classifications using SAVI images and principal components outside the densest areas (Garcia and Perez, 2016).

Alternatively, Wood et al. (2006) recommend the following process: collate date from the following two sources:

i) OS MasterMap® to identify a priori, areas of known sealing – principally roads and buildings; and
ii) Quickbird (or Orbview-3, or IKONOS) satellite imagery, which is classified and used in all remaining areas, i.e. not designated by OS MasterMap® as building or roads.

The drawback is that it requires an image processing system, the knowledge to operate it and keep it updated, and the time to do the processing. For those with some latitude in the amount they can spend, there are a wide variety of products available from vendors with a wide range of costs. If the amount that can be spent is limited, the least expensive option is to purchase imagery off the shelf from a government agency or primary distributor.

Effort

Remote sensing imagery combined with techniques of image analysis can provide an up-to-date, detailed and spatially-differentiated analysis of soil sealing. Previous studies at the local and regional level have confirmed the potential of these techniques to determine the extent of soil sealing both in Germany (such as Agglomeration Cologne/Bonn, Stuttgart, North Rhine-Westphalia, Bavaria (Behnisch et al., 2016) and elsewhere (such as the Columbus Metropolitan Area, Ohio, large regions in the USA and Italy. Furthermore, efforts have been made to predict impervious surface extents based on urban growth models.

Data availability

Recently available remote-sensing data provided by the European Environmental Agency (EEA) now enable the uniform detection of sealed surfaces for the whole of Europe. This also permits us to specify possible correlations with other economic, social, ecological and technical variables.
Data from the Landsat archive (for free) can be selected to obtain full coverage, and, together with high-resolution IKONOS data for selected areas, can be used in a multi-resolution linear regression modelling framework to obtain fraction estimates for each time step. Spatial trends of sealed surface growth should be analysed at the level of municipalities and for different land-use classes.

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After geocorrection, the NDVI image is calculated and extracted, and a maximum likelihood pixel classification of the NDVI is used to classify the image into unsealed and sealed surfaces (vegetated and non-vegetated).

The segmented layer of roads and buildings is classified as 100% sealed. All remaining OS MasterMap® polygons are used to automatically extract the average area of sealed pixels from the classified NDVI image, by counting the number of sealed pixels and dividing by the polygon area. The two data sets are then reconstituted to produce a single combined map of sealed and unsealed land.

In strongly fragmented landscapes such as in an urban and peri-urban environment, the larger pixel size of medium resolution imagery will result in the omnipresence of mixed pixels. The spectral response of such pixels is a combination of the spectral responses of each distinct land-cover type found within the pixel. To deal with these mixed pixels, subpixel classification techniques can be applied, enabling estimation of the fraction of sealed surface cover present within each pixel.

Different subpixel classification strategies have been proposed to map sealed surface cover fraction, using regression-based learning approaches, such as multi-layer perceptrons (MLP) (Hu and Weng, 2009; Van de Voorde et al., 2009), self-organizing maps (Hu and Weng, 2009), regression trees (Xian et al., 2007), support vector regression (Okujeni et al., 2014), or using physically-based unmixing methods, such as linear spectral mixture analysis (LSMA) (Weng et al., 2011) or multiple endmember spectral mixture analysis (MESMA) (Rashed et al., 2003; Demarchi et al., 2012).

To avoid under- or overestimation of sealed surface cover fraction, due to spectral similarities between bare soil and substrate (Xian et al., 2007), several studies propose the delineation of an urban mask prior to applying the sub-pixel classifier (Weng et al., 2011; Van de Voorde et al., 2009). Outside the urban mask a complete absence of sealed surfaces is then assumed, whereas pixels belonging to the urban mask are considered to be composed of vegetation and/or sealed surfaces only.

Geographical scale

Analysis possible at various geographical scales.

Temporal scale

Analysis can be carried out at various temporal scales. However, lack of availability of high resolution historical data can limit assessment of historical change over time.

Participatory process

Since assessment of soil sealing is based on land use change data, modeling of future soil sealing and soil loss can also involve participatory impact assessment. The major data inputs for soil sealing are satellite image based land use maps and soil maps. The participatory impact assessment involved series of meetings with stakeholders and collecting their opinions in a semi-quantitative form.

Connection with SDGs

Goal 2	Goal 9	Goal 14
Goal 3	Goal 10	Goal 15
Goal 4	Goal 11	Goal 16
Goal 8	Goal 13	Goal 17

Applied methods

For more information on applied and participatory methods see:
Soil sealing - Applied/Participatory Review

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Perhaps the most straightforward method to estimate the sealed surface cover fraction from a pixel's spectral properties is the use of linear or non-linear regression (Van de Voorde et al., 2009), where the fraction of sealed surface cover or its complement – the vegetation fraction – is directly inferred from the pixel's reflectance in one or more spectral bands, and/or from spectral indices that can be related to the sealed surface or vegetation fraction.

Yang and Liu (2005) propose the use of tasselled cap brightness and greenness to estimate the fraction of sealed surface cover from Landsat TM/ETM+ imagery for Pensacola, Florida (US) for two different moments in time to identify hot spots of urban growth.

Bauer et al. (2004) apply non-linear regression to estimate sealed surface cover from Landsat tasselled cap greenness for the cities of St. Cloud and Rochester (Minnesota, US). Sawaya et al. (2003) report a strong linear relationship between NDVI, perhaps the most commonly used vegetation index, and the fraction of sealed surface cover for high-resolution Ikonos imagery covering the City of Eagan, Minnesota (US). Van de Voorde et al. (2009) use stepwise multiple regression to estimate the vegetation fraction from Landsat imagery for the Greater Dublin area and obtain the sealed surface fraction as the complement of the vegetation fraction within a predefined urban mask.

b) References for Indicator based on the NbS projects from the CN database

PLUREL (Peri-urban Land Use Relationships - Strategies and Sustainability Assessment Tools for Urban-Rural Linkages) www.plurel.net

- Remote sensing and GIS for sustainable urban development science to provide geo-referenced information on the shape, size and distribution of different land-use classes of the urban environment

References

Original reference for indicator

Connecting Nature Review

Metric references

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CONNECTING NATURE

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The main application areas of these technologies in urban growth research within the project can be defined as follows:

- Monitoring urban growth (area change, structures, land consumption, soil sealing
- Monitoring land cover/land-use changes (loss of agricultural area, wetland infringement, loss of areas important for biodiversity, spatial distribution of inner-urban green and open spaces and natural areas)
- Mapping of environmental parameters (base data important for urban climate, access to and distribution of open space, calculation of sealed surfaces).

References:

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OPPLA (https://oppla.eu)
There different projects in this regard presented in the OPPLA data base

Naturvation (2017 – ongoing)
From the NATURVATION database on the value and benefit assessment methods for urban NBS:

- deterministic model, using remote sensing of greenness as well as surface sealing to estimate recreation supply (input data: Remote sensing data, NVDI & surface sealing; output data: Spatially normalized minimum of green space provision per person suggested by the city administration (m^2 per Block; m^2/m^2).

- remote sensing & satellite imagery and digital orthophotos together with Geographic Information Systems (GIS) used to develop a digital elevation model and a digital surface model (input data: qualitative and GIS data; output data: quality of life, tree coverage; spending time in city parks, gardens, and open spaces)

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ENVIRONMENTAL INDICATORS - CORE

CONNECTING NATURE

Change in ecosystem service provision

Applied/Participatory Review

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Description

Measure number/quantity of a suite of ecosystem services to evaluate change in ES provision in relation to NbS using more applied methods.

Methodology

Studies such as the Millennium Ecosystem Assessment (2005) and the UK National Ecosystem Assessment (Watson et al., 2011) demonstrated the linkages between the natural environment, ecosystem services (ES) and human well-being.
Urban greenspaces can deliver essential ES and a detailed map of urban GI can provide the baseline for measuring urban ES. Detailed spatial data is needed to identify service providing units, and GI is typically classified according to land cover and land use type.

Level of expertise

See Change in ecosystem service provision - Earth Observation/Remote Sensing Review.

Data collection

Cost

See Change in ecosystem service provision - Earth Observation/Remote Sensing Review.

Effort

See Change in ecosystem service provision - Earth Observation/Remote Sensing Review.

Data availability

See Change in ecosystem service provision - Earth Observation/Remote Sensing Review.

Geographical scale

See Change in ecosystem service provision - Earth Observation/Remote Sensing Review.

Temporal scale

See Change in ecosystem service provision - Earth Observation/Remote Sensing Review.

Participatory process

Change in ecosystem service provision - Earth Observation/Remote Sensing Review includes two research papers that involve community participation.

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Scientific solid evidence

See Change in ecosystem service provision - Earth Observation/Remote Sensing Review.

Extended methodology

Most techniques therefore involve remote sensed data and modelling approaches, therefore the metrics have been grouped within the remote sensing/earth obervations review indicator guidelines: Change in ecosystem service provision - Earth Observation/Remote Sensing Review.

Mapping and measuring changes in land use and land cover that supply ES can support decision making for using NBS approaches to urban development, for instance by providing information regarding costs and benefits of NBS versus grey infrastructure. If undertaken with comparison to a non-NBS project or no change scenario, it can assist with environmental management decisions and support evidence-based decision-making to improve human well-being and ensure environmental sustainability (Value of Nature to Canadians Study Taskforce, 2017). Consideration needs to be given that synergies and trade-offs between ES can occur (de Groot et al., 2010).

Mapping ecosystem service provision in these ways can be used to:

- Set targets for ecosystem service provision;
- Monitor change in ecosystem service provision over time;
- Inform strategic planning decisions in relation to individual sites or networks of sites;
- Assess the effects of different scenarios of design/management change on sites.

Earth observation/remote sensing/modelling

For earth observation, remote sensing and/or modelling approaches, including those used on past and current EU projects, see indicator guidelines:
Change in ecosystem service provision – Earth observation/Remote Sensing Review

Connection with SDGs

Goal 1	Goal 8	Goal 13
Goal 2	Goal 9	Goal 14
Goal 3	Goal 10	Goal 15
Goal 4	Goal 11	Goal 16
Goal 6	Goal 12	Goal 17
Goal 7		

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UnaLab

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ENVIRONMENTAL INDICATORS - CORE

CONNECTING NATURE

Connecting Nature

Change in ecosystem service provision

Earth Observation/Remote Sensing Review

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Description

Measure number/quantity of a suite of ecosystem services to evaluate change in ES provision in relation to NbS focusing on earth observation/remote sensing approaches.

Methodology

The role of novel Earth observation techniques and data sets is becoming increasingly important in environmental monitoring, both for biodiversity (Vihervaara et al. 2017), and for ecosystem services (Cord et al. 2017). Satellite Earth observation, as well as airborne and drone observations, have huge potential to improve quantification, mapping, and assessment of ecosystems and their services. Optical, radar, and Light Detection And Ranging (LiDAR) data can be used for direct measurements, or to gather information that feeds into the models.

Level of expertise

It is important to clarify the resources that are needed to carry out ecosystem services assessments, such as technical and human resources, and the time needed for certain analyses. The methods vary greatly depending on the required expertise, availability of the data and its coverage, available software, time, and financial costs. The most suitable approach will depend on the research questions which need to be addressed, whether the study will be an assessment, or if maps are also required. For mapping methods, the level of scale should be considered. The limitations are often set by the availability of the data. For small research areas more detailed data sources, or even opportunities to conduct field measurements, may be available. However, for larger studies Earth Observation products may offer a solution for areas of poor data coverage. In addition to scale, it is also important to pay attention to the purpose of which the assessment is aimed at: Which biophysical units can and should be used to gain information on ecosystem services? Do we want to know if sufficient ecosystem service potential is available, or do we wish to quantify the rate at which the ecosystem service is delivered? Also, do we wish to deliver spatially explicit information for the chosen locations? The most suitable methods should be identified and selected according to the answers to these questions. Using a mixture of remote sensing and field methods appears to deliver the best results (e.g Mikolajczak et al., 2015; Vihervaara et al., 2017). Yet, this requires ecologists and remote sensing experts to collaborate closely with the newest methods and capabilities.

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Scientific solid evidence

The integration of RS technologies into ES concepts and practices leads to potential practical benefits for the protection of biodiversity and the promotion of sustainable use of Earth's natural assets. The last decade has seen the rapid development of research efforts on the topic of RS for ES (especially, in the context of spatially explicit RS and valuation of ES), which has led to a significant increase in the number of scientific publications. Remote sensing can be used for ecosystem service assessment in three different ways: direct monitoring, indirect monitoring, and combined use with ecosystem models. Some plant and water related ecosystem services can be directly monitored by remote sensing. Most commonly, remote sensing can provide surrogate information on plant and soil characteristics in an ecosystem. For ecosystem process related ecosystem services, remote sensing can help measure spatially explicit parameters. We conclude that acquiring good in-situ measurements and selecting appropriate remote sensor data in terms of resolution are critical for accurate assessment of ecosystem services.

The assessment of ES is often limited by data, however, a gap with tremendous potential can be filled through Earth observations (EO), which produce a variety of data across spatial and temporal extents and resolutions. Despite widespread recognition of this potential, in practice few ecosystem service studies use EO. There are some challenges and opportunities to using EO in ecosystem service modelling and assessment which we can identify:

- technical - related to data awareness, processing, and access (these challenges require systematic investment in model platforms and data management)
- other challenges – more conceptual but still systemic; they are by-products of the structure of existing ecosystem service models and addressing them requires scientific investment in solutions and tools applicable to a wide range of models and approaches.

As stated by variety of research, more widespread use of EO for ecosystem service assessment will only be achieved if all of these types of challenges are addressed. This will require non-traditional funding and partnering opportunities from private and public agencies to promote data exploration, sharing, and archiving. Investing in this integration will be reflected in better and more accurate ES assessment worldwide.

Data collection

Cost

Many remotely sensed EO products, including those from MODIS (250 m+), Landsat (30 m), and Sentinel's Ocean Land Color Instrument (OLCI, 300 m), are freely available. However, EO data at finer resolutions (< 3 m) can be expensive to obtain.

Effort

According to Andrew et al. (2014), efforts to map the distribution of ESs often rely on simple spatial surrogates that provide incomplete and non-mechanistic representations of the biophysical variables they are intended to proxy. However, alternative datasets are available that allow for more direct, spatially nuanced inputs to ES mapping efforts. Remote sensing data acquisition and processing requires financial, technological, and professional capacity. Even though there are some freely available data sets, the quantification of broad categories of ecosystem services cannot be achieved with these datasets alone. Acquiring the commercially available satellite images (e.g., QuickBird) incurs higher costs which also applies to the current hyperspectral, RADAR, and LiDAR sensors. Data acquisition from these sensors is usually upon request by the users which creates inconvenience in obtaining data from a specific area. Besides the acquisition, processing and analysis of data like hyperspectral images demands a very high technical capacity and computers with storage capacities up to tens of Terrabytes or even Petabytes.
As stated by Ayanu et al. (2012), the quantification of ESs can be better and more correctly achieved by linking remotely sensed information to a limited number of in-situ observations using semi-empirical linear or nonlinear regression models.

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Remote sensing provides a useful data source that can monitor ecosystems over multiple spatial and temporal scales. Although the development and application of landscape indicators (vegetation indices, for example) derived from remote sensing data are comparatively advanced, it is acknowledged that a number of organisms and ecosystem processes are not detectable by remote sensing. The potential for applying remote sensing for analysis and mapping of ES efforts has not been fully realised due to concerns about ease-of-use and cost. Historically, RS data have not always been easy to find or use because of specialised search and order systems, unfamiliar file formats, large file size, and the need for expensive and complex analysis tools. That is gradually changing with increasing implementation of standards, web delivery services, and the proliferation of free and low-cost analysis tools. Although data cost used to be a common prohibitive factor, it is no longer a big stumbling block for most users except where high resolution commercial images are needed.

Extended methodology

Data and software needs:

- Data – Satellite images, airborne images, LIDAR points.
- Software: Remote sensing softwares e.g. Erdas Imagine, ENVI, GIS softwares and tools e.g. QGIS, ArcGIS, TerraScan, LasTools, FUSION

The ES indicators are then applied to these high-resolution UGS datasets within a GIS environment using these bespoke tools. The area of each element is multiplied by the ES supply per m2 of the respective UGS type (aggregated to neighbourhood and/or district level). Results can be interpreted at individual ES level or at ES bundle level (using cluster analysis) and in terms of an ES supply score in relation to their spatial distribution i.e. radius from the source of nuisance such as air/noise pollution. Synergies and trade-offs between the type and quantity of UGS and ES supply can also be identified e.g. cooling, carbon storage and air purification demonstrate synergies as these are primarily being supplied by the same UGS types. The method can reveal differences between neighbourhoods in terms of amount and type of ES supplied, and can highlight possible ES shortages in neighbourhoods. The following provides a summary from the literature of the state of available and feasible remote sensing variables used in the assessment and valuation of ecosystem services.

For example, vegetation indices derived from the near-infrared and red proportion of the electromagnetic spectrum can be linked to in-situ biomass measurements to derive a proxy for timber production. Irrespective of the regression type, the statistical relationship between the sensor signal and the data derived from field observations is affected by the sensor characteristics like spectral, spatial, and temporal resolution. Moreover, multiple boundary conditions like time of the day and year, actual state of ecosystem components, and the atmosphere also affect the statistical relationship and reduce its validity for monitoring and spatial transfers to other study areas. The properties of remote sensing systems vary significantly among each other making selection of the sensor system and the optimal methodology prerequisites for an accurate delineation of the proxies for ecosystem services.

For instance, many indicators can be delineated for extensive areas within a clearly defined range of uncertainty based on operationally available data and well-established methods. Other indicators useful for exact quantification of ecosystem services can be only derived experimentally at local scale. The success of remote sensing application therefore depends on careful selection of the data from which the relevant parameters are derived for the chosen indicators of ecosystem services.The quantification of ecosystem services is limited by the respective resolution of the remote sensing system. While multispectral data (e.g., Landsat, MODIS) have been widely used, the retrieval of some variables is limited by the rather poor combination of spatial and spectral resolution. Thus, utilizing high resolution hyperspectral, radar and LiDAR sensors would be desirable.

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Examples of methods:
·Green oriented urban development
Martinico et al. 2014 http://dx.doi.org/10.3832/ifor1171-007
SIAM (Satellite Image Automatic Mapper) García-Feced et al. 2014 http://dx.doi.org/10.1007/s13593-014-0238-1
·Data: Land cover data (GIS layers): terrain, vegetation, soil, bathymetry, habitat distribution etc.
Software: Remote Sensing software e.g. ENVI, Erdas Imagine, GIS software e.g. ArcGIS
·Mapping examples: Emergy assessment Mellino et al. 2014 https://doi.org/10.1016/j.ecolmodel.2012.12.023

The following figures are taken from a very recent systematic review on urban ES quantification using RS (Tavares et al. 2019). Figure 3 shows the most used data sources for the selected studies, Figure 4 the most cited methodologies used, and Figure 5 the four main ES groups (Provisioning, Regulating, Supporting, and Cultural) identified in the literature review and their ES sub-types.

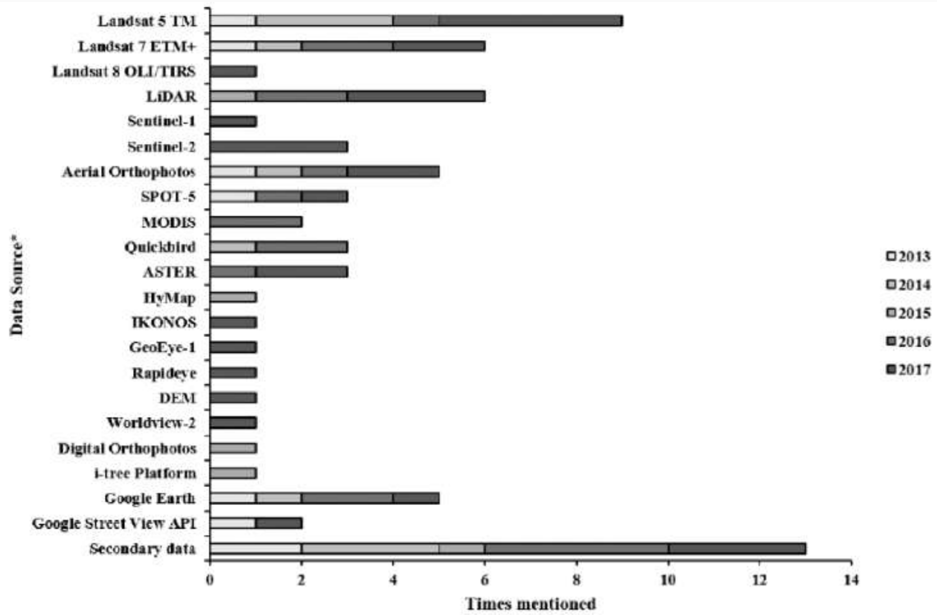

Figure 3. Identification of data source used by the authors, separated by year (2013–2017). * Abbreviations mentioned in the data source axis stands for TM, thematic mapper; ETM+, enhanced thematic mapper plus; OLI/TIRS, operational land imager/thermal infrared sensor; SPOT, satellite pour l'observation de la Terre; MODIS, moderate-resolution imaging spectroradiometer; ASTER, advanced spaceborne thermal emission and reflection radiometer; DEM, digital elevation model; API, application programming interface.

With respect to the current status of these sensors, the derivation of ecosystem parameters such assoil clay mineralogy, belowground biomass, or water quality indicators like chlorophyll-a content, nitrogen, and phosphorus loading is primarily restricted to experimental landscape scale studies. Therefore, in situ measurements are needed for validation when using remote sensing data.

Data availability

Once ecosystem service analysts have identified a useful EO product and have the capacity to process it, they may still be unable to access it. Though many remotely sensed EO products, including those from MODIS (250 m+), Landsat (30 m), and Sentinel's Ocean Land Color In-strument (OLCI, 300 m), are freely available, EO data at finer resolutions (< 3 m) can be expensive to obtain (Schaeffer et al., 2013). While many assessments can be done at coarser resolutions, high resolution data are important for precise assessments, such as delineating urban canopies. Data producers could collaborate with public agencies to make EO data and products available at low or no cost for non-commercial research purposes. Since Landsat archives were released for free to the public, there has been a dramatic uptake and use of the data worldwide (Engel-Cox et al., 2004; Popkin, 2018; Wulder and Coops, 2014).
Data access may also be limited by restricted use permissions or lack of public availability, particularly derived data products that are not available in data archives. Many new EO products are generated through one-off analyses that are novel (and therefore seen as worthy of publication) but result in data products that quickly become outdated or that cannot be regenerated due to technical and resource limitations.

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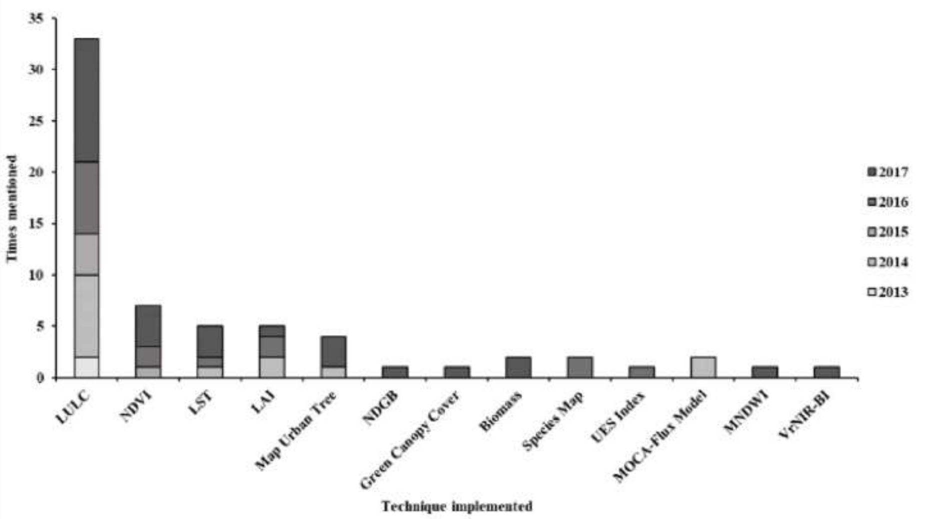

Figure 4. Methods implemented by the authors to infer UES results, separated by year (2013–2017).

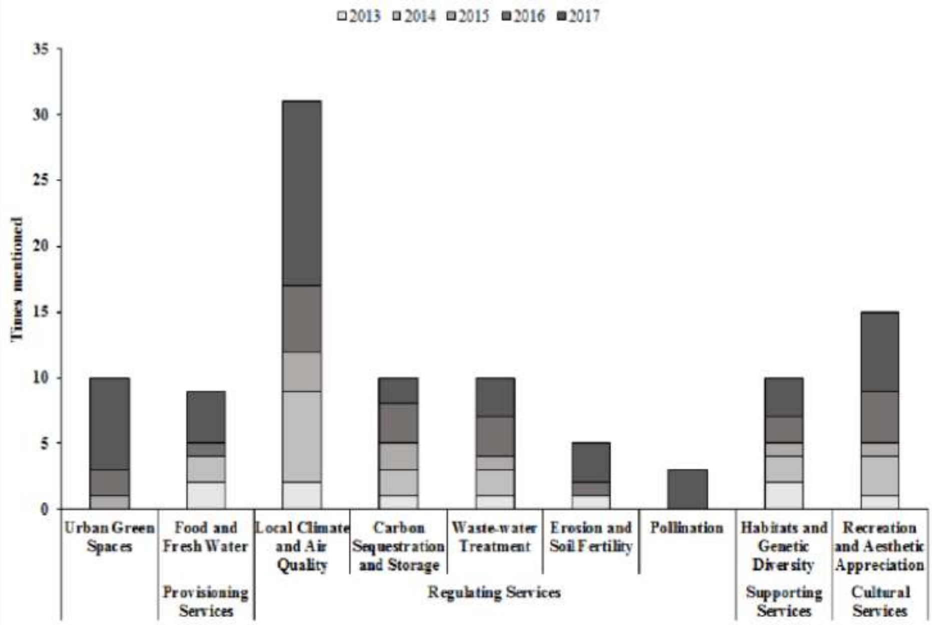

Figure 5. UES identified in the literature reviewed, separated by year (2013–2017).

ES maps can suffer from a lack of spatial and thematic detail to account for fine-scale NBS features that supply ES in cities close to people's demand, therefore Derkzen et al. (2015) propose a method to quantify a bundle of 6 urban ES supplied by different urban greenspace types.

Producing regularly updated EO products requires ongoing funding to operationalize such products and to allow for algorithm and product improvement to meet the continually evolving needs of end users. This does not align with traditional time-limited calls for research innovation, yet in the absence of such funding, the ecosystem services and broader geographic science community loses the value created by initial research outputs.

Geographical scale

Remotely sensed data are inherently suited to provide information on urban vegetation and land cover characteristics, and their change at various geographical scales. However, the higher the resolution required, the more expensive would be RS data needed. In some cases, it would be better to use images provided by drones, but in this case permissions for survey mapping will be required and depends on the local and national / government regulations. Methods can be applied from small to large geographical scales but are linked to the limitations of the data sources.

Temporal scale

Remotely sensed data are inherently suited to provide information on urban vegetation and land cover characteristics, and their change over time, at various temporal scales.

Participatory process

Participatory activities can be combined with remote sensing analysis into an integrated methodology to describe and explain land-cover changes and changes in ES provision caused by them. In doing so, semi-structured interviews, focus group discussions, transect walks and participatory mapping can be used to identify and assess priority ES.

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The six ES indicators derived from the literature are as follows:
·Air purification expressed as g PM10 captured per m2 UGS per year;
·Carbon storage estimate expressed as g PM10 captured per m2 UGS per year;
·Noise reduction expressed as attenuated dB(A) per 100 m2;
·Run-off retention expressed as litres of retention per m2;
·Cooling expressed as a weighted score between 0 and 1 based on UGS type;
·Recreation expressed as an index value m2.

The ES indicators are then applied to high-resolution UGS data within a GIS environment, by multiplying the area of each element by the ES supply per m2 of the respective UGS type (aggregated to neighbourhood and/or district level). Results can be interpreted at individual ES level or at ES bundle level (using cluster analysis) and in terms of an ES supply score in relation to their spatial distribution i.e. radius from the source of nuisance such as air/noise pollution. Synergies and trade-offs between the type and quantity of UGS and ES supply can also be identified e.g. cooling, carbon storage and air purification demonstrate synergies as these are primarily being supplied by the same UGS types. The method can reveal differences between neighbourhoods in terms of amount and type of ES supplied, and can highlight possible ES shortages in neighbourhoods. This can help prioritise locations for NbS interventions and match NbS type to the ES demand. For a more applied approach, direct measurement of ecosystem service provision for different UGS typologies within a city can provide more precision to the analysis, rather than relying on the generic values presented by Derkzen et al. (2015).
A weakness is that this method takes no account of biodiversity. Pedersen-Zari (2019) presents a method for assessing ecosystem service provision and needs that promotes a more urban biodiversity-based approach.

In the creation of models of ecosystem service supply and demand, EO can be used in a variety of ways. Currently, most ES supply models are based on thematic LULC maps, often derived from remotely sensed surface reflectance (Cord et al., 2017). Instead, models could use continuous variables from EO products that are more closely tied to ecosystem functions of interest; for example, Leaf Area Index (LAI) has been incorporated in mechanistic models to approximate air quality regulation (Braun et al., 2018).

Local community members and experts can together discuss which (positive) impact (benefits) the implemented NbS will have on various ES for local, regional, national and international users. This participatory process can help to identify priority ES (e.g. air purification, carbon sequestration, water regulation, soil protection, landscape beauty, biodiversity, etc.).
The approach will reveal if there any strong variations in the valuation of different ES between local people and experts who apply RS techniques, between genders and between different status and income classes in the local communities. Scientific evidence has demonstrated that participatory tools, combined with free-access satellite images and repeat photography are suitable approaches to engage local communities in discussions regarding ES and to map and prioritise ES values (Brown & Donovan, 2014; Brown et al., 2012).

Connection with SDGs

Goal 1
Goal 2
Goal 3
Goal 4
Goal 6
Goal 7
Goal 8
Goal 9
Goal 10
Goal 11
Goal 12
Goal 13
Goal 14
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Goal 16
Goal 17

Applied methods

For more applied and participatory approaches, please see:
Change in ecosystem service provision - Applied/Participatory Review

References

Original reference for indicator

UnaLab

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An emerging trend is the use of EO products for quantifying ecosystem structure and functional traits, such as vegetation height and leaf dry matter content, which are better indicators of biomass production than simple cover-based proxies (Díaz et al., 2007; Lavorel et al., 2011; Ramirez-Reyes et al., 2019). There is also tremendous potential to use EO for calibration and validation of existing or new ecosystem service models. On the demand side, ES models could be created using EO products representing populations and demographics, which represent where and how people benefit from ES (Watson et al., 2019). For instance, EO have recently been used to locate human settlements (Elvidge et al., 2017) and to estimate characteristics including social groups and poverty (Watmough et al., 2019; Wurm and Taubenböck, 2018). Poverty can then be used as a proxy for vulnerable populations that rely more heavily on ecosystem services such as access to fresh water and food production (Ramirez-Reyes et al., 2019).
EO products can also be used to drive ecosystem service models, providing forcing data and informing parameters. Inputs critical to modelling biophysical processes, such as precipitation and elevation, are globally available EO products, and these could be used to complement and extend local gauge data (Pasetto et al., 2018). Parameter coefficients in ES models are typically derived from field studies or literature review, but could be obtained through statistical regressions of in situ information with remotely sensed data (Ayanu et al., 2012). For example, estimates of cloud water interception could be related to and then predicted from canopy density instead of simple absence or presence of forest in cloudy sites (Ponette-González et al., 2015). The use of EO data to quantify how demand for ES varies over space and time is limited, representing a frontier for ES modelling (Ramirez-Reyes et al., 2019).
A Green Infrastructure Spatial Planning (GISP) model has been developed that provides an integrated, stakeholder-driven approach to maximize ecosystem services, revealing trade-offs, synergies and hotspots for future GI/NBS implementation (Meerow & Newell, 2017). This is a GIS-based multi-criteria approach that integrates six ES benefits: 1) stormwater management; 2) social vulnerability; 3) green space; 4) air quality; 5) urban heat island amelioration; and 6) landscape connectivity. Stakeholders then weight priorities to identify hotspots where green infrastructure benefits are needed most (23 expert stakeholders representing government agencies, local and national non-profits, and community development organizations).

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The results can be compared with locations of current GI to plan for future NbS so that it maximises social and ecological resilience, and provides a planning approach for evaluating competing and complementary ecosystem service priorities for a particular landscape. GISP model for Detroit available at: http://umich.maps.arcgis.com/apps/MapSeries/index.html?appid=4b257ce673ed4a178d11b4a267a9967e.
See also Kremer et al. (2016) who apply Spatial Multi-Criteria Analysis (SMCA) to evaluate the distribution of ecosystem services across New York City as a means to identify priority areas for green infrastructure. This uses spatially explicit calculations of physical properties of urban ES, which allows for fine resolution, quantitative evaluation of ecosystem services across the city's landscape.

Greater London Authority now has a 'GI Focus Map' for London that shows where there is more or less need for GI interventions based on different social and environmental (ES) issues that GI can address https://maps.london.gov.uk/green-infrastructure/ it shows which ES issues there is greatest need for in a particular area and so where best to target and focus GI investment, and highlights the issues GI should be designed to address.

The Natural Capital Planning Tool was developed to give local authorities, planners and developers a fit-for-purpose, easy-to-use tool that calculates an ES impact score indicating the direction of change and magnitude of impact http://ncptool.com/. The tool also states the maximum potential scores for each ecosystem service towards which designers can work to achieve the best outcomes in terms of ecosystem services delivery through smart design. Can be used to assess and monitor if a proposed plan or development provides a net-positive impact on ecosystem services and to compare different design options.

The TESSA toolkit is an easy-to-use workbook that leads the user through the steps needed to assess the ecosystem services provided at a particular site http://tessa.tools/. It is built around a comparison of the site in two alternative states, e.g. before and after restoration or conversion, and encourages a high level of stakeholder engagement.

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Petorelli N. et al. (2018) Satellite remote sensing of ecosystem functions: opportunities, challenges and way forward. Remote sensing in ecology and conservation 2 (4), 71-93. doi: 10.1002/rse2.59
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EcoServ-GIS is a toolkit for mapping ecosystem services at a county or regional scale. It uses input GIS/map data to generate fine-scale maps that illustrate human need or demand for ecosystem services as well as the capacity of the natural environment to provide them. There isn't an official website but the latest version (3.3) can be downloaded here: https://drive.google.com/drive/folders/0B_v9QO2jyC4eNIVUbzY1UUstZU0

The National Ecosystem Approach Toolkit http://neat.ecosystemsknowledge.net/ecosystem-mapping-tool.html provides guidance on Ecosystem Mapping.
Natural England have an Ecosystem Services Transfer Toolkit in the form of an Excel spreadsheet with an accompanying User Guide and Quick Start Guide.
http://publications.naturalengland.org.uk/publication/5890643062685696 The spreadsheet can be searched and queried to find evidence of the effects of specific land management actions on ecosystem services provided by urban areas. The toolkit indicates the magnitude of the effect on an ecosystem service and the strength of the supporting evidence. Where available, abstracts from the peer-reviewed papers are included in the toolkit.
ARIES (Artificial Intelligence for Ecosystem Services) is a software technology designed for rapid ES assessment and valuation. Prototypes of the software are available by experienced modellers for case studies and a web-based ARIES will come online for non-technical users http://aries.integratedmodelling.org/
The Ecosystem Knowledge Network's Tool Assessor has a list of the above tools and links to other websites and tool that may assist with ES avaluations https://ecosystemsknowledge.net/tool-assessor-list-of-tools

Mapping and measuring changes in land use and land cover that supply ES can support decision making for using NBS approaches to urban development, for instance by providing information regarding costs and benefits of NBS versus grey infrastructure. If undertaken with comparison to a non-NBS project or no change scenario, it can assist with environmental management decisions and support evidence-based decision-making to improve human well-being and ensure environmental sustainability (Value of Nature to Canadians Study Taskforce, 2017). Consideration needs to be given that synergies and trade-offs between ES can occur (de Groot et al., 2010).

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Wurm M., H. Taubenböck (2018) Detecting social groups from space – assessment of remote sensing-based mapped morphological slums using income data. Remote Sens. Lett., 9, 41-50, 10.1080/2150704X.2017.1384586

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b) References for Indicator based on the NbS projects from the CN database

AMICA (Adaptation and Mitigation – an Integrated Climate Policy Approach)
http://www.amica-climate.net
·remote sensing of urban areas (Wilson et al. 2003) has revealed a patchwork of discrete heat islands related to the distribution and structure of buildings and streets, as well as areas with much lower temperatures associated with parks and green space (Yu & Hien 2006).
Charlesworth S M (2010) A review of the adaptation and mitigation of global climate change using sustainable drainage in cities. Journal of Water and Climate Change, volume 1 (3): 165-180.
http://dx.doi.org/10.2166/wcc.2010.035
Wilson JS, Clay M, Martin E, Stuckey D, Vedder-Risch K. (2003) Evaluating environmental influences of zoning in urban ecosystems with remote sensing. Remote Sensing of Environment. 85, 303–321.
Yu, C., & Hien, W. N. (2006). Thermal benefits of city parks. Energy and buildings, 38(2), 105-120.

Green Surge (Green Infrastructure and Urban Bio- diversity for Sustainable Urban Development and the Green Economy) www.greensurge.eu
One of the project tasks was "Identification, description and quantification of the full range of urban green spaces". In this regard, the research was based on remote sensing results in combination with relevant case studies field observation.
Cvejić R., Eler K., Pintar M., Železnikar Š., Haase D., Kabisch N., Strohbach M. (2015) A typology of urban green spaces, ESS provisioning services and demands. GREEN SURGE project report.
Spronken-Smith, R. A., and Oke, T. R. (1998) The thermal regime of urban parks in two cities with different summer climates. International Journal for Remote Sensing, 19, 2085–2107.
Weeks J.R. (2010). Defining urban areas. In: Remote sensing of urban and suburban areas. Rashed T., Jürgens C. (eds.). Springer, Dordrecht, Heidelberg, London, New York: p. 33-45.

iSCAPE (2016 – 08.2019)(Improving the Smart Control of Air Pollution in Europe) https://www.iscapeproject.eu
·19 case studies on transport and air quality – remote sensing for measuring emissions from cars as they pass by
·Application of remote sensing instruments for the control of carbon emissions and air quality monitoring in European cities in the context of climate change
Pilla F., Broderick B., Gallagher J. et al. (2018) iSCAPE: Improving the Smart Control of Air Pollution in Europe. https://www.researchgate.net/project/iSCAPE-Improving-the-Smart-Control-of-Air-Pollution-in-Europe

IMPRESSIONS (Impacts and risks from high-end scenarios: strategies for innovative solutions)
http://www.impressions-project.eu/
·Mapping land use, ecosystem functions, and ecosystem services using cutting-edge remote sensing and machine learning techniques
·A coordinated effort to integrate and analyse a higher quantity and quality of CO_2 and CH_4 data, from in situ and remote sensing observations encompassing atmosphere, land and oceans.
·Remote sensing of forestry

OpenNESS Operationalisation of Natural Capital (NC) and Ecosystem Services (ES)
http://www.openness-project.eu
·Use of such indicators as vegetation health and functional diversity in applying of remote sensing techniques.
Smith A., Berry P., Harrison P. Sustainable Ecosystem Management. OpenNESS Synthesis Paper.

OPERAs
http://www.operas-project.eu
·Remote sensing algorithms to estimate evapotranspiration are available but often not at sufficient resolution, and do not provide predictions on upcoming water use.
·More experience needs to be gained in combining technologies and scales: direct mapping of soil moisture as done with in-situ, air- or space borne radar, crop water stress mapping by thermal infrared sensors or derived from crop vigour and/or modelling of the crop/soil/atmosphere continuum.

OPPLA (https://oppla.eu) – the platform presents many more studies on the analysis of the change in ES provision within the NbS. Here we selected only a few of them.

·Mapping and assessment of pollutant removal by urban trees in Rome
Mapping (Fusaro et al., 2017) the removal of PM_{10} and ozone by urban trees in Rome, one of the EnRoute city labs, as well as at regional level. They combined high resolution remote sensing data with measured pollutant concentrations to estimate the physical removal of pollutants by trees. A damage cost approach was used to estimate the monetary value associated to pollutant removal. The overall pollution removal accounted for 5123 and 19,074 tonne of PM_{10} and O_3, respectively, with a relative monetary benefit of 161 and 149 Million euro for PM_{10} and O_3, respectively.
Fusaro et al. (2017) Mapping and Assessment of PM_{10} and O_3Removal by Woody Vegetation at Urban and Regional Level. Remote Sensing 2017, 9(8), 791; doi:10.3390/rs9080791
·Growing with green ambitions. Case study of Leipzig
An important lesson is that mapping should be combined with in situ green space monitoring of, for example, vegetation biomass. This would add value to remote sensing data and improve the capacity to assess ecosystem services provided by urban green space such as carbon dioxide removal. In addition, data were only available for 2012. An account based on time series of land cover and land use would help city planners to better understand to what extent urban green infrastructure is under pressure. Limitations of the mapping approach: Mapping accuracy: The UFZ team used a remote sensing-based approach utilizing digital ortho photos. All remote sensing techniques map from above, and overlaid featured cannot be detected. As a consequence, GI features at ground level such as lawn/meadow and blue structures may be underestimated if covered by large trees and/or dominant shrubland.
Banzhaf, E., Arndt, T., Ladiges, J. (2018a): Potentials of urban brownfields for improving the quality of urban space. In: Kabisch, S., Koch, F., Gawel, E., Haase, A., Knapp, S., Krellenberg, K., Nivala, J., Zehnsdorf, A. (eds.) Urban transformations - Sustainable urban development through resource efficiency, quality of life and resilience. Future City 10 Springer International Publishing, Cham, pp. 221 – 232. https://doi.org/10.1080/02513625.2018.1487643.
Banzhaf, E., Kollai, H., Kindler, A. (2018b). Mapping urban grey and green structures for liveable cities using a 3D enhanced OBIA approach and vital statistics. Geocarto International. DOI: 10.1080/10106049.2018.1524514.
Banzhaf, E., Kabisch, S., Knapp, S., Rink, D., Wolff, M., Kindler, A. (2017): Integrated research on land use changes in the face of urban transformations – An analytic framework for further studies. Land Use Policy, 60, 403-407.

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PLUREL (Peri-urban Land Use Relationships - Strategies and Sustainability Assessment Tools for Urban-Rural Linkages)
www.plurel.net
·Based on the remote sensing and GIS, geo-referenced information was achived and mapping of environmental parameters (base data important for urban climate, access to and distribution of open space, calculation of sealed surfaces) was conducted.
Herold, M., Hemphill J., Dietzel, C. & Clarke, K.C. (2005): Remote Sensing Derived Mapping to Support Urban Growth Theory. Proceedings URS2005 conference, Phoenix, Arizona, March 2005.

URBACT (European exchange and learning programme promoting sustainable urban development)
https://urbact.eu
·remote sensing (production of high spatial resolution, including the urban atlas, built-up areas, and air pollution) and so-called big data, a growing source of detailed data can now be used to compare and benchmark cities.

URBES (Urban Biodiversity and Ecosystem Services)
https://www.biodiversa.org/121
·Remote Sensing of Urban Ecology (EO sensors, modelling algorithms)
·spatial and remote sensing data analyses, mostly engaged in WP2: Case study conditions and co-design workshops for identifying local policy solutions and WP5: Resilient supply of ecosystem services.
Larondelle N, Haase D, Kabisch N (2014) Diversity of ecosystem services provisioning in European cities. Global Environmental Change 26, 119-129.
Larondelle N, Hamstead Z A, Kremer P, Haase D, McPhearson T (2014) Comparing urban structure-function relationships across cities: Testing a new general urban structure classification in Berlin and New York. Applied Geography 53, 427-437.
Andersson E, McPherson T, Kremer P, Frantzeskaki N, Gomez-Baggethun E, Haase D, Tuvendal M, Wurster D (2015) Scale and Context Dependence of Ecosystem Service Providing Units. Ecosystem Services 12, 157-164.
Baró F, Frantzeskaki N, Gómez-Baggethun E, Haase D (2015) Assessing the match between local supply and demand of urban ecosystem services in five European cities. Ecological Indicators 55, 146-158.
Hamstead Z A, Kremer P, Larondelle N, McPhearson T, Haase D (2016) Classification of the heterogeneous structure of urban landscapes (STURLA) as an indicator of landscape function applied to surface temperature in New York City. Ecological Indicators 70, 574-585.
Baró F, Palomo I, Zulian G, Vizcaino P, Haase D, Gómez-Baggethun E (2016) Mapping ecosystem service capacity, flow and demand for landscape and urban planning: a case study in the Barcelona metropolitan region. Land Use Policy 57, 405-417 https://doi.org/j.landusepol.2016.06.006.

EKLIPSE
·digital mapping (e.g., remote sensing, GIS) of the potential for NBS and status of implementation (Giannico et al., 2016; Gómez-Baggethun and Barton, 2013).
Giannico, V., Lafortezza, R., John, R., Sanesi, G., Pesola, L., Chen, J. (2016) Estimating Stand Volume and Above-Ground Biomass of Urban Forests Using LiDAR. Remote Sens. 8, 339. doi:10.3390/rs8040339
Gómez-Baggethun, E., Barton, D.N. (2013) Classifying and valuing ecosystem services for urban planning. Ecol. Econ. 86, 235–245. doi:10.1016/j.ecolecon.2012.08.019
Raymond et al. (2016) An impact evaluation framework to guide the evaluation of nature-based solutions projects.

ENABLE (Enabling Green and Blue Infrastructure Potential in Complex Social-Ecological Regions)
http://projectenable.eu/partners/
·spatial and remote sensing data analyses, mostly engaged in WP2: Case study conditions and co-design workshops for identifying local policy solutions and WP5: Resilient supply of ecosystem services.

Nature4Cities* (2017 – ongoing)
·identifying the needs for observation and modeling of coastal areas and examination of the current contributions of remote sensing (space and airborne).
International Space Science Institute (ISSI) (2017) Monitoring the evolution of coastal zones under various forcing factors using space-based observing systems. White Paper on Observing and Modeling Coastal Areas.
Gonçalves, J. A., et al. (2015). UAV photogrammetry for topographic monitoring of coastal areas. ISPRS Journal of Photogrammetry and Remote Sensing, 104, pp 101-111, DOI: 10.1016/j.isprsjprs.2015.02.009.
Long, N., et al. (2016). Monitoring the topography of a dynamic tidal inlet using UAV imagery. Remote Sensing, 8(5), pp. 387, DOI:10.3390/rs8050387.
Taramelli, A., et al. (2014). Modeling uncertainty in estuarine system by means of combined approach of optical and radar remote sensing. Coastal Engineering, 87, pp. 77-96, DOI: 10.1016/j.coastaleng.2013.11.001.
Taramelli, A., et al. (2015a). Remote Sensing Solutions to Monitor Biotic and Abiotic Dynamics in Coastal Ecosystems. Coastal Zones. Chap.8, pp. 125-135, DOI: 10.1016/B978-0-12-802748- 6.00009-7.

Naturvation (2017 – ongoing)
From the NATURVATION database on the value and benefit assessment methods for urban NBS:
·a model based on remote sensing – MODIS NPP (Input data: allometric equations, net photosynthesis (PSNnet) data of 2010 provided by the MODIS, average growths in diameter of specific tree species, trees diameter at breast high), output data: Net primary productivity kg C per tree and year
·classification via remote sensing to determine tree species, LIDAR data to determine size of tree and allomeric equations to model above ground tree biomass (Input data: land cover (tree canopy %, spatial distribution of tree species), tree crown height, stem diameter (dbh), tree height, crown diameter & field surveys for tree data (# trees, tree location, stem diameter) (for calibration and validation); output data: above-ground carbon storage (biomass) (tC/ha, MtC, kg)
·deterministic model based on allomeric equations, LIDAR data and remote sensing to estimate tree carbon sequestration over the city (input data: remote sensing data, urban structure type data (e.g. green space, streets, low buildings with yards etc.), tree characteristics (tree height, crown width, crown base height, diameter at breast height (DBH))(from models); output data: aboveground carbon storage (kg C/building type, tC/ha, total tC)
·remote sensing together with distributed lag nonlinear models used to assess the risk of death due to heat as an effect of distance to green and blue space (input data: Metrological, NVDI, distance to green and blue infrastructure)
·modeling and detecting heat islands at different scales depending on a kernel smoothing and using remote sensing. Greenness and heat islands showed high correlation (input data: ASTER remote sensing images; output data: temperature in Kelvin).
·modeling the needs of green space for several ecosystem services, using GIS information, remote sensing and Pareto optimization (input data: GIS raster layers with information about green spaces; output data: air temperature.

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·remote Sensing and LIDAR data used to estimate vegetation volume and NVDI. A 3D NVDI as constructed by multiplying the NVDI with the vegetation volume. Measured temperatures was modelled using Maximum Likelihood as a function of NVDI, 3D NVDI, distance to green / blue areas and built-area volume (input data: Remote images (1 m resolution), LIDAR data, temperature measurements; output data: temperature).
·a set of modelled GIS and remote sensing parameters used to model temperature as an effect of greenness, aerosols, buildings. Likely the method needs to be calibrated for each city/town separately (input data: GIS data of buildings, Landsat data; NVDI & AH CHRIS/PROBA satellite images, ASTER image data; output data: temperature).
·a framework using satellite images, remote sensing and statistical modelling to compute accessibility of parks and green space dependent on economic and population data (input data: percentage of green cover in a city, population density, GDP per capita, City land area, Per capita green space provision, Aggregation index; output data: Effects of and between the different types of in data)
·deterministic model, using remote sensing of greenness as well as surface sealing to estimate recreation supply (input data: Remote sensing data, NVDI & surface sealing; output data: Spatially normalized minimum of green space provision per person suggested by the city administration (m^2 per Block; m^2/m^2)
·remote sensing & satellite imagery and digital orthophotos together with Geographic Information Systems (GIS) used to develop a digital elevation model and a digital surface model (input data: qualitative and GIS data; output data: quality of life, tree coverage; spending time in city parks, gardens, and open spaces)
·remote sensing for ES matrix – the ES matrix approach is an easy-to-apply concept based on a matrix linking spatially explicit biophysical landscape units to ecological integrity, ecosystem service supply and demand. By linking land cover information from, e.g. remote sensing, land survey and GIS with data from monitoring, statistics, ecosystem service supply and demand can be assessed and transferred to different spatial and temporal scales. The ES matrix approach is a quick and simple way to get an overall spatially-explicit picture of the ES in case study areas (input data: land cover and land use data (GIS) (incl. Additional biotic and abiotica information (e.g. land use intensity, soil quality, climate data); output data: ES provision capacity per landuse class (0-5 values & biophyscial units).
Banzhaf, E., Kollai, H. (2015) Monitoring the Urban Tree Cover for Urban Ecosystem Services-The Case of Leipzig, Germany. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 40(7), 301.
Burkhard B. F., Kroll, F. Müller, W. (2009) Wind horst Landscapes' capacities to provide ecosystem services – a concept for land-cover based assessments. Landscape Online, 15, 1-22.
Davis et al. (2016) Combined vegetation volume and "greenness" affect urban air temperature, Applied Geography, 71, 106–114
Karteris, M., Theodoridou, I., Mallini, G., Tsiros, E., and Karteris A. (2016) Towards a green sustainable strategy for Mediterranean cities: Assessing the benefits of large-scale green roofs implementation in Thessaloniki, Northern Greece, using environmental modelling, GIS and very high spatial resolution remote sensing data, Renewable and Sustainable Energy Reviews, 58, 510-525
Larondelle et al. (2016) Balancing demand and supply of multiple urban ecosystem services on different spatial scales, Ecosystem Services, 22, Part A, 18-31
Neema et al. (2013) Multitype Green-Space Modeling for Urban Planning Using GA and GIS, Environment and Planning B: Planning and Design, 40, 447-473
Schreyer et al. (2014) Using Airborne LiDAR and QuickBird Data for Modelling Urban Tree Carbon Storage and Its Distribution-A Case Study of Berlin, Remote Sensing, 6(11), 10636-10655
Tigges et al. (2017) Modeling above-ground carbon storage: a remote sensing approach to derive individual tree species information in urban settings, Urban Ecosystems, 20(1), 91-111
Weng et al. (2011) Modeling Urban Heat Islands and Their Relationship With Impervious Surface and Vegetation Abundance by Using ASTER Images. IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, 49(10), 4080-4089

Think Nature platform
www.platform.think-nature.eu
·remote sensing from urban gardens in Barcelona, Spain, including municipal 'allotment gardens' and 'civic gardens' emerging from bottom-up initiatives (identifying different urban gardens types regarding the ES values they provide, and specific garden characteristics including biophysical garden properties etc.
Langemeyer J., Camps-Calvet M., Calvet-Mir L., Barthel S., Gómez-Baggethun E. 2018. Stewardship of urban ecosystem services: understanding the value(s) of urban gardens in Barcelona. Landscape and Urban Planning. https://doi.org/10.1016/j.landurbplan.2017.09.013

UnaLab
·technical handbook takes the Key performance indicators as basis for detailed evaluation of NBS. One of them is leaf area index which can be measured using remote sensing.
https://www.unalab.eu/

URBAN Green-UP* (2017 – ongoing)
As based on Technical report by the Joint Research Centre (JRC), the European Commission's science and knowledge service and references below:
·Mapping the removal of PM10 and ozone by urban trees (Rome, one of the EnRoute city labs) as well as at regional level. They combined high resolution remote sensing data with measured pollutant concentrations to estimate the physical removal of pollutants by trees. A damage cost approach was used to estimate the monetary value associated to pollutant removal. The overall pollution removal accounted for 5123 and 19,074 t of PM10 and O3, respectively, with a relative monetary benefit of 161 and 149 Million euro for PM10 and O3, respectively.
·mapping and assessing the contribution of urban vegetation to microclimate regulation (a) Deriving a map of Land Surface Temperature based on Landsat 8 Data, using a methodology based on (Du et al. 2015); b) Aggregating Land types to assess the changes in average temperature (see Figure 12), c) Estimate the Influence of green cover on surface temperature index (Under development)
·mapping urban temperature using remote sensing information (split window algorithm), using the model for assessing urban temperature and the indicator for microclimate regulation
Du C, Ren H, Qin Q, Meng J, Zhao S. (2015) A Practical Split-Window Algorithm for Estimating Land Surface Temperature from Landsat 8 Data. Remote Sens. 7:
Fusaro L, Marando F, Sebastiani A, Capotorti G, Blasi C, Copiz R, Congedo L, Munafò M, Ciancarella L, Manes F. (2017) Mapping and Assessment of PM10 and O3 Removal by Woody Vegetation at Urban and Regional Level. Remote Sens. 9:
Wegmann M, Leutner BF, Metz M, Neteler M, Dech S, Rocchini D. (2017) A grass GIS package for semi- automatic spatial pattern analysis of remotely sensed land cover data. Methods Ecol Evol. doi: 10.1111/2041-210X.12827
Zulian, G., Thijssen, M., Günther, S. Maes, J. (2018) Enhancing Resilience Of Urban Ecosystems through Green Infrastructure (EnRoute). Progress report, EUR 29048 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-79-77697-7, doi:10.2760/958542, JRC110402)

ESMERALDA - Enhancing ecosystem services mapping for policy and decision making
www.esmeralda-project.eu
use of different data sources which rely on biophysical value in physical units, but this value needs further interpretation, certain assumptions, or data processing before it can be used. They can be based on remote sensing and Earth observation derivatives such as land cover, Normalised Difference Vegetation Index (NDVI), surface temperature, or soil moisture which are extracted from the original sources by specific procedures.
Different case studies. As a selected study – the Northern German case study area Bornhöved Lakes District, several provisioning ecosystem services were assessed with the direct measuring method based on a remote sensing approach. The aim of the study was to detect temporal changes in the supply area of the provisioning ecosystem services crops, fodder and biomass for energy.
Vihervaara P, Mononen L, Nedkov S, Viinikka A (2018) Biophysical Mapping and Assessment Methods for Ecosystem Services. Deliverable D3.3. Horizon 2020 ESMERALDA Project, Grant agreement No. 642007.

CONNECTING NATURE
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ENVIRONMENTAL INDICATORS - CORE

CONNECTING NATURE

Community garden area per capita and in a defined distance

Applied/Participatory Review

STUART CONNOP (1), CAROLINE NASH (1), JACK ELLIOT (1), DAGMAR HAASE (2), DIANA DUSHKOVA (2)

(1) University of East London, United Kingdom
(2) Humboldt-Universität zu Berlin, Germany

Description

A measure of per capita garden area per target distance - public community gardens provide active interaction with nature and opportunities for social cohesion.

Methodology

Measuring community gardens as part of the greenspace network in cities gives an indicator of a range of factors such as: accessible greenspace provision and preservation, diversity of land use for humans and biodiversity, sustainable use of vacant land, climate regulation (cooling, stormwater, reduced GHG emissions associated with food transportation), food security, physical activity, access to healthy food/fruit and vegetable consumption, community cohesion and empowerment.

Level of expertise

Some mapping/GIS expertise is likely to be needed.

Data collection

Cost

Some map datasets and satellite imagery are freely available online, more comprehensive data needed for network-based measures potentially can involve a licence fee. Would be costs associated with acquiring GIS software if not already available, and GIS specialists.

Effort

The level of effort involved would be dependent on the amount of data already recorded by the city on community garden distribution, and the expertise available in terms of GIS.

Data availability

Some GS map data is freely available for mapping distance, aerial data is increasingly available but the quality and resolution can still be variable.

Geographical scale

Typically used at city-scale, but other scales are possible.

Temporal scale

Can provide a snapshot or a temporal view of change over time if adequate historical data available.

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Scientific solid evidence

Robustness of evidence will be biased by how detailed existing data is on CGs in a city and accuracy of census data. Similarly, the accuracy of distance to CG will vary based on the distance measure used. They can however represent a useful indicator basis for urban planning.

Extended methodology

Ultimately community gardens deliver a social function. Mapping exercises can also be used to identify areas where future community garden (CG) projects should be targeted (i.e. need for CGs).

Metrics will largely concern identification of CGs as part of the city's greenspace provision and then quantification in relation to population census data and an assessment of accessibility in relation to proximity measures.

Identification of CGs within a city will involve data gathering from land use plans on location, extent and characteristics, analysing official websites to identify additional CGs not included in planning documents, interrogating available satellite imagery provided on regional geoportals, and ground truthing by observation surveys (Senes et al., 2016). The collated data can then be entered into a GIS database for digitisation. From this, it would be possible to generate metrics regarding average CG area within the city (m2), and distance from urban centres by overlaying a land use map and mapping buffer areas of 330 and 660 m (which correspond to a walking distance of 5 and 10 min respectively at a speed of 4km/h) (as outlined in Senes et al, 2016).

Alternative metrics that have been calculated in a GIS environment include: measuring the district area (ha) and the area of CGs (ha) and calculating a CG area proportion for the city as a % of the overall district area (Speak et al., 2015). Measuring the proportion of households within 0.25 miles of a CG, or a measure of the acreage used for CG per 1,000 residents as measures of accessibility and density (Jakubowski & Frumkin, 2010).

Participatory process

The project Incredible Edible Lambeth demonstrates it may be possible to validate CG distribution using a PPGIS-type citizen science exercise.

Earth observation/remote sensing/modelling

No earth observation, remote sensing or modelling approaches were identified during the review.

Connection with SDGs

Goal 1	Goal 7	Goal 13
Goal 2	Goal 8	Goal 14
Goal 3	Goal 9	Goal 15
Goal 4	Goal 10	Goal 16
Goal 6	Goal 11	Goal 17

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Original reference for indicator

SDG11; Kabisch et al., 2016; Eklipse

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Metrics outlined in the ‘accessibility of greenspaces’ indicator review can also be applied here to provide a ‘defined distance’ measure for this indicator, for instance La Rosa’s ‘simple distance indicators’ which measures the Euclidean distance or Network distance to a greenspace, in this case CGs, at a fixed threshold distance of 300 m or 600 m. Within GIS, the total population present (taken from census data) within the considered distance thresholds can be calculated in relation to each CG.

Senes et al (2016) also provide a methodology for identifying possible sites suitable for CG projects. They identify areas potentially suitable for new CGs on the basis of the following criteria: i) proximity to residential road network, because the accessibility to the MCGs is a fundamental requirement for a public service (considers only the residential road network, usually not characterized by heavy traffic); ii) compatible land-use, in order to exclude areas with a land-use that doesn’t allow a future transformation to CG; iii) identify areas with soils with land capability class 1 and 2 and exclude from the possible conversion into CG to allow the preservation of agriculture. The data is mapped in a GIS environment to generate a plan of potentially suitable and available areas for new CGs.

‘Incredible Edible Lambeth’ (IEL) have created an online map of community garden projects in the borough https://www.incredibleediblelambeth.org/map/ which can be updated by citizens who become a member (for free) online. As well as connecting citizens to CGs in the borough, this also provides a public participation mechanism for generating a comprehensive map of CGs in an area.

Mapping community garden accessibility in these ways can be used to:

- Identify deficits and inequalities in relation to community garden access;
- Assess changes in access in relation to new projects/sites;
- Inform strategic planning decisions in relation to community garden provision;
- Assess different types of accessibility;
- Set targets in relation to community garden provision and monitor progress towards targets.

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ENVIRONMENTAL INDICATORS - FEATURE

CONNECTING NATURE

Carbon storage OR carbon sequestration in vegetation/soil

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Description

Carbon storage refers to the quantity of carbon locked away in vegetation or soil. Carbon sequestration is the process of capture and long-term storage of carbon. The metrics associated with these processes represent a measure of the carbon removed/stored by nature-based solutions in soil and vegetation per unit area/unit time or tonnes stored in vegetation/soil. This can be measured as a basic static volume stored, or a more fluid measure in relation to ongoing carbon balance and maintenance costs. Cities are typically net carbon sources (Velasco and Roth 2010), but evidence has been generated that this pattern could be reversed, at least during the growing season, if urban areas are designed sustainably and are heavily vegetated (Crawford et al. 2011).

Methodology

Typically, metrics associated with nature-based solutions are based on carbon storage in above ground vegetation, usually trees.

Level of expertise

For tools such as i-Tree a basic level of expertise is required for using the software. Dependent upon the i-Tree resource utilised, field skills in surveying and measuring vegetation may also be required. For more detailed direct measures, skills in soil and vegetation sampling and analysis are required. Similarly eddy covariance monitoring requires skills in equipment use and data analysis. For remote sensing, the selection of method used to interpret images is generally determined by the level of the analyst's expertise and familiarity with the particular urban landscape and the land cover area being analysed. For example, if the analyst has sufficient understanding of sophisticated remote sensing techniques and good knowledge of the sample area, a supervised classification technique and/or hierarchical decision tree classifier is recommended, using tools similar to Knowledge Engineer and Knowledge Classifier. For an area with no pre-existing land cover information the analyst may initiate the analysis using the unsupervised classification technique in order to see the spectrally similar and spatially contiguous spatial objects or phenomena. In general, unsupervised classification, supervised classification techniques and hierarchical decision trees and soil classification will be complementary to determine the classes of land cover in the study area and what issues regarding the carbon storage can be evaluated from them.

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Scientific solid evidence

Robustness of evidence depends upon the precision and accuracy of the method adopted. Precision of automated tools like i-Tree can be increased through greater sample sizes in terms of ground-truthing. Similarly, for soil carbon storage, greater numbers of soil core analyses can increase the accuracy compared to automated models. Type of soils on which calculations are being made can also affect the precision of results, for example CARBINE (Forest Research 2019) has a greater level of accuracy for calculations on mineral soils than organic soils.

For greatest accuracy of change over time, eddy covariance monitoring techniques are necessary. In using remote sensing for assessment of carbon storage/sequestration in soil and vegetation, it was observed (Angelopoulou et al., 2019; Goetz et al., 2009; Jeyanny et al., 2014; Raciti et al.; 2014) that prediction accuracy reduces from Unmanned Aerial Systems (UASs) to satellite platforms, though advances in machine learning techniques could further assist in the generation of better calibration models.

There are some challenges concerning atmospheric, radiometric and geometric corrections, vegetation cover, soil moisture and roughness that still need to be addressed.

Remote sensing is widely used to collect information regarding vegetation structure as well as to monitor and map vegetation biomass and productivity on large scales (Main-Knorn et al., 2011) by measuring the spectral reflectance of the vegetation (Lu, 2006). However, optical remote sensing does not directly assess above-ground urban forest biomass, and radiometry is sensitive to vegetation structure (i.e., crown size and tree density), texture, and shadow, which are correlated with above-ground biomass, particularly in the infrared bands.

Remote sensing data are now considered to be the most reliable method of estimating spatial biomass in different regions over large areas. Nonetheless, remote sensing as a desk study cannot capture the entire picture and requires some level of ground-truthing for optimum accuracy (e.g. verification in the field, field survey, participatory mapping).

Data collection

Cost

Use of basic automated tools such as i-Tree Canopy can be very low cost and just involve the time required to input and analyse the data. Costs for other i-Tree resources can become more expensive the greater the volume of sample sites and complexity of information required. Soil or vegetation sampling and analysis can be relatively cheap for small sites/sample numbers. Costs can also be reduced through the use of citizen science volunteers.

Alternatively/additionally, the cost of such an approach can be reduced by partnering local universities to carry out laboratory analyses as student research projects. Equipment for eddy covariance gas analysers can be expensive. Again, cost can be reduced through academic collaborations. In comparison to conventional methods for monitoring of carbon storage in soil and vegetation, which can be time consuming and costly, remote sensing techniques are evaluated as rapid, cost-effective and non-destructive, for the estimation of different soil properties, including soil organic carbon and carbon stored in biomass (Angelopoulou et al., 2019; Goetz et al., 2009; Jeyanny et al., 2011; Raciti et al., 2014). Thus, high resolution remote sensing can provide a cost-efficient methodology to supply sufficient data on local differences and temporal changes.

Effort

Automated tools such as i-Tree Canopy are relatively low effort with reports generated automatically after minimal data input. More complex tools such as i-Tree Eco require more involved data generation and input. Direct vegetation and soil analysis require fieldwork for sample planning and collection. Analysis can be relatively low effort if commercial analytical laboratories are used. Eddy covariance data gathering can be relatively low effort if automated on-site equipment is used.

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Extended methodology

This involves the estimation of annual carbon sequestration on individual trees, at a local scale, stand scale (Forestry Research 2019), or at the scale of the entire city. Calculations are made through the application of allometric equations, relationships between biomass (carbon stored) and physical dimensions (e.g., diameter and height) of trees, and predictive growth models applied to tree inventories (e.g., McPherson, Xiao, & Aguaron, 2013). Several tools exist for basic calculation of carbon dioxide storage estimates for vegetation in urban areas. These include i-Tree Eco (2019), i-Tree Canopy (2019), i-Tree Streets (2019), CUFR Tree Crown Carbon Calculator (CTCC) (2019), Urban General Equations (UGEs) (Schreuder et al. 2003). Based on their evolution from forestry calculation models, and the complexities of transferring these to urban woodlands and street trees, results from these tools can be varied. A comparative review of these in Sacramento found UGEs to produce the most conservative results (Agauron and McPherson 2012), however i-Tree tools appear to be becoming more commonly used for the many countries where they can be applied (iTree 2019).

The scale of analysis is one aspect that has been identified as bringing in variability in relation to the results of these various tools, with many broad-scale methods failing to capture the fine-scale variation associated with mosaic urban landcover (Davies et al. 2013). Capturing fine-scale data can present an opportunity for community participation in relation to ground-truthing vegetation. An example of such an approach was the London i-Tree project (Rogers et al. 2015). For this, i-Tree Eco was used to calculate a range of values in relation to the ecosystem service benefits of London's urban trees, including carbon storage. London-wide data was calculated based on a series of sample plots across the city. The majority of these plots were surveyed by volunteers trained as part of the programme.

Whilst the approach of focusing on above ground vegetation is relatively straightforward and can generate high-profile impactful data, one shortfall is that these methods do not take into account the complex carbon balance in urban ecosystems (Velasco et al. 2016).

For this installation, data analysis and equipment maintenance are the only inputs required. The only onerous aspect can be the volume of data generated. Remote sensing technology has been applied to biomass assessment in many studies because it can obtain forest information over large areas at a reasonable cost and with acceptable accuracy based on repetitive data collection with minimal effort (Lu, 2006).

Data availability

Generates new data. If using automated methods, baseline data prior to intervention may be possible from historical aerial photos. Many tools use landuse data, a data form that is typically available for cities. Base maps can be developed from different sources of satellite images depending on the best resolution available and lowest cloud coverage (e.g. Landsat). However, cloud-free coverage of the study area can be a limitation with such data and in some cases, cloud-free data during a particular time period may not be available for specific locations.

Geographical scale

Direct sampling tends to be focused on a component or site scale, but can be extended to a city scale if enough eddy covariance gas analysers are available. Analysis using automated tools can be carried out across all scales from individual street trees to entire urban, peri-urban and landscape scales. While remote sensing analysis provides a quick and precise assessment of the vegetation cover mostly on a large scale, it has more difficulty capturing locally driven changes and small-scale deforestation or changes in vegetation cover. In this regard, a combination of social science and remote sensing approaches can provide a more complete picture of the situation on the ground (e.g. participatory mapping described above).

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In order to get a more holistic measure of a nature-based solution's contribution to carbon sequestration, particularly a newly created nature-based solution that changes/impacts the underlying substrates, consideration should also be given to the below ground storage volumes, and emissions from soil respiration, and greenery management (Baldocchi 2008; Velasco et al. 2016).

Similarly to above ground carbon storage, tools exist for calculation of below ground carbon stores in relation to landuse type, for example InVEST (Sharp et al. 2018). Calculations have been made of typical carbon storage volumes per unit area for a variety of urban land use and land cover types (Pouyat et al. 2006), alternatively, soil sampling and analysis can be carried out to compare local patterns (Edmondson et al. 2014). However, as these models and methods tend to simplify the carbon cycle to enable ease of use, they can also lead to important limitations. Perhaps most significant being the tendency to represent landscapes as static over time, not gaining or losing carbon through soil respiration.

Soil respiration in relation to carbon is carbon efflux, typically driven by autotrophic respiration of plant roots and associated microorganisms, and heterotrophic respiration via microbial decomposition of soil organic matter (Hansen et al. 2000). The most commonly applied method for quantifying these carbon balances is the use of eddy covariance techniques (Velasco et al. 2016). These can be implemented to obtain ecosystem-scale measurements of CO2 fluxes (Crawford et al. 2011) and methane fluxes (Le Mer and Roger 2001). A key finding from these studies with particular relevance to urban ecosystems and nature-based solution implementation is that recently disturbed ecosystems tend to lose carbon, unlike stable ecosystems such as old-growth forests and undisturbed peat bogs that usually act as carbon sinks (Baldocchi 2008; Luyssaert et al. 2008; Lindsay 2010; Yu et al. 2011; Stephenson et al. 2014). As disturbance of soil through the creation and management of nature-based solutions can have a substantial effect on soil respiration (Velasco et al. 2016), it should also be considered in calculations of carbon storage/sequestration. These are not typically considered as part of carbon/storage sequestration indicators though, as they capture a more holistic but complex evaluation of urban carbon balances.

Temporal scale

Monitoring methods can be adopted for short-term snapshots associated with current status and impacts immediately following nature-based solution implementation (or predicted impacts as part of planning). However, longer-term in-situ monitoring is generally more effective in terms of capturing a more comprehensive overview of how the carbon storage of the nature-based solution changes over time, both in terms of accumulation by maturing vegetation and the carbon balance of the soils. For remote sensing approaches, there is a limitation with time series regarding the availability of reliable satellite imagery for a given period. The multi-temporal data are also affected by seasonal factors. Participatory monitoring of land use changes, combined with remote sensing, could quickly verify the problems related to carbon storage and sequestration, assess the effectiveness of related interventions and provide local communities with incentivised alternative livelihoods (Beaudoin et al., 2016).

Participatory process

Participatory processes are possible, particularly in relation to gathering samples (soil/vegetation) or gathering data ground-truthing vegetation for feeding into automated tools. Examples of the type of data the citizen science can generate include: number of trees and species of trees present; size of the trees (height, canopy spread and diameter of trunk); tree health. It is essential to increase awareness on the contribution of urban green space to carbon storage and to strengthen stakeholder participation and institutional capacities engaged in the management of urban green spaces.

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One example of the risk of considering urban landuse types as being stable carbon stores over time is the potential underestimation of the value of brownfield (post-industrial) sites to urban carbon balance. Recent research has indicated that the high levels of calcium on such sites from demolition wastes (e.g. concrete dust and lime) could play a key role in urban carbon sequestration (Goddard 2016). This is due to rapid weathering of calcium silicate and hydroxide minerals derived from the demolition materials, which release calcium that combines with CO_2, precipitating as calcite - a long-term carbon store (Washbourne et al, 2015). Initial results have indicated potential sequestration rates of global significance. Such understanding opens the possibility of engineering carbon sequestration into urban nature-based solutions, and has implications in relation to how brownfield sites are managed (Goddard 2016).
Another example of how urban manure-based solutions can be engineered to offset any increased carbon loss caused by disturbance of soils is the potential to incorporate cradle-to cradle technology in nature-based solutions design to act as a source of carbon storage. The application of urban waste, for example through the recycling of waste materials into aggregates (Li et al. 2007; Molineux et al. 2016), offers a sustainable means to increase urban soil carbon reserves (Brown et al. 2012). If such techniques are incorporated into nature-based solution delivery, they can also be included in nature-based solution urban soil carbon calculations.
In addition to urban terrestrial habitats, urban wetland areas also need consideration. As with terrestrial habitats, basic calculations of total stored carbon can be carried out on above ground vegetation (Owers et al. 2018) and soils (Xiong et al. 2018). However, eddy covariance measuring stations are required to quantify the carbon balance of these systems in terms of being carbon sinks or sources (Mitsch and Mander 2018).
Since conventional methods for monitoring of carbon storage in soil and vegetation can be time consuming and costly (Angelopoulou et al., 2019; Omran, 2017), researchers have investigated implementation of alternative approaches that can be applied in different climate conditions, vegetation zones and soil types.

Opportunities for participatory processes include combining community-based participatory carbon measurement and monitoring in the field with satellite remote sensing and GIS approached. Complementing remote sensing analysis using participatory mapping can help provide information for an initial vegetation cover assessment, gain better understanding of how local land use might affect changes, and provide a way to engage local communities.

Earth observation/remote sensing/modelling

The Feature indicator reviews are combined for applied metrics and earth observation/remote sensing/modelling approaches.

Connection with SDGs

Goal 1	Goal 9	Goal 13
Goal 3	Goal 10	Goal 15
Goal 4	Goal 11	Goal 16
Goal 6	Goal 12	Goal 17
Goal 8		

References

Original reference for indicator

Eklipse; Davies et al., 2011; Pataki et al., 2006

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Current trends are oriented towards the evaluation of Remote Sensing (RS) techniques as rapid, cost-effective and non-destructive, for the estimation of different soil properties, including carbon storage (Xu et al., 2017). Remote sensing techniques in the Visible-Near Infrared–Shortwave Infrared (VNIR–SWIR, 400–2500 nm) region could provide a more direct, cost-effective and rapid method to estimate important indicators for soil and vegetation monitoring purposes. Soil reflectance spectroscopy has been applied in various domains apart from laboratory conditions, e.g., sensors mounted on satellites, aircrafts and Unmanned Aerial Systems (Angelopoulou et al., 2019).

Remote sensing (Landsat Thematic Mapper (TM) image) can be used for land-cover classification and development of a total above-ground biomass estimation model. The relationships between above-ground biomass and remote sensing data (e.g., single TM band, various vegetation indices (VIs), and elevation) can be investigated using a multiple linear regression analysis. The results of the total carbon stock assessments from the ground data can reveal sites with the highest and lowest values.

Increasing resolution has enabled small-sized and fragmented vegetation analysis with high amounts of detail at multiple scales using satellite imagery like QuickBird (< 1 m pixel size), ultra-high resolution of airborne digital sensors (e.g., ADS40, < 10 cm pixel size) or recent developments and sensors attached to low-altitude unmanned aerial vehicles (Feng et al., 2015v). This has updated conventional moderate resolution remote sensing, which has been frequently applied using space-borne systems like Landsat (30 m pixel size). LiDAR (Light Detection and Ranging) data or stereo imagery has extended the spatial dimension and added very high-resolution height information, which has been successfully applied to improve delineating vegetation types or green volume estimates (Huang et al., 2013). New satellite imagery, for example RapidEye, offers high spatial resolution data (6.5 m), as well as consistent large area coverage (a swath width of 77 km with continuous observation coverage up to 1500 km).

For implementing greening actions, community participation is fundamental, and a general consensus can be crucial for successful operationalization. For instance, demand for carbon sequestration could be assessed using participatory methods at the local scale, then analyzed using proxy or expert-based methods at the global scale (Jacobs et al., 2014).

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Combining these methods would facilitate a wide range of ecosystem service assessments ranging in scope from education to accounting for human well-being to specific landscape planning and management problems. Research on integrating community-based participatory carbon measurement and monitoring with satellite remote sensing and GIS was conducted by Skutsch et al. (2009) and KTGAL (2009). They proposed field guides for field measurements and for assessing and monitoring vegetation degradation and carbon sequestration by local communities. In particular, they highlighted that to be most accurate, remote sensing tools and techniques for measuring and monitoring forest carbon should be integrated with ground-based forest and biomass inventories.

Where available, National or Urban Forest Inventory data can be used.

An alternative or a possible supplement to existing data is community-based carbon data collection. The inclusion of data collected by local communities provides a field-based sampling that can be used to validate and calibrate the remote sensing and GIS approaches to large areas carbon measurement and monitoring, thereby reducing uncertainty in the carbon estimates. In addition, the inclusion and involvement of local people and communities as stakeholders in project activities can empower them.

Participatory Mapping Research has shown that the remote sensing data (including LiDAR-based tree height estimates) was integrated with field-based observations to map canopy cover and aboveground tree carbon storage at ~1 m spatial scale.

Data on the performance of nature-based solutions in relation to carbon storage and sequestration collected in these ways can be used to:

- Quantify the benefits of nature-based solutions in terms of carbon storage and sequestration;
- Assess the contribution of urban areas to national carbon balance targets;
- Calculate the impact of tree/vegetation/soil removal for development;
- Calculate the potential yield of urban biofuels.

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ENVIRONMENTAL INDICATORS - FEATURE

CONNECTING NATURE

Albedo

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Description

Measuring albedo (reflecting power) of urban surfaces (e.g. average albedo or an area) as albedo impacts cooling (Urban Heat Island) and building energy use.

Methodology

Metrics are typically based on measures of the proportion of incoming solar radiation reflected by the various surfaces in the urban environment (reflection coefficient), defined as the ratio of incoming to outgoing radiation. It is measured on a scale of 0 – environments that absorb all incoming radiation without reflection (e.g. a black body), and 1 – environments that reflect 100% of incoming radiation. Additonally albedo varies in accordance to (amongst other things) the incident solar radiation spectrum, the solar angle, surface texture and surface roughness.

Level of expertise

This represents a technical indicator with expertise required for interrogating satellite data, modelling and use of technical instruments in the field. As previously mentioned, due to its repetitive global coverage, remote sensing provides the most promise for estimating regional and global albedo. There are already many algorithms used operationally for the retrieval of surface albedo from remote sensing data, however there are still many difficulties that must be taken into consideration when measuring surface albedo from space. Thus, expertise is required to create and validate the satellite retrieval methods in order to avoid the difficulties inherent to satellite albedo measurements and the many potential errors that can occur.

Data collection

Cost

Many remotely sensed EO products are freely available, however, EO data at finer resolutions can be expensive to obtain (Ban-Weiss et al. (2015) estimate as of 2014, minimum costs for fine resolution data (~1 m) are roughly US$15 per km2, so acquiring imagery for only the City of Los Angeles would cost circa $20,000, and for the entire metropolitan area of Los Angeles approximately $200,000). Field instruments vary in cost, depending on the precision required. Burakowski et al. (2013) quoted US$700 for their citizen science toolkit, including a pyranometer. The labour and financial expense of UAVs are much lower than those of aircraft (Cao et al., 2018; Yang et al., 2017)).).

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Scientific solid evidence

Satellite remote sensing has been widely used for the determination of land surface albedo (Ban-Weiss et al., 2015; Cescatti et al., 2012; Liang, 2000; Smith, 2010; Trlica et al., 2017). An advantage of satellite monitoring is that it provides global coverage.

New satellites can provide albedo measurements at reasonably high frequencies (2–3 days in the best case for Sentinel 2) and spatial resolutions (pixel size 10 m in the case of Sentinel 2, and several cm in the case of DigitalGlobe) to provide useful information for studies on ecosystem (tens of meters) to landscape (several kilometers to tens of kilometers) scales. However, all satellite measurements are biased towards cloud-free sky conditions.

In urban landscapes with heavy haze pollution, retrieval of the true surface albedo from satellite imageries must remove signal contamination caused by particle scattering. Lightweight unmanned aerial vehicles (UAVs) as an alternative for albedo monitoring may be able to overcome these limitations.

UAVs can cover areas ranging from 0.01 km2 to 100 km2, depending on battery life and type of UAV (Cao et al., 2018; Watts et al., 2012), can provide measurements at sub-decimeter spatial resolutions, and can be used to obtain data under both clear sky and cloudy conditions (Salamí et al., 2014; Watts et al., 2012). UAV experiments can be conducted at almost any time, and at any locations (Cao et al., 2018). Finally, UAVs can measure albedos at locations that are not accessible by ground-based instruments, such as steep rooftops in cities.

Whilst there are uncertainties related to albedo measurements from satellite remote sensing, there are however methods for validating coarse spatial resolution albedo products.

Field measurement accuracy will depend on the precision class of instruments used and the conditions under which measurements are taken but, typically, field measurements are used to validate satellite data and refine model predictions.

Effort

Effort is directly related to the methodology used. Participatory processes can represent lower effort in terms of data collection, but can still require a substantial input in terms of establishing and managing the scheme. When using remote sensing, the role of radiation forcing versus atmosphere forcing requires a thorough knowledge of the surface albedo. Moreover, the following aspects should be considered: mapping from patch, impact of directional sampling, surface radiation modelling, spectral albedo conversion, satellite data merging, environmental monitoring, criteria for quality and uncertainty assessment, link with land cover and land use classification, data assimilation, thematic applications, satellite missions, field campaigns, ground observation networks, and validation.

Data availability

Can use existing satellite data or generate new data through in-situ field measurements.

Geographical scale

Can be measured at various geographical scales. At larger (city-wide) scales, analysis of satellite data is the most appropriate metric. Remote sensing measurements have high potential to provide valuable information regarding the mapping of land surface albedo at various spatial and temporal scales.

Temporal scale

Monitoring could be used to establish a baseline and to capture impacts following an NBS project implementation. If satellite imagery is used, it may be possible to establish a historical baseline using archived data. Remote sensing measurements have high potential to provide valuable information regarding the mapping of land surface albedo at various spatial and temporal scales.

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Extended methodology

Albedo can be measured at diverse scales either in a laboratory, in the field or using remote sensing methods. In the laboratory, solar spectrophotometer or commercial portable solar reflectometer tools are typically used, and in the field pyranometers, albedometers or field spectrometers (see Li, Harvey & Kendall, 2013; Qin & He, 2017 for some examples). There are various standard testing method guidelines available depending on the tools used (e.g. ASTM C1549 - 16 Standard Test Method for Determination of Solar Reflectance Near Ambient Temperature Using a Portable Solar Reflectometer). Larger surface areas (e.g. 1km2) can be measured using remote sensing satellite-based tools such as Landsat 8 Operational Land Imager or advanced hyperspectral sensors like Airborne Visible/Infrared Imaging Spectrometer (AVIRIS).

Albedo values have been generated using coarse-scale remote sensing measurements and assuming generalised albedo values for different land cover categories in urban landscapes measurements, and by modelling the urban canyon and canopy albedos or combinations of these approaches (Qu et al. 2015; Trlica et al. 2017). Qu et al. (2015) provide a comprehensive review of algorithms and products for mapping surface broadband albedo with satellite observations. Remote sensing at higher resolutions is allowing more detailed categorisation of urban land covers, therefore improving the characterisation of albedo and model accuracy (Trlica et al. 2017), enabling finer-scale evaluation of albedo variation, for instance among different roof types (Ban-Weiss et al., 2015). High-resolution geospatial data has been used to quantify urban summertime albedo at 30 m resolution for the city of Boston, although clear trends in albedo and urbanisation emerged only after aggregating data to 500 m resolution (Trlica et al. 2017).

As remote sensing instruments do not directly measure surface albedo, the albedo must be inferred through a series of manipulations to the raw remote sensing data. Firstly, a method for determining which pixels are cloud-free within the data is necessary so that they are not used in the measurements of surface albedo (step: applying cloud-free mask to get cloud-free pixel – DN (digital numbers)).

Participatory process

Opportunities are available for a participatory process if members of the public can be provided with the necessary instruments to measure albedo (Burakowski et al., 2013).

Earth observation/remote sensing/modelling

The Feature indicator reviews are combined for applied metrics and earth observation/remote sensing/modelling approaches.

Connection with SDGs

Goal 3	Goal 10	Goal 15
Goal 4	Goal 11	Goal 16
Goal 6	Goal 13	Goal 17
Goal 8	Goal 14	

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Original reference for indicator

UnaLab

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Secondly, remote sensing data are originally stored as digital numbers which must be calibrated in order to represent geophysical units of radiance, or W·m-2·sr-1 (calibration step to get DN radiance). The third step involves atmospheric corrections when satellite instruments measure radiance-reflectance at the top of the atmosphere (TOA). Since we are concerned with albedo at the Earth's surface, a correction must be made to account for the effects of the intervening atmosphere (step: anisotropic correction). The data can then be divided by the Planck irradiance curve to derive the surface reflectance. However, there is difficulty that most satellite instruments only take measurements at one or a few viewing angles. Thus, a computation must be made to estimate albedo from reflectance, which requires an understanding of the bidirectional reflectance distribution function (BRDF) of the surface being measured. Finally, satellites normally measure the Earth's radiation in a number of separate narrowband channels, but albedo must represent the total broadband region of solar radiation of approximately 0.3-3.0 μm. A conversion is necessary, therefore, to extrapolate the narrowband albedo values inferred from remote sensing instruments to broadband values (step: narrowband-to-broadband (NTB) conversion).

For albedo calculations, Landsat imagery has to be converted from digital numbers to Top of Atmosphere (TOA) reflectance. Liang (2000) developed a series of algorithms for calculating albedo from various satellite sensors. His Landsat formula to calculate Landsat shortwave albedo was normalized by Smith (2010) and is presented below:

$$\alpha_{short} = \frac{0.356\rho_1 + 0.130\rho_3 + 0.373\rho_4 + 0.085\rho_5 + 0.072\rho_7 - 0.0018}{0.356 + 0.130 + 0.373 + 0.085 + 0.072}$$

where ρ represents Landsat bands 1,3,4,5, and 7. Note that Landsat band 2 (green) is not used. This formula can be implemented in ENVI using Band Math as:

((0.356*B1) + (0.130*B2) + (0.373*B3) + (0.085*B4) + (0.072*B5) -0.018) / 1.016.

In-situ measurements are typically used to ground-truth and corroborate satellite data, for instance from fixed tower-mounted instruments.

Cao C., Lee X., Muhlhausen J., Bonneau L., Xu J. (2018) Measuring Landscape Albedo Using Unmanned Aerial Vehicles. Remote Sensing 10, 1812; doi:10.3390/rs10111812

Cescatti, A., Marcolla, B., Vannan, S.K., Pan, J.Y., Román, M.O., Yang, X., Ciais, P., Cook, R.B., Law, B.E., Matteucci, G.; et al. (2012) Intercomparison of MODIS albedo retrievals and in situ measurements across the global FLUXNET network. Remote Sens. Environ., 121, 323–334.

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Whilst these provide accurate data, this is limited in terms of spatial range and may not accurately represent landscape variation.Pyranometers mounted on Unmanned Aerial Vehicles (UAVs) have been used to capture more site-to-site variation in albedo and provide finer-scale data caused by local landscape heterogeneity than satellite measurements, and provide a bridge between in-situ (tower) measurements (Levy et al., 2018). Cao et al. (2018) developed an UAV method for determining the landscape albedo which was tested at two sites typical of urban landscapes consisting of impervious and vegetated surfaces. They compared the visible and shortwave band albedo derived from their method with those of Landsat 8 and confirmed that this method can save labour costs and can be applied to landscape albedo estimations where direct field measurement may be difficult.

Public participation in measuring albedo has been successfully trialled in a pilot citizen science project in the USA. This used an existing volunteer network - Community Collaborative Rain, Hail & Snow (CoCoRaHS) - that measure and map precipitation (rain, hail and snow) in their local communities, to measure surface albedo (https://www.cocorahs.org/; Burakowski et al., 2013). Equipped witha low-cost toolkit including a pyranometer, the volunteers collected high-quality albedo data for research and education applications, that will be combined with a network of tower, aircraft, and satellite albedo measurements to investigate the climate response to historical and future land cover change in North-eastern USA (Burakowski et al., 2013; Amaral et al., 2017).

An albedo app is available online that could potentially be used as a public engagement tool https://play.google.com/store/apps/details?id=com.h2optics.albedo&hl=en.

Data on changes to albedo by nature-based solutions collected in these ways can be used to:

- Provide baseline data and prediction of albedo for planning and design processes (e.g. construction materials/geometrical configurations);
- Establish targets in relation to changing of surface albedo;
- Quantify the contribution of NBS to albedo in terms of providing thermal comfort zones for residents and reducing cooling energy use;
- Quantify changes to UHI on a city-wide scale;
- Contribute towards health and well-being evaluation linked to UHI.

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ENVIRONMENTAL INDICATORS - FEATURE

CONNECTING NATURE

Air temperature - Energy demand

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Description

The use of vegetation/wetlands in urban areas to reduce peak air temperatures with the objective of reducing energy demand for cooling.

Methodology

The metrics are based on quantifying a percentage reduction in energy demand for cooling under different landscape management strategies. As such, this indicator comes under the umbrella of greenspace management and corresponds to a modelling urban planning/landuse approach. This indicator has particular relevance in hot arid situations where air conditioner energy use is high but can have relevance in most cities. For instance, since most cities today experience some level of urban heat island (UHI) from urbanisation, the problem of air cooling is an issue for settlements of all sizes in all climatic regions (Leal Filho et al., 2017).

Level of expertise

For methods such as monitoring building energy use or internal and external temperature, expertise is required for experimental design of the monitoring. Following this, data analysis can be relatively straightforward. For tools such as i-Tree and ENVI-MET a basic level of expertise is required for using the software. Dependent upon the i-Tree resource utilised, field skills in surveying and measuring vegetation may also be required. Similarly for ENVI-MET, expertise can be required for field survey. Expertise is required to create and validate the satellite retrieval methods in order to avoid the difficulties inherent to satellite measurements of surface temperature and the many potential errors that can occur.

Data collection

Cost

Use of basic automated tools such as i-Tree Canopy and ENVI-MET basic can be very low cost and just involve the time required to input and analyse the data. Costs for other i-Tree and ENVI-MET resources can become more expensive the greater the volume of sample sites and complexity of information required. Thermal sensors and energy monitoring can also be relatively low cost, although cost increases proportionally with sophistication of sensors. Cost of both applied and modelling approaches can be reduced by partnering local universities to carry out laboratory analyses, for example as student research projects.

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Scientific solid evidence

Assuming that suitable comparable controls can be found, solid scientific evidence can be generated using applied metrics. This will, however, depend upon the accuracy of monitoring equipment and the level of replication. In relation to modelling, robustness of evidence depends upon the precision and accuracy of the method adopted. Precision of automated tools like i-Tree and ENVI-MET can be increased through greater understanding of local conditions through ground-truthing. Finally, remote sensing techniques and UAVs can measure air temperature reduction by vegetation at locations that are not accessible by ground-based instruments, such as steep rooftops in cities.

Extended methodology

UHI defined as a metropolitan area, which is significantly warmer than surrounding rural areas, can occur year-round, during the day or night, but generally the UHI reaches its peak during the summer nights in temperate cities.
Cooling is typically achieved by reducing the internal temperature of buildings directly through thermal insulation provided by vegetation added onto a building envelope (e.g. green roof or green wall), or indirectly though shading (e.g. tree canopy or green curtains shade). A similar effect can also be achieved by reducing external peak temperatures by changing external landscaping from hard surfaces to permeable vegetated surfaces that increase evapotranspiration. In particular, the implementation of green roofs can help decrease the use of energy for cooling and heating buildings by between 20% and 25%, depending on the construction materials used and whether or not green roofing is being used (Leal Filho et al., 2017; Sahnoune and Benhassine, 2017; Susca et al., 2011). Trees and vegetation lower surface and air temperatures by providing shade and through evapotranspiration (EPA, 2020). As such, shaded surfaces, may be 11–25°C cooler than the peak temperatures of unshaded materials, and evapotranspiration, alone or in combination with shading, can help reduce peak summer temperatures 1–5°C.

The selection of remotely sensed imagery depends on acquisition costs, scale, the extent of analysis, amount of detail (spatial and temporal resolutions), and type of information (number of bands) required. Most remotely sensed studies employed medium and low spatial resolution imagery acquired from Landsat 5TM, Landsat 7ETM+, ASTER and MODIS satellites as this was freely accessible. Contrastingly, the use of high-resolution satellite imagery (IKONOS, WORLD-View 2 and QuickBird) and very high-resolution airborne-based imagery is still less common due to the complex logistics and prohibitive costs for most users.

Effort

Automated tools such as i-Tree Canopy are relatively low effort with reports generated automatically after minimal data input. More complex tools such as i-Tree Eco and ENVI-MET as well as use of remote sensing require more involved data generation and input. Direct monitoring can involve some effort installing sensors, but analysis can be relatively low effort. For this installation, data analysis and equipment maintenance are the only inputs required. The only onerous aspect can be the volume of data generated.

Data availability

Generates new data. Baseline data prior to NBS installation is essential unless a similar control building can be identified. Energy usage can be calculated from past energy records, although there needs to be certainty in relation to any other variables that could have affected energy usage.

Geographical scale

Can be applicable across scales, from a single room to networks of buildings. The typical unit, however, is on a building scale.

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When planted in strategic locations around buildings or to shade pavements in parking lots and on streets, trees and vegetation planted to the west is typically most effective for cooling a building, especially if they shade windows and part of the building roof (EPA, 2020).
An applied approach for implementing this indicator would be to monitor internal building temperatures relative to external temperatures before and after the NBS implementation or compared to a control building that is not being similarly impacted by the NBS (D'Orazio et al. 2012; Hunter et al. 2014; Olivieri et al. 2017). An alternative approach is to monitor changes in building energy demand, particularly associated with air conditioner use, before and after nature-based solution implementation (Jim 2014; Skelhorn et al. 2016). Again, this can also be carried out in comparison with a control building with a similar thermal signature but without the nature-based solution intervention.
A general methodology for measuring the impact of green-roofs on the UHI, and defining a decision model that helps calculate the best green-roof/green-infrastructure ratio, includes: a) measurement instruments to gather on-site temperatures, and data from the local weather-station; b) ArcGIS analysis tools and effective ways of converting complex measurement data in simple charts and graphics that can be easily readable by decision makers or the general public; c) probabilistic and comparative approaches, which can be evaluated using different green-roof models (to calculate the contribution of flat roofs in regulating the imbalance between mineral and natural surfaces), in most cases ENVI-met 4.02, which provides many simulation features and models. In addition to direct measurement, predictive impact of nature-based solutions applied to buildings on building energy performance can be modelled. This can be done on a building scale, for example using the Energy Plus calculation engine of the Design Builder interface to optimise the envelope energy performance of buildings (Zinzi and Agnoli 2011; Sailor et al. 2012), or can be evaluated based on the implementation of NBS on buildings across regions or city scales (Langemeyer et al. 2020).
Sailor et al. (2012) also used modelling (the EnergyPlus building energy simulation program) to study the building energy impacts of green roof design decisions in four distinct climates, complete with an integrated green roof simulation module. They concluded, that in all cases, a baseline green roof resulted in heating energy cost savings compared to the conventional black membrane roof.

Temporal scale

Monitoring methods can be adopted for short-term snapshots associated with current status and impacts immediately following NBS implementation (or predicted impacts as part of planning). However, longer-term in-situ monitoring is generally more effective in terms of capturing a more comprehensive overview of how temperature/energy usage changes over time in relation to maturing of the vegetation of the NBS and potential impacts from NBS management.

Participatory process

Participatory processes are not typical for this indicator, although citizens can be included in data analysis/reporting to raise awareness of benefits. Citizens can also be involved in ground surveys for modelling methods like i-Tree and ENVI-MET.

Earth observation/remote sensing/modelling

The Feature indicator reviews are combined for applied metrics and earth observation/remote sensing/modelling approaches.

Connection with SDGs

Goal 1
Goal 3
Goal 4
Goal 6
Goal 8
Goal 9
Goal 10
Goal 11
Goal 13
Goal 14
Goal 15
Goal 16
Goal 17

References

Original reference for indicator

Eklipse; Akbari 2002

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The effect of green roofs in office building districts for mitigating the UHI effect and reducing CO_2 emissions have been measured using a simulation-based evaluation method (Hirano et al., 2019). To calculate energy consumption, they proposed a technique that combines intensity and temperature sensitivity methods and a simulation-based evaluation using an air-conditioning load calculation. A coupled urban canopy/building energy model (CM-BEM) was utilized to simulate the effectiveness of green roofs. The amount of water needed for evapotranspiration was calculated by using latent heat flux, which was derived from the results of roof surface heat balance calculations. The effect of green roofs on CO_2 emissions was determined based on their effectiveness to reduce the energy demand for space cooling, calculated by air-conditioning load simulation (Hirano et al., 2019).
A methodical approach for measuring the effects of facade greening (in particular cooling towards the greened structures through shadowing, transpiration cooling and thermal insulation) has been described and applied by Hoelscher et al. (2015), who conducted outdoor experiments during hot summer periods on three building facades in Berlin, Germany. They determined transpiration rates (sap flow) and surface temperatures of greened and bare walls as well as of plant leaves (temperature probes) of several climbing plants, and measured air temperature, relative humidity and incoming short-wave radiation. They found that surface temperatures of the greened exterior walls were up to 15.5 ◦C lower than those of the bare walls, and concluded that greening can be an effective strategy to mitigate indoor heat stress as long as the plants are sufficiently irrigated with up to 2.5 $L\ m^{-2}\ d^{-1}$ per wall area.
Modelling metrics can also be applied to other types of greenspace beyond NBS directly incorporated into building envelopes. This includes the prediction of the impact of urban trees to reduce building energy use (Akbari, 2002; Skelhorn et al. 2016) using tools such as iTree Design (iTree 2020), and the evaluation of the greening of street canyons (Alexandri and Jones 2008). Decisions regarding different types of NBS implementation across a city scale can also be carried out in relation to predicted thermal benefits (Derkzen et al. 2015). Such mapping of air temperature improvements can be carried out as part of a broader ecosystem service evaluation associated with greenspace design/distribution (Derkzen et al 2015).

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ENVI-MET (Bruse 2007) is emerging as a commonly used tool to evaluate the impact of vegetation implementation on both microscale simulations on building envelopes (López-Cabeza et al. 2018) and on larger scales across street canyons (Zhao et al. 2018) and neighbourhoods (Wu et al. 2019; Ziaul and Pal 2020). Consideration must be given, however, to the precision of results from modelled scenarios as they might not capture some of the nuances of real-world implementation (López-Cabeza et al. 2018; Crank et al. 2018; Salata et al. 2016).

The STAR tools (STAR, 2020) allow users to assess the potential of green infrastructure in adapting their areas to climate change. They include a surface temperature tool and a surface runoff tool which can be used at a neighbourhood scale (in the North West of England and beyond) to test the impact of different land cover scenarios of greening and development on surface temperatures and runoff, under different temperature and precipitation scenarios.

Earth observation data from space-borne sensors have been widely exploited to examine UHI effects (Bonafoni et al., 2017). Unlike in situ measurements, providing uneven distributed data, satellite observations have the advantages of covering large areas at the same time, and during different temporal intervals, ensuring a more effective analysis of the intra-urban UHI spatial variability, closely related to building distribution, surface materials and vegetation density. Different space-borne platforms, such as AVHRR (which use advanced very high-resolution radiometers), MODIS (use moderate resolution imaging spectrometers), and medium-resolution sensors such as ASTER and Landsat can be used to retrieve the UHI. Furthermore, satellite sensor measurements of surface reflectivity make it possible to retrieve albedo maps, both at the local and global spatial scale.

Most studies applied the retrieval from Landsat satellite data of urban land surface temperature. The 60 m pixel size of Landsat 7 ETM+ thermal channel proved to be suitable to monitor SUHI changes at the district level, making it possible to point out if urban construction changes move towards an urban sustainable criterion. Based on combined technology, using Landsat and Thematic Mapper (TM) images at a city scale, several studies examined the relationships between the effect of vegetation on the land surface temperature in different contexts (Wang et al., 2019).

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Studies by Sobrino et al. (2008) and Wang et al. (2019) applied the radiative transfer equation to acquire land surface temperatures, using measured atmospheric sounding data synchronized with satellite transit time. Santos et al. (2016) estimated the potential of green cover at rooftop level using 3D data obtained by Light Detection and Ranging (LiDAR) data and Very High Resolution (VHR) images. This approach allows for a detailed estimation of available roof areas since the physical aspects, such as slope, orientation, and shadows cast by surrounding buildings and topography, are calculated for each building in the area. Results can be presented in scenarios: on the one hand, taking into consideration the current vegetation cover at the ground level; and on the other, estimating the potential cover area on rooftops, according to different geographical and planning criteria. In a similar study, Mallinis et al. (2014) proposed a methodology based on GEographic Object-Based Image Analysis (GEOBIA) to estimate green roof retrofitting areas using VHR orthoimages and a Digital Surface Model (DSM). Several studies confirmed the possibility of using unmanned aircraft systems (UAS) for remote building inspection and monitoring (Eschmann et al., 2012; Morgenthal and Hallermann, 2014), especially for visual identification of areas of thermal anomalies using UAS equipped with thermal cameras, and detailed inspection applied to areas of high interest to quantify envelope heat-flow using computer vision techniques.

Data on the reduction of air temperature in relation to NBS implementation assessed in this way can be used to:

- Identify areas where NBS is needed;
- Plan NBS delivery to ensure social justice in relation to thermal stress on buildings;
- Establish thresholds for strategic NBS delivery;
- Support the planning of nature-based solutions for built infrastructure (e.g. green roofs and walls);
- Form part of a strategy to reduce building energy use;
- Compare modelled predictions with indicators that deliver air temperature quantifications.

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ENVIRONMENTAL INDICATORS - FEATURE

CONNECTING NATURE

Flood damage (economic)

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Description

Evaluating the change in economic impact of flood damage due to nature-based solution implementation. For example, estimation of avoided damages and costs from flooding (stage-damage curves relating depth and velocity of water to material damages £).

Methodology

Adequate management of floods is reliant on a priori assessments of flood events and their consequences. Such assessments give insights into what can be expected, and thereby open up the discussion on how to tackle such situations, for instance by using nature-based solutions. Such assessment frameworks can be used to evaluate (or predict) the effectiveness of measures in a standardised way. This supports decision-making on possible measures that can be taken and prioritisation of areas where action is required (IPCC 2012).

Level of expertise

Expertise required is very much based on the complexity of the method implemented. Damage curve assessment requires complex analysis and inclusion of numerous data sets requiring a significant level of expertise. Questionnaire-based approaches can require a lower level expertise, particularly at more local scales, but expertise is still required in relation to correlating responses with flooding event scales. Model-based approaches need expertise in modelling and use of related software.

Data collection

Cost

With complex analyses and multiple datasets, costs can be relatively high. Costs can be reduced by working with specialists that have predeveloped processes for delivering such analyses. Questionnaire methodologies can be cheaper, but this is typically dependent upon the scale of the area in question with damage-curve/modelling approaches potentially more cost-effective over larger scales.

Effort

Similar to the level of expertise required, effort is directly related to the method adopted and the associated data requirements. For small-scale survey-based approaches, effort can be low, particularly if online surveys with automated data analyses are adopted.

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Scientific solid evidence

Robustness of evidence depends upon the level of precision of the simulation software and the data analysed. Typically, simulations requiring the most basic data input are associated with the least precise results. This is not always the case, however, and model validation (either through real-world testing or validation against other models) is recommended. Empirical methods that use direct questionnaires can provide scientifically robust outputs, particularly if delivered in partnership with reconstruction experts. Again, however, validation can be required in relation to increasing certainty that quantified impacts are related to the nature-based solution implemented rather than due to different rainfall, ground conditions, and/or other catchment changes between flooding events.

Extended methodology

Flood risk and damage is commonly associated with economic cost. Cost is linked to aspects such as damage to property, disruption of transport networks, lost work hours due to unsafe/inaccessible workspace, etc (IPCC 2012). Various approaches exist regarding damage appraisals, such as financial and economic valuation based on market values (i.e. based on historical values or replacement values), and scales of analysis (micro-, meso- or macro-scale) (Pistrika, 2010; World Bank 2017). Today the typical approach is economic estimation of direct damage, mostly by applying depth-damage functions. An integrated, unifying approach is, however, missing. For consistent decision making it is desirable to have a more or less standardized approach for damage estimation at least at higher aggregation levels, such as a river basin or a complete region. As such, impact on the economic cost of flood damage can be an integral component of evaluation of the performance of nature-based solutions implemented to reduce the impact of floods. Nevertheless, the economic cost of flood damage (Env20) indicator is strongly linked with the indicator Env19 (Reduction of inundation risk for critical urban infrastructures - probability), as quantifying risk typically comprises a necessary precursor step in understanding the economic impacts of flood damage.

Data availability

Baseline data is required from multiple sources. Some of this can be obtained through open source data (e.g. digital terrain models), but other aspects need to be generated or modelled.

Geographical scale

These metrics are applicable over a range of spatial scales. Typically, the larger the scale the more complex the analyses. Questionnaires tend to be more applicable on smaller scale assessments.

Temporal scale

Monitoring methods can be adopted for short-term snapshots associated with single extreme events. They can also be adopted for long-term strategic simulations in relation to city-wide rollout programmes over long time periods and for predicting changes in the economic cost of flood damage with future climate change predictions.

Participatory process

Participatory processes are possible through questionnaire-based approaches. Similarly, participation can be incorporated into damage-curve/modelling approaches for some aspects of data generation (e.g. flood extent/damage mapping). For more details on participatory approaches to modelling see "Inundation risk for critical urban infrastructures (probability)".

Earth observation/remote sensing/modelling

The Feature indicator reviews are combined for applied metrics and earth observation/remote sensing/modelling approaches.

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Therefore, it is recommended that "Inundation risk for critical urban infrastructures (probability)" is also read as an introductory foundation when reading this indicator review.
Nature-based solutions for flood risk management need to be tested, designed, and evaluated using quantitative criteria (World Bank 2017). There are international standards and guidelines for engineered flood management structures, e.g. the International Levee Handbook (CIRIA 2013) and the Coastal Engineering Manual, which not only provide guidance for implementation but also for evaluating the effectiveness (especially economic) of such measures. EC FP7 project CONHAZ developed guidance for assessing flood losses (Green et al., 2011), which include evaluating the losses of productive and consumption assets. The first stage is to estimate the shock to the systems; the second stage, how the trajectories of the systems will consequently be affected. In assessing the shock, it is appropriate to differentiate between resources, production durables, productivity durables, and consumption durables. The most frequently used procedure for the assessment of direct monetary flood damage comprises three steps described in detail by Green et al. (2011):
1)classification of elements at risk
2)exposure analysis and asset assessment by describing the number and type of elements at risk and by estimating their asset value
3)susceptibility analysis by relating the relative damage of the elements at risk to the flood impact.

In terms of considering the economic impact of flood damage, damage assessments are typically based on metrics such as depth-damage curves, stage-damage curves or other multi-variable models (de Moel et al. 2015; Oubennaceur et al. 2019). These estimate the flood event in terms of flood extent and inundation depth, how probable such an event is, and the possible consequences. The conceptual framework is that risk is a function of hazard, exposure and vulnerability.
For the de Moel et al. (2015) metric, the economic impact assessment starts with an assessment of the flood hazard, based on observed hydrological data/simulation models (e.g. observed rainfall data input into a hydrological catchment model). The hazard data (i.e. inundation depth/extent) can be combined with information on exposure – the people, property and other assets present in the hazard zone.

Connection with SDGs

Goal 1
Goal 3
Goal 4
Goal 6
Goal 7
Goal 8
Goal 9
Goal 10
Goal 11
Goal 13
Goal 14
Goal 15
Goal 16
Goal 17

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Original reference for indicator

Eklipse

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Datasets on population, land use, etc, or remotely sensed data can be used and assessed in a binary (i.e. affected/not affected) way, or by gradations (e.g. relative to water depth). Cultural values can also be incorporated (monuments, heritage sites, etc) and indirect effects such as GDP production.

For evaluation, direct consequences are usually expressed in a single monetary figure (£/Euros), allowing comparison with evaluations of other measures (de Moel et al. 2015). Water depth is typically the main indicator of hazard, but also duration/flow velocity can be used, by estimating stage-damage curves (de Moel et al. 2015). Most commonly, direct damages are based on depth-damage curves (Huizinga et al. 2017). Assessment of different damage probabilities are estimated as the monetary risk per year, or expected annual damage (EAD, or average annual loss (AAL)) (de Moel et al. 2015).

Such risk-based damage assessment models can suffer from uncertainties and need validation to ensure the accuracy and precision of their outputs (Gerl et al. 2016). For more applied/participatory approaches to this indicator, it is possible to generate empirical data on flood damage before and after nature-based solution implementation. For example, telephone or face-to-face interviews can be held that use questionnaires with individuals whose properties and/or business premises have been affected by flooding to estimate damages (Booysen et al. 1999; Bubeck et al. 2012).

Alternatively, feedback from experts on damage reconstruction costs, cost of clean-up, and cost of assistance can be used for economic damage assessments prior to and following nature-based solution interventions (Wind et al. 1999). Such approaches can be particularly useful for categories that are very heterogeneous and need specific details (such as industrial land-use) (de Moel et al. 2015). In addition, de Moel et al. (2015) present some multi-parameter models that have been developed: this includes a conceptual model in the UK (Nicholas et al. 2001), a multi-variate regression model to estimate losses in private households in Japan (Zhai et al. 2005), and rule-based models for loss estimation to companies and private households in Germany (Kreibich et al. 2010; Elmer et al. 2010). Multi-parameter probability methods such as these have the advantage of being able to incorporate additional factors into decision-making and evaluation processes. This can include factors such as contamination issues and warning times (de Moel et al. 2015). They can also provide quantitative information about model uncertainty.

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In order to assess the ability of the NBS to protect the surrounding area from flooding, it is essential to value the benefits of improved flood protection using Cost-Based Methods. This can help in valuing the flood protection services of the particular NBS, especially when a budget available for a valuation study is not large. The method can be applied in 2 steps:

·Step 1: to conduct an ecological assessment of the flood protection services provided by the NBS. This assessment would determine the current level of flood protection, and the expected level of protection if the NBS is implemented.

·Step 2: The Damage Cost Avoided method might be applied using two different approaches. One approach is to use the information on flood protection obtained in the first step to estimate potential damages to property / ecosystems / humans if flooding were to occur. In this case, the researcher would estimate, in monetary value, the probable damages to property / ecosystems / humans if the NBS will be not implemented. A second approach would be to determine whether nearby property / ecosystems' owners have spent money to protect these from the possibility of flood damage, for example by purchasing additional insurance or by reinforcing their basements. These avoidance expenditures would be summed over all affected properties to provide an estimate of the benefits from increased flood protection. However, one would not expect the two approaches to produce the same estimate. One might expect that, if avoidance costs are expected to be less than the possible damages, people would pay to avoid those damages.

The replacement cost method is applied by estimating the costs of replacing the affected ecosystem services. In this case, flood protection services cannot be directly replaced, so this method would not be useful. The substitute cost method is applied by estimating the costs of providing a substitute for the affected services. For example, in this case a retaining wall or a levee might be built to protect nearby properties from flooding. The researcher would thus estimate the cost of building and maintaining such a wall or levee and compare them with the costs of the planned NBS. The monetary values of the damages avoided, or of providing substitute flood protection services, provide an estimate of the flood protection benefits of particular NBS, and can be compared to the implementation costs to determine whether it is worthwhile to strengthen the flood protection services of the planned NBS.

According to Johnson et al. (2020), the flooding costs could be reduced through the acquisition and conservation of natural land in floodplains, also through NBS. They quantify the benefits and costs of reducing future flood damages in the United States by avoiding development in floodplains. They find that by 2070, cumulative avoided future flood damages exceed the costs of land acquisition for more than one-third of the unprotected natural lands in the 100-yr floodplain (areas with a 1% chance of flooding annually). Large areas have an even higher benefit–cost ratio: for 54,433 km2 of floodplain, avoided damages exceed land acquisition costs by a factor of at least five to one. As such, strategic conservation of floodplains and implementing NBS related to flood mitigation would avoid unnecessarily increasing the economic and human costs of flooding, while simultaneously providing multiple ecosystem services.

Several models (Dutta et al., 2003; Win et al., 2018; Zhai et al., 2005) based on survey results were developed to estimate flood damage cost caused in cities, which investigate such factors as the influence of income, inundation duration and inundation depth, slope, population density and distance to major roads on the loss costs.

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Surveyed data can be analysed using Excel and ArcGIS 10 software. Ordinary least square and the geographically weighted regression analyses can be used to predict flood damage costs. Estimates should then be delineated using geostatistical map tools. In addition, these models should be applied and validated using actual official records as reference data. Finally, the use of a calculation-based approach is suggested to determine flood damage costs in order to reduce subjectivity during surveys.

Evaluation of the reduction of the economic impact of flood damage by nature-based solutions simulation can be used to:

- Support the development of strategic plans for nature-based solution implementation to reduce the economic impact of flooding;
- Predict the impact of individual nature-based solutions projects;
- Quantify the impact of implemented nature-based solutions;
- Promote stakeholder engagement in nature-based solution planning;
- Support the leveraging of finances necessary for delivering nature-based solution projects through cost-benefit analysis;
- Underpin decision-making about insurance values associated with flood damage risk.

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ENVIRONMENTAL INDICATORS - FEATURE

CONNECTING NATURE

Community accessibility

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Description

Measure of distance to and use of greenspace to evaluate/inform viable strategies to increase the use of green space.

Methodology

To achieve the benefits of urban green spaces supporting the activities of various social groups, urban green spaces must be accessible to the public, as accessibility is a key indicator used to evaluate the effective social and ecological functioning of cities (Chen and Chang, 2015). Accessibility is defined as "relative ease" of approach to specific attractive locations from certain places (Kazmierczak et al., 2010; So, 2016) and how visible the site is to the public. Accessibility usually refers to the non-linear distance travelled in the specific time unit without the use of means of transportation, from the user's location to the closest green space (So, 2016).

Level of expertise

Expertise in relation to mapping and modelling will be necessary. Also, expertise in leading participatory processes would be of value to maximise the quality of outputs.

Data collection

Cost

Some map datasets and satellite imagery are freely available online, others involve a licence fee. There can be costs associated with acquiring GIS software and GIS specialists if not already available in-house. Also costs for questionnaires to capture qualitative data if not already known and participatory GIS can also involve costs in relation to designing a portal, hosting the webpage, generating engagement, and analysing data.

Effort

The level of effort involved would be dependent on the scale of the project, the amount of data to be captured and analysed and expertise already available.

Data availability

Some GS map data is likely to be available for mapping distance to GS but factors relating to use might not be available and new data would need to be generated. Participatory data can be obtained in the form of already available data from local authorities, land managers, and non-government organisations, or generated through participatory engagement processes with organisations and individuals.

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Scientific solid evidence

Greenspace accessibility based on measures of distance to greenspace alone can miss other important factors, but when coupled with complementary data such as reasons/frequency of use, ratings from visitors etc., can provide solid evidence for evaluating accessibility strategies for nature-based solutions planning.

Extended methodology

Although the definition of accessibility is relatively simple, its implementation can be quite challenging, due to the characteristics of city's transport networks (Comber et al., 2008). Size and distance (from home) criteria have typically been used as a metric for evaluating greenspace accessibility, but determining whether greenspace is accessible can also involve physical and social aspects that can constrain the extent to which sites are accessed (as much as legal site ownerships and access rights). Physical constraints include factors such as: distance from home; factors that sever access such as busy roads, private land, steep gradients linked to the potential users' degree of independent mobility, etc (Harrison et al., 1995). Social and cultural factors that can impact accessibility include: personal safety, fear of crime, social and cultural stigmas/preferences (Cronin-de-Chavez et al. 2019). Mapping greenspaces provides information on their extent and distribution in a city, but this data alone does not necessarily capture the contribution these greenspaces have as accessible places for city residents to use and enjoy.
Measures of distance to and use of greenspace can provide data to evaluate which factors influence their use and metrics related to this have been reviewed in "Accessibility of greenspaces". A model for greenspace (GS) accessibility can be developed in the ModelBuilder environment of ArcGIS, where the actual proximity of GS can be calculated and can be enriched using a proximity sub-model based on theoretical functional levels (TFLs) and GS quality and sub-quality information based on a quality assessment (Stessens et al., 2017).

Geographical scale

Most published studies examine the city-scale, but a local accessibility analysis is also possible.

Temporal scale

Evaluation methods can be adopted for short-term snapshots for strategic greenspace accessibility planning, or can represent a baseline for long-term evaluation of change in accessibility/use.

Participatory process

PPGIS tools such as Maptionnaire and/or questionnaires on GS accessibility and The Place Standard Tool or a similar mechanism could provide a participatory element.

Earth observation/remote sensing/modelling

The Feature indicator reviews are combined for applied metrics and earth observation/remote sensing/modelling approaches.

Connection with SDGs

Goal 3	Goal 10	Goal 15
Goal 4	Goal 11	Goal 16
Goal 8	Goal 13	Goal 17
Goal 9	Goal 14	

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Original reference for indicator

Eklipse

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GS quality can be described as a weighted linear combination of inherent (e.g. naturalness and biodiversity, spaciousness, quietness) qualities based on publicly available GIS data, and user-related sub-qualities (e.g. feeling of safety) based on ratings given by a sample of GS visitors (Stessens et al., 2017). This provides data on the provision of public GSs, and their quality and sub-qualities for each urban block, and each of the sub-qualities can then be separately used to evaluate alternative design scenarios (Stessens et al., 2017). This approach gives a clear overview of inequalities in the quality and accessibility of GS, and maps can be produced that facilitate well-informed design and policy interventions not only on GS and the path network connecting residents and GS, but also on densification and general planning strategies (Stessens et al., 2017).

Alternatively, three aspects of urban greenspace (UGS) provision can be distinguished to make the common claim of "access to UGS" more specific (Biernacka and Kronenberg, 2018):

- Availability – greenspace exists within a suitable distance;
- Accessibility – the user feels welcome, can freely reach enter GS and safely use at any time;
- Attractiveness – the user willingly wants to use/spend time in GS because it corresponds with the individual's needs, expectations and preferences

The above three aspects represent a hierarchical order and can be connected to proximity to where the user lives, and are important to operationalising 'universal access' commitments (Biernacka and Kronenberg, 2018). Cities should consider performing an analysis of institutional barriers preventing UGS availability, accessibility and attractiveness as part of any urban planning initiative (Biernacka and Kronenberg, 2018). Whilst availability is typically represented during most UGS mapping exercises, attention needs to be paid to different UGS types as some are only rarely considered as greenspaces, for instance informal GS and brownfields (Feltynowski et al., 2018). To verify whether specific UGS are accessible, investigations should examine local zoning plans, as well as collate detailed maps of UGS (e.g., using orthophotomaps or local land surveying resources) with data and maps related to property rights, new investments (a UGS may be closed, at least temporarily, due to construction), schools and kindergartens (educational garden), tree felling and road traffic, etc (Biernacka and Kronenberg, 2018).

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UGS attractiveness involve participatory GIS or questionnaires to reflect the perceptions of urban inhabitants (e.g. Kothencz & Blanschke, 2017). Accessibility and attractiveness can best be investigated through field research to check which UGS are fenced, abandoned or in poor condition, who uses which UGS (e.g., using participant observations, time-use surveys), or where there is not enough park furniture and leisure equipment (Biernacka and Kronenberg, 2018). Once key barriers are identified policy makers or other interested stakeholders can create a comprehensive inventory of UGS and visualize UGS availability, accessibility and attractiveness on a map, which can be used to improve the current situation (Biernacka and Kronenberg, 2018). Le Texier et al. (2018) argued that urban green space accessibility must be defined from different land use data types. They propose to compare UGS indicators measured from an imagery source (NDVI from Landsat), an official cadastre-based map, and the voluntary geographical information provided by OpenStreetMap (OSM). Pafi et al. (2016) suggest a methodology to calculate accessibility to urban green areas using the Green European Settlement Map 2016, and outline input data, tests and tools plus the results of running tests for some European cities. The spatial analysis of this workflow has been implemented using ESRI ArcGIS tools, including the toolbox Network Analyst, and script using Python language and the ArcPy library for ArcGIS. Multi-dimensional models can measure both objective (geographic) accessibility and subjective (perceived) accessibility (Wang et al. 2014). These use socio-economic data, questionnaires and GIS to map data. Bivariate correlations and regression models can measure the relationship between distance and perceived access and the various relationships of dimensions of perceived and physical accessibility (Wang et al. 2014). Kabisch & Haase (2014) and Kabisch (2015) use a multi-method approach that examines the distribution and provision of UGS as well as the distribution of different population groups to establish possible relationships between UGS provision and socio-demographic indicators of population density, immigrant status and age, and calculated the percentage of immigrants and individuals aged ≥65 years within specific distances from park entrances to quantify potential accessibility. By using this multi-method approach, two levels can be addressed: a district level for the whole city including all sub-districts, and a site level with the focus on a large urban green space in a particular city.

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A number of different GIS and statistical methods can be applied, including hierarchical cluster analysis to identify clusters of districts with significantly different socio-demographic characteristics and simultaneously differing urban green space distribution. The standardized variables share of UGS, population density, percentage of immigrants and percentage of addresses situated in a residential area classified as “simple residential area” (defined as areas with continuous urban fabric and rather bad building conditions with nearly no renovation). The selection of these variables is based on their importance of indicating possible areas with diverging land uses and demographics. Cluster analysis can be conducted in SPSS (or other statistical programs), based on the WARD-Method with squared Euclidian distance (Kabisch, 2015).

In general, accessibility analysis of urban green spaces (UGS) includes the development of a spatial database as the first step in generating UGS accessibility indicator. Data can be collected using supervised classification methods of multispectral LANDSAT images and manual vectorization of high-resolution digital orthophoto (DOP). An analysis of UGS accessibility can be conducted according to Accessible Natural Greenspace Standards (ANGst) proposed by English Nature (2003) and further developed by Natural England (2010). Accessibility indicators can be generated based on seven objective measures which include the UGS per capita and accessibility of six UGS functional levels. It can be beneficial for UGS accessibility indicators to be compared with subjective measures that can be obtained by field survey of respondents within statistical units. The collected data reflect an individual assessment and subjective evaluation of UGS accessibility. The importance of using such objective and subjective measures in the process of understanding UGS accessibility has been confirmed by several studies (Kabisch and Haase, 2014; Natural England, 2010). Often, while evaluating accessibility, residents emphasize the immediate residential environment, neglecting the UGS of higher functional levels. The outputs from measuring this indicator may serve as guidelines for further development of the functional UGS city network. Large-scale questionnaire campaigns provide opportunities for public participatory processes, and can be used to capture data on a variety of variables including distance and type of greenspace, frequency of use, main reasons for visiting GS (e.g. to enjoy the weather, observing flora and fauna, to exercise etc), socio-demographic/economic status (Schipperijn et al 2010).

Multiple logistic regression analysis can be used to investigate the relationships between these variables and obtain a thorough analysis of a neighbourhood or city, its population, and the available green spaces, to inform viable strategies to increase the use of green space (Schipperijn et al 2010). For instance, the results from the Schipperijn et al 2010 Danish study highlighted that distance to green space was not a limiting factor.

Public Participation GIS methods such as ‘Maptionnaire’ (Raymond et al., 2016) and ’By the Water’ (Laatikainen et al., 2015) can be used to collect activity and user data in green/blue spaces. Users can mark on a map the sites they use and identify activities they undertake there (e.g. recreational activities, relaxing and spending time together; sports activities and nature activities) as well as data regarding the location of their home, places they perceive as inaccessible, modes of transport used and visiting frequency (Raymond et al., 2016; Laatikainen et al., 2015). Raymond et al.’s (2016) tool also collected demographic and socio-economic data about the user, users then map their experiences based on a range of options (the options listed are related to barriers regarding perceived accessibility). Cluster analysis and Shannon Diversity Index calculations can be applied to the data to understand different components of activity and user diversity, so that landscape planners can use the tool to spatially identify barriers/opportunities regarding perceived accessibility (Raymond et al., 2016).

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Glasgow's Place Standard tool https://www.placestandard.scot/ could also potentially be used as a citizen science tool to determine community perceptions of accessibility to greenspaces and how they could be improved to increase use. An Australian pilot project has developed a citizen science smartphone tool for auditing how and why older people engage with public greenspaces, to gather evidence beyond mere utilisation of greenspace (Barrie et al., 2019). The tool provides a geocoded data on the location and perceived quality of the greenspace, duration of visit, etc, and the data can be used to inform how urban greenspaces can become enablers of ageing well from the perspective of older people. This project followed a co-creation process, with citizens participating in data collection, analysis, and feedback on the design of the tool and the wider project. The tool could be used with different population groups.

Refer to other metrics detailed in 'Env41 - Accessibility of Greenspace' indicator review regarding mapping accessibility in relation to distance/travel time.

Data on community accessibility to greenspace generated in these ways can be used to:

- Improve the design of new nature-based solution greenspaces to enhance perceived and actual accessibility and achieve equitable distribution;
- Prioritise sites for interventions and increase the use of existing greenspaces;
- Support the planning of new nature-based solution greenspace initiatives;
- Promote community engagement in nature-based solution planning;
- Underpin other indicators that require an understanding of greenspace distribution and accessibility as a foundation.

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ENVIRONMENTAL INDICATORS - FEATURE

CONNECTING NATURE

Mapping ecosystem services and spatial-temporal biodiversity legacies

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Description

Biodiversity mapping (in a temporal context) and ecosystem services (ES) mapping to identify where nature-based solutions efforts should focus (to maximise conservation/ES outcomes and minimise costs).

Methodology

Approaches to mapping urbanisation impacts on biodiversity have typically used an urban to rural gradient, but this can be too simplistic to capture the spatial-temporal characteristics of contemporary urbanisation, which tends to be more dispersed and non-linear (Ramalho & Hobbs, 2012). It is important to understand how implemented NBS along with the environmental conditions and heterogeneity affect the distributions of species and how do the spatial-temporal dynamics of heterogeneity affect ecological and evolutionary drivers of biodiversity?

Level of expertise

It is important to clarify the resources that are needed to carry out ecosystem services assessments, such as technical and human resources, and the time needed for certain analyses. The methods vary greatly depending on the required expertise, availability of the data and its coverage, available software, time, and financial costs. The most suitable approach will depend on the research questions which need to be addressed, whether the study will be an assessment, or if maps are also required. For mapping methods, the level of scale should be considered. The limitations are often set by the availability of the data. For small research areas more detailed data sources, or even opportunities to conduct field measurements, may be available. However, for larger studies Earth Observation products may offer a solution for areas of poor data coverage. In addition to scale, it is also important to pay attention to the purpose of which the assessment is aimed at: Which biophysical units can and should be used to gain information on ecosystem services? Do we want to know if sufficient ecosystem service potential is available, or do we wish to quantify the rate at which the ecosystem service is delivered? Also, do we wish to deliver spatially explicit information for the chosen locations? The most suitable methods should be identified and selected according to the answers to these questions. Using a mixture of remote sensing and field methods appears to deliver the best results (e.g Mikolajczak et al., 2015; Vihervaara et al., 2017). Yet, this requires ecologists and remote sensing experts to collaborate closely with the newest methods and capabilities.

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Scientific solid evidence

The integration of RS technologies into ES concepts and practices leads to potential practical benefits for the protection of biodiversity and the promotion of sustainable use of Earth's natural assets. The last decade has seen the rapid development of research efforts on the topic of RS for ES (especially, in the context of spatially explicit RS and valuation of ES), which has led to a significant increase in the number of scientific publications. Remote sensing can be used for ecosystem service assessment in three different ways: direct monitoring, indirect monitoring, and combined use with ecosystem models. Some plant and water related ecosystem services can be directly monitored by remote sensing. Most commonly, remote sensing can provide surrogate information on plant and soil characteristics in an ecosystem. For ecosystem process related ecosystem services, remote sensing can help measure spatially explicit parameters. We conclude that acquiring good in-situ measurements and selecting appropriate remote sensor data in terms of resolution are critical for accurate assessment of ecosystem services.
The assessment of ES is often limited by data, however, a gap with tremendous potential can be filled through Earth observations (EO), which produce a variety of data across spatial and temporal extents and resolutions. Despite widespread recognition of this potential, in practice few ecosystem service studies use EO. There are some challenges and opportunities to using EO in ecosystem service modelling and assessment which we can identify:

- technical - related to data awareness, processing, and access (these challenges require systematic investment in model platforms and data management)
- other challenges – more conceptual but still systemic; they are by-products of the structure of existing ecosystem service models and addressing them requires scientific investment in solutions and tools applicable to a wide range of models and approaches.

As stated by variety of research, more widespread use of EO for ecosystem service assessment will only be achieved if all of these types of challenges are addressed. This will require non-traditional funding and partnering opportunities from private and public agencies to promote data exploration, sharing, and archiving. Investing in this integration will be reflected in better and more accurate ES assessment worldwide.

Data collection

Cost

If the data and GIS expertise is already available in-house then should be fairly low cost. If not, many remotely sensed EO products, including those from MODIS (250 m+), Landsat (30 m), and Sentinel's Ocean Land Color Instrument (OLCI, 300 m), are freely available. However, EO data at finer resolutions (< 3 m) can be expensive to obtain. Obtaining GIS expertise can also be costly, if none is available in house.

Effort

The level of effort involved would be dependent upon the amount of data and expertise already available. According to Andrew et al. (2014), efforts to map the distribution of ESS often rely on simple spatial surrogates that provide incomplete and non-mechanistic representations of the biophysical variables they are intended to proxy. However, alternative datasets are available that allow for more direct, spatially nuanced inputs to ES mapping efforts. Remote sensing data acquisition and processing requires financial, technological, and professional capacity. Even though there are some freely available data sets, the quantification of broad categories of ecosystem services cannot be achieved with these datasets alone. Acquiring the commercially available satellite images (e.g., QuickBird) incurs higher costs which also applies to the current hyperspectral, RADAR, and LiDAR sensors. Data acquisition from these sensors is usually upon request by the users which creates inconvenience in obtaining data from a specific area. Besides the acquisition, processing and analysis of data like hyperspectral images demands a very high technical capacity and computers with storage capacities up to tens of Terrabytes or even Petabytes.

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Remote sensing (RS) provides a useful data source that can monitor ecosystems over multiple spatial and temporal scales. Although the development and application of landscape indicators (vegetation indices, for example) derived from remote sensing data are comparatively advanced, it is acknowledged that a number of organisms and ecosystem processes are not detectable by remote sensing. The potential for applying remote sensing for analysis and mapping of ES efforts has not been fully realised due to concerns about ease-of-use and cost. Historically, RS data have not always been easy to find or use because of specialised search and order systems, unfamiliar file formats, large file size, and the need for expensive and complex analysis tools. That is gradually changing with increasing implementation of standards, web delivery services, and the proliferation of free and low-cost analysis tools. Although data cost used to be a common prohibitive factor, it is no longer a big stumbling block for most users except where high resolution commercial images are needed.

Remote sensing is generally most useful when combined with in situ observations, and these are usually required for calibration and for assessing RS accuracy. RS can provide excellent spatial and temporal coverage, for example, though its usefulness may be limited by pixel size which may be too coarse for some applications. On the other hand, in situ measurements are made at very fine spatial scales but tend to be sparse and infrequent, as well as difficult and relatively expensive to collect. Combining RS and in situ observations takes advantage of their complementary features (Geller et al., 2016).

Extended methodology

Past land-uses strongly shape remnant ecosystems and time-lags can mask remnant biodiversity response to ongoing fragmentation and environmental change, which an explicit temporal measure could capture (Ramalho & Hobbs, 2012). A more comprehensive 'Dynamic Urban Framework' (DUF) has been proposed that uses a temporal perspective and records land-use legacies, past remnant configurations, urbanisation age, local environment, and socio-economics and urban land use (Ramalho & Hobbs, 2012).

As stated by Ayanu et al. (2012), the quantification of ESs can be better and more correctly achieved by linking remotely sensed information to a limited number of in-situ observations using semi-empirical linear or nonlinear regression models. For example, vegetation indices derived from the near-infrared and red proportion of the electromagnetic spectrum can be linked to in-situ biomass measurements to derive a proxy for timber production. Irrespective of the regression type, the statistical relationship between the sensor signal and the data derived from field observations is affected by the sensor characteristics like spectral, spatial, and temporal resolution. Moreover, multiple boundary conditions like time of the day and year, actual state of ecosystem components, and the atmosphere also affect the statistical relationship and reduce its validity for monitoring and spatial transfers to other study areas. The properties of remote sensing systems vary significantly among each other making selection of the sensor system and the optimal methodology prerequisites for an accurate delineation of the proxies for ecosystem services. For instance, many indicators can be delineated for extensive areas within a clearly defined range of uncertainty based on operationally available data and well-established methods. Other indicators useful for exact quantification of ecosystem services can be only derived experimentally at local scale. The success of remote sensing application therefore depends on careful selection of the data from which the relevant parameters are derived for the chosen indicators of ecosystem services. The quantification of ecosystem services is limited by the respective resolution of the remote sensing system. While multispectral data (e.g., Landsat, MODIS) have been widely used, the retrieval of some variables is limited by the rather poor combination of spatial and spectral resolution.

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For urban planning this can provide guidance on the selection of remnant sizes and landscape configurations that will allow reasonable conservation outcomes in the future, help prioritise remnants for conservation, help understand thresholds for restoration and identify interventions to improve quality of remnants (Ramalho & Hobbs, 2012). The DUF can be used to identify the drivers controlling remnant ecosystems and elucidate where management and restoration efforts should focus in cities, helping to formulate meaningful management guidelines and tailor strategies of action for urban planners (Ramalho & Hobbs, 2012). The spatiotemporal context of biodiversity, e.g. individual organisms, populations and species defines their environmental and biotic setting. This setting, in turn, drives ecological processes and provides the arena for micro- and macro-evolutionary mechanisms (Jenz, 2011).

Methods for ecosystem services mapping can be found in core indicator review guidelines for Env85 (Change in ecosystem service provision – remote sensing and applied). De Groot et al. (2010) provides a list of potential indicators that can be used to determine the capacity of landscapes/nature-based solutions to provide ES, based on two main indicator categories: state indicators describing what ecosystem process or component is providing the service and how much (e.g. total biomass or Leaf Area Index), and (2) performance indicators describing how much of the service can potentially be used in a sustainable way (e.g. maximum sustainable harvest of biomass or the effect of Leaf Area Index on air-quality). Various integrated and multicriteria ES assessment/evaluation frameworks and modelling tools have been proposed that can help identify and prioritise nature-based solutions implementation in order to boost ES provision in cities (i.e. Nelson et al., 2009; De Groot et al., 2010; Haase et al., 2012; Pedersen Zari, 2015 & 2019; Kremer et al., 2016). As with mapping biodiversity, land-use legacies that influence the structure, function and biota of ecosystems can affect ES supply and time-lags may influence predictions of ES provision and should therefore be considered when evaluating indicators of current ES supply (Dallimer et al., 2015; Ziter et al., 2017). The third European Commision report on mapping and assessing the condition of Europe's ecosystems (EU, 2016) provides an overview about available information on ecosystem condition and proposes a flexible methodology for assessment of ecosystems and their services building on the outcomes of previous work undertaken mainly by the European Environment Agency and based on existing data flows, especially from reporting obligations.

Thus, utilizing high resolution hyperspectral, radar and LiDAR sensors would be desirable. With respect to the current status of these sensors, the derivation of ecosystem parameters such assoil clay mineralogy, belowground biomass, or water quality indicators like chlorophyll-a content, nitrogen, and phosphorus loading is primarily restricted to experimental landscape scale studies. Therefore, in situ measurements are needed for validation when using remote sensing data.

Data availability

Once ecosystem service analysts have identified a useful EO product and have the capacity to process it, they may still be unable to access it. Though many remotely sensed EO products, including those from MODIS (250 m+), Landsat (30 m), and Sentinel's Ocean Land Color Instrument (OLCI, 300 m), are freely available, EO data at finer resolutions (< 3 m) can be expensive to obtain (Schaeffer et al., 2013). While many assessments can be done at coarser resolutions, high resolution data are important for precise assessments, such as delineating urban canopies. Data producers could collaborate with public agencies to make EO data and products available at low or no cost for non-commercial research purposes. Since Landsat archives were released for free to the public, there has been a dramatic uptake and use of the data worldwide (Engel-Cox et al., 2004; Popkin, 2018; Wulder and Coops, 2014). Data access may also be limited by restricted use permissions or lack of public availability, particularly derived data products that are not available in data archives. Many new EO products are generated through one-off analyses that are novel (and therefore seen as worthy of publication) but result in data products that quickly become outdated or that cannot be regenerated due to technical and resource limitations.

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A systematic process is outlined in the report, consisting of the following steps (EU, 2016):

1)mapping which involves identifying and delineating the spatial extent and temporal dynamics of different ecosystems through the spatio-temporal integration of a wide range of data sets on land/sea cover and environmental characteristics;

2)assessment of ecosystem state/condition based on analysing the major pressures on ecosystems and the impact of these pressures on the condition of ecosystems in terms of the health of species, the condition of habitats and other factors including soil, air and water quality. If impacts or condition cannot be quantified, the pressures are also used as indicators of ecosystem condition;

3)assessment of ecosystem service delivery which include assessing the links between ecosystem condition, habitat quality and biodiversity, and how they affect the ability of ecosystems to deliver ecosystem services, and then evaluating the consequences for human well-being.

The mapping and assessment process can be coherently structured using the well-established DPSIR (Drivers, Pressures, State, Impact and Response) framework. This is used to classify the information needed to analyse environmental problems and to identify measures to resolve them (EEA, 2015; Maes et al., 2013; Turner et al., 2010).
Drivers of change (D), such as population, economy and technology development, exert pressures (P) on the state (condition) of ecosystems (S), with impacts (I) on habitats and biodiversity across Europe that affect the level of ecosystem services they can supply. If these impacts are undesired, policymakers can put in place the relevant responses (R) by taking action that aims to tackle negative effects.
This framework is particularly useful, as it can be adapted and applied for any ecosystem type at any scale (EU, 2016).

Producing regularly updated EO products requires ongoing funding to operationalize such products and to allow for algorithm and product improvement to meet the continually evolving needs of end users. This does not align with traditional time-limited calls for research innovation, yet in the absence of such funding, the ecosystem services and broader geographic science community loses the value created by initial research outputs.

Geographical scale

Remotely sensed data are inherently suited to provide information on urban vegetation and land cover characteristics, and their change at various geographical scales. However, the higher the resolution required, the more expensive would be RS data needed. In some cases, it would be better to use images provided by drones, but in this case permissions for survey mapping will be required and depends on the local and national / government regulations. Methods can be applied from small to large geographical scales but are linked to the limitations of the data sources.

Temporal scale

Remotely sensed data are inherently suited to provide information on urban vegetation and land cover characteristics, and their change over time, at various temporal scales.

Participatory process

Participatory activities can be combined with remote sensing analysis into an integrated methodology to describe and explain land-cover changes and changes in ES provision caused by them. In doing so, semi-structured interviews, focus group discussions, transect walks and participatory mapping can be used to identify and assess priority ES.

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Several European Union FP7 projects such as OPERAs (OPERAS, 2015) and OpenNESS (OPENNESS, 2015) have undertaken a critical review of these mechanisms and their application, and along with the EU H2020 project ESMERALDA (ESMERALDA, 2015) provide a flexible methodology for European, national and regional integrated mapping and assessment of ecosystem services and their biophysical, economic and social values at different scales. H2020 project Eklipse has published the report from its first request from policy makers for synthesizing available knowledge and provided an impact evaluation framework to support planning and evaluation of nature-based solutions projects (Raymond et al., 2017). Indicators of ecosystem service supply and demand are also developed by Burkhard et al. (2012), Haines-Young et al. (2012), Maes et al. (2013).

Mapping biodiversity and ecosystem services in these ways can be used to:

- Evaluate how land-use legacies and configuration can influence nature-based solutions designs/outcomes;
- Help planners target nature-based solutions strategies to improve conservation outcomes and boost ES provision;
- Assess the effects of different scenarios of design/management change on sites.

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Local community members and experts can together discuss which (positive) impact (benefits) the implemented NBS will have on various ES for local, regional, national and international users. This participatory process can help to identify priority ES (e.g. air purification, carbon sequestration, water regulation, soil protection, landscape beauty, biodiversity, etc.). The approach will reveal if there any strong variations in the valuation of different ES between local people and experts who apply RS techniques, between genders and between different status and income classes in the local communities. Scientific evidence has demonstrated that participatory tools, combined with free-access satellite images and repeat photography are suitable approaches to engage local communities in discussions regarding ES and to map and prioritise ES values (Brown & Donovan, 2014; Brown et al., 2012). A review of several citizen science projects found they can provide opportunities to support ecosystem service assessments, although are predominantly applied in relation to assessing regulating and cultural services (Schröter et al., 2017). Citizen science participation formats mostly comprised volunteered data collection as the most successful employing approaches for ecosystem service assessments, meanwhile direct assessments of ecosystem services remain rare (Schröter et al., 2017).

Connection with SDGs

Goal 1	Goal 8	Goal 14
Goal 2	Goal 9	Goal 15
Goal 3	Goal 10	Goal 16
Goal 4	Goal 11	Goal 17
Goal 6	Goal 13	

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ENVIRONMENTAL INDICATORS - FEATURE

CONNECTING NATURE

Accessibility of greenspaces

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Description

Distance from/or time to public greenspaces as a measure of accessibility.

Methodology

Greenspace accessibility has become an important issue for sustainable urban planning, particularly in relation to public health and social justice. It is widely acknowledged that access to greenspace may be particularly beneficial for children, socio-economically deprived groups and those with physical/mental illness. Distance-based metrics are often used to investigate relationships between greenspace availability and accessibility and health and wellbeing outcomes because studies have tended to indicate usage declines with increased distance to greenspace.

Level of expertise

Expertise in GIS tools, spatial analysis methods and processing of sensor data are needed.

Data collection

Cost

Some map datasets and satellite imagery are freely available online, more comprehensive data needed for network-based measures potentially can involve a licence fee. Typically, the higher the resolution of the data required, the greater the cost. Potentially, there are also costs for acquiring GIS software and GIS specialists if not already available in-house.

Effort

The level of effort involved would be dependent on the scale of the project, the amount of data to be captured and analysed and expertise already available.

Data availability

Some GS map data is freely available for mapping distance to GS but the quality and resolution can still be variable.

Geographical scale

Most published studies examine the city-scale, but local analyses are also possible.

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Scientific solid evidence

Greenspace accessibility based on measures of distance to greenspace can vary based on the methodologies used but represent a sound broad base for urban planning. However, it is critically important that a consistent methodology is used by a city to avoid overstating/underestimating actual greenspace availability/accessibility.

Extended methodology

A review to test the World Health Organisation's urban greenspace indicator for public health suggests everyone should live within 300 metres of a greenspace (with a minimum size of 1 hectare), equivalent to a five-minute walk, and this has been recommended as an indicator of greenspace accessibility (Van den Bosch et al., 2016). The decision of where to create greenspace and nature-based solutions should ideally be based on criteria related to maximising its accessibility (among other factors), so that it is easier for it to be accessed by the highest number of people, across social groups, and particularly those already lacking access. Feature indicator Env26 (Community accessibility) includes metrics that also capture public perception and use of greenspaces as a measure of accessibility. As these are important factors in evaluating accessibility, ideally both indicator reviews should be consulted for a detailed accessibility study. Greenspace accessibility will require a mapping exercise. However, different urban green space (UGS) datasets are based on different definitions and parameters, which can result in large differences in the total amount of UGS depicted in cities (Feltynowski et al., 2018). A Polish study comparing data from five publicly available sources: 1) public statistics, 2) the national land surveying agency, 3) satellite imagery (Landsat data), 4) the Urban Atlas, and 5) the Open Street Map revealed that the most commonly used data source - public statistics (1) - excluded many types of greenspace (i.e. informal greenspaces and brownfields) creating inaccuracies in spatial extent, whereas the most comprehensive dataset was from the national land surveying agency (Feltynowski et al., 2018).

Temporal scale

Evaluation methods can be adopted for short-term snapshots for strategic greenspace accessibility planning, or can represent a baseline for long-term evaluation of change in accessibility in relation to nature-based solution project implementation.

Participatory process

PPGIS tools can provide valuable supplementary information to accessibility research and provide additional approaches for the planning of public greenspaces.

Earth observation/remote sensing/modelling

The Feature indicator reviews are combined for applied metrics and earth observation/remote sensing/modelling approaches.

Connection with SDGs

Goal 3	Goal 10	Goal 15
Goal 4	Goal 11	Goal 16
Goal 8	Goal 13	Goal 17
Goal 9	Goal 14	

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Original reference for indicator

Eklipse

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Resources typically used for creating spatial datasets of urban green spaces include: Open Street Map (OSM); satellite imagery (Landsat, Sentinel etc.); orthophotomaps; LiDAR; Urban Atlas; and CORINE which are then typically geoprocessed in a GIS environment (Feltynowski et al., 2018). Core indicator review Env56-RS has further detailed information on mapping using remotely sensed data. To differentiate private and public green space, data sources are again an important concern because, for instance, Landsat data cannot distinguish private from public UGS, while OSM data does not depict private UGS (Le Texier et al., 2018). It may therefore be necessary to undertake a manual exercise in order to evaluate and define public versus private greenspaces, for instance consulting land ownership maps (Feltynowski et al., 2018).
Two common approaches used for measuring greenspace (GS) accessibility (La Rosa, 2014) comprise:
·the number of green areas within a fixed distance/time from a user's origin point, i.e. number of greenspaces within a fixed distance of residential areas, people within a fixed distance, minimum distance to closest greenspaces, or average distance to greenspaces (GS). This does not account for the actual spatial distribution of the population that can use certain GS and the relative distance of the population to GS; calculate proximity measures based on users/members of population in relation to specified distance/time to GS; or
·calculate proximity measures based on users/members of population in relation to specified distance/time to GS.
Users/population data can be georeferenced from census data. The location of the GS will differ in relation to the selected destination place in the GS (i.e. geometric centroids, boundaries, access points, entrances) which must therefore be considered.
Three types of distance measures are typically used:
·Euclidean (straight line),
·Manhattan (distance along the two sides of a right-angled triangle opposed to the hypotenuse); and
·network distance (shortest time and distance).
The first two are easily calculated in GIS, the latter requires more detailed GIS layers (i.e. the city's street network).
Depending on the needs of the accessibility analysis, two approaches can be used (La Rosa, 2014):
1.to understand the geographical distribution or supply of urban greenspaces, indicators such as the number/area of GSs within a

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Synergies:
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fixed distance from population, or the minimum distance from GSs would be preferable;
2.to understand the potential demand of greenspaces for planning, indicators need to quantify a characteristic of the potential users in an urban context and then attribute it to a greenspace, then the number of people living within a fixed distance from a greenspace is a typical measure.
‘Simple’ indicators account for the number of people or users that can have access to a particular greenspace, while ‘proximity’ indicators weight people or users with the distance from their location to the greenspaces (La Rosa, 2014). The choice of metric used as an indicator of accessibility will depend on the aim of the project and the number and type of geo-datasets available. If the aim is to chose specific types of GS for high-accessibility areas, with high proximity to residential settlements, e.g. allotments, playgrounds and other informal green areas, understanding the spatial configurations of the most accessible spaces to create this nature-based solution would be the most suitable metric to use.
Measurement methods used to calculate distance to/accessibility of greenspace can have implications for determining the strength of relationships between access and health (Higgs et al., 2012). When network-based metrics are used to measure distance to greenspace they can result in different findings to Euclidean distance, similarly whether the destination point at the greenspace is the nearest centroid, nearest boundary point or nearest actual access point. If a uniform approach is not used, then different greenspaces can be identified as ‘closest’ and this in turn could influence the strength and accuracy of associations. The ‘gold standard’ for measuring potential accessibility to the nearest greenspace using proxy measures would be to measure from individual households to public entrances (or other actual physical access points) of greenspaces using network distance (based on as detailed path or road network as is available) (Higgs et al., 2012). A range of different accessibility techniques should be considered when providing objective measures of access to GS as analysis of the relationships between access measures, health variables, and the attributes of such green spaces may be fundamentally flawed unless the consequences of alternative methodological approaches are at least highlighted and sensitivity analyses conducted.
De la Barrera et al. (2016) propose a range of indicators for measuring GS accessibility related to quantity of GS (i.e. per inhabitant, per built up area, etc, at the municipal scale), quality of GS (e.g. mean size of GS, vegetation cover, etc) and spatial distribution and accessibility to GS (e.g. aggregation index, share of blocks served by GS >0.5 ha, etc). Accurate measurement of accessibility requires the most refined demographic data available (e.g. population per block) combined with the location of the GS, so that the population supplied by GS can then be derived from the population living in each block (De la Barrera et al., 2016). This gives a socio-spatial differentiation of GS accessibility making it possible for planners to compare different neighbourhoods to steer and evaluate public investment toward the more deprived sectors (De la Barrera et al., 2016).
Geocoded land-use data from the European Atlas can be merged with national census data and a set of variables measuring provision of GS at household level then defined (Wüstemann et al., 2016). For instance, the distance to the nearest GS measured as the Euclidean distance between the household and the border of the GS provides a proxy for how long it takes to reach the nearest GS (Wüstemann et al., 2016). The coverage of GS can be measured as the square meters covered by GS in a predefined buffer area of 500 m around households and grid centroids respectively to allow estimation of a per capita GS provision (Wüstemann et al., 2016). Ideally both should be measured because distance can be short, but coverage can be low, therefore the two do not represent substitutes (Wüstemann et al., 2016). To analyse for

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provision of GS in relation to socioeconomic background, household must be controlled for in terms of age, income, employment, etc, and then distance and coverage can be tested against household data using Welch's t-tests (i.e. to show differences in GS provision for income) (Wüstemann et al., 2016). There can be inconsistency in findings using these metrics depending on the minimum size of GS used in the study, for instance, Wüstemann et al. (2016) use 0.25 ha as a minimum, whereas Kabisch et al. (2016) use 2 ha as a minimum, resulting in a considerably different GS provision value.

Provision of, and access to, UGS can also be examined with respect to the spatial distribution of the following four indicators: (i) availability (share of land dedicated to urban green space divided by a reference surface), (ii) fragmentation (the ratio of the total perimeter of UGS over their total area), (iii) privatisation (the ratio of private (i.e. residential gardens) to total UGS cover, and (iv) accessibility (the average distance, per neighbourhood, from each cell to the nearest public UGS through the road network (Le Texier et al., 2018).

Given the varied methodologies available for assessing greenspace accessibility, results reported can be inconsistent (Mears & Brindley, 2019). The heterogeneity in the types of objects included and the minimum mapping units used in different datasets (e.g. Landsat, OSM) must therefore be controlled for if data is to be used for comparative purposes (Le Texier et al., 2018). Straight-line distances can over-estimate accessibility by failing to consider actual routes available for travel, therefore network-based distance calculations can be more accurate. Other factors such as neighbourhood size and aggregation levels, local context and the complexities of relationships between deprivation and greenspace must be considered to avoid bias and understand reasons behind observed patterns and improve GS distribution equity (Mears & Brindley, 2019).

A PPGIS tool called 'By the Water' has been used to gather data on actual access patterns, providing not only a public participation opportunity but also revealing that proximity and availability did not always correlate with utilisation, and that measuring distance to the nearest blue/greenspace available alone is not enough to evaluate the true multidimensional nature of greenspace accessibility (Laatikainen et al., 2015). PPGIS approaches can therefore provide valuable information to accessibility research and provide additional approaches for the planning of public greenspaces (Laatikainen et al., 2015).

Data on greenspace accessibility generated in these ways can be used to:

- Achieve more equitable greenspace accessibility;
- Prioritise areas with limited accessibility for nature-based solution initiatives;
- Support the planning and design of new greenspaces;
- Track trends in public greenspace accessibility and set targets for equitable greenspace distribution (environmental justice);
- Underpin other environmental, health and wellbeing and economic indicators that require an understanding of greenspace distribution and accessibility as a foundation.

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ENVIRONMENTAL INDICATORS - FEATURE

CONNECTING NATURE

Ratio of open spaces to built form

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Description

Measures change in urban densification by recording the ratio of green (open) space to built form.

Methodology

The success of urban regeneration projects partly depend on integrating biodiversity, urban greenery and ES with the built form. With the rise in high density developments, ensuring adequate open space provision can be a challenge but is crucial to promoting a high-quality urban environment. Open spaces should be considered in conjunction with the built form as together they influence air movement and modify the microclimate. The size and scale of open spaces should therefore be optimised as part of city planning. Evaluating and increasing understanding of the relationship between the urban population and the quality and amount of open and green space in cities is vital to creating sustainable, healthy and resilient urban areas.

Level of expertise

Expertise in relation to mapping and modelling/statistical analysis will be necessary and knowledge regarding applicable data sources and appropriate methods/measures for processing data will be needed. Processing remote sensing data requires advanced expert knowledge.

Data collection

Cost

Increasingly high resolution, high-quality data is becoming freely available (i.e. OpenStreetMap (OSM)) and the main costs would be associated with employing suitably experienced specialists/technology to analyse data if this is not already available in-house. High resolution data to accurately characterise small land parcels can be expensive. See indicator review for "Land use change and greenspace configuration" - Remote sensing review, for some commercial costs for newly acquired high resolution RS imagery.

Effort

More detailed studies will be more data-intensive and time-consuming and effort will be directly related to the level of expertise available. Much of the effort associated is required upfront and especially when using remote sensing techniques, however, once a land use map has been developed, updating it can be relatively low effort if links to good processes are established with planning departments.

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Scientific solid evidence

Accuracy will be influenced by the resolution of land use/land cover data that is used. The variety of published methodologies and approaches to data collection mean there is a lack of consistency for comparative analyses nationally and internationally, and the use of density indicators often suffers from an imprecise definition of the reference area (Krehl et al., 2016). A city-scale ratio measure could mask distribution inequities.

Extended methodology

The basic methodologies of applying geostatistical approaches to spatial data for recording and assessing land use and land cover needed for this indicator have been covered in other indicator reviews (for instance refer to Env55 (Greenspace area) for metrics related to spatial recording of urban green (open) spaces), and Env63 (Land use mix) for metrics related to recording other urban morphologies). The European Urban Atlas provides free and reliable, inter-comparable, high-resolution land use maps for over 300 Large Urban Zones, available at: https://www.eea.europa.eu/data-and-maps/data/copernicus-land-monitoring-service-urban-atlas, with a minimum mapping unit of 0.25 hectare. Alternatively, OpenStreetMap (OSM) (https://www.openstreetmap.org/) is a freely-licensed, global geospatial database built by a community of volunteer mappers that can provide an up-to-date Land Use Land Cover (LULC) Wherever possible studies of urban form should cover different scales as most cities are composed of a nested network of scales with inter and intra-scale relationships (Sharifi, 2019a). The scale hierarchy ranges from:

- Macro: overall structure of the city and some major elements and aspects such as city size, development type (i.e., compact, dispersed, etc.), distribution pattern of people and jobs, degree of clustering, and landscape connectivity (Sharifi, 2019a);
- Meso: the structure and layout of neighbourhoods, blocks, lots, open spaces and streets (Sharifi, 2019b); and
- Micro: the granular design and structure of buildings, and their position with respect to neighbouring buildings, open spaces, and pathways individual buildings (Sharifi, 2019a).

Data availability

Land use and land cover data is widely available in the EU, depending on the resolution required, and some data can be accessed for free (e.g. OSM). The extensive and increasingly affordable availability of remote sensing data, with which not only land use, but also the height of built structures can be modelled, offers entirely new opportunities. Large-scale volume calculations can be made, from which density measures, such as the floor area ratio, can be derived (Krehl et al., 2016). Further benefits ensue as a result of: (i) the objectivity of the density calculation, since building heights and volumes can be reliably determined; (ii) the high spatial resolution of the data and the possibility to aggregate them at will into spatial reference systems (such as ring zones or grid cells) that are independent of local administrative units; (iii) the extensive availability at comparatively moderate costs; and (iv) the ability to easily link data with demographic and socioeconomic data at the sub-municipal level.

Geographical scale

Typical metrics such as FAR/GAR tend to examine data at the project/neighbourhood scale, however macro and micro-scale analyses are possible.

Temporal scale

Suitable for various temporal scales, although the availability of high-resolution historical data can sometimes be a barrier to studying past trends. Wagtendonk & Koomen (2019) propose a methodology that can model future trends.

Participatory process

Projects such as OSM and LandSense offer a mechanism for community participation in the process of recording and/or verifying land cover/uses (see "Land use mix") for further information on these platforms).

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Bottom-up development where the lower-scale components support/reinforce the higher scales strengthen the self-organisation capacities cities and can promote resilience (Sarafi, 2019a). The following metrics tend to concern the meso-scale level, however as part of upscaling and out-scaling, meso and micro-scale nature-based solutions interventions can have a cumulative macro-scale impact. Sharifi (2019b) provides a review of how various open space parameters such as their design, configuration, size, spatial distribution and connectivity can influence their performance in terms of microclimate regulation, supporting biodiversity, stormwater management, urban food production, accessibility and resilience, and note that optimal distribution of open space tends to be context specific (therefore no one-size-fits-all perfect configuration).

A commonly used density metric at the macro-scale level is Floor Area Ratio (FAR), also known as floor area density or floor-space index, typically defined as the amount of floor space of building divided by that building's plot area (Krehl et al., 2016). This is often used as a regulatory mechanism for new development to ensure density regulations are met. For use as a density indicator, determining the floor area ratio can be a complex task, since official surveys of building metrics (e.g., floor number, volume or height data) may not be available (Krehl et al., 2016). Stereo images acquired by the Remote Sensing Satellite, which employs the Cartosat-1 stereo sensor on board, provides the spatial and the geometric requirements for an area-wide and cost-effective derivation of height information from various large urban regions, enabling analysis at the spatial level of individual buildings and generation of 3D building models using digital surface models (DSMs) (Wurm et al., 2014; Krehl et al., 2016). Alternatively, an optical image and a DSM can be acquired by the same platform, with the concurrent utilization of the Advanced Land-Observing Satellite (ALOS) to generate urban volume which can be divided up into built-up volume and green volume (Handayani et al., 2018). Alternatives measures that focus on estimates of greening/landscaping are Landscape Surface Ratio (LSR) or Green Area Ratio (GAR). For LSR, the area of designated landscaping/open space area on development is divided by the area of the site proposed for development. Keeley (2011) provides an overview of the Green Area Ratio (GAR) calculation used in Berlin. It is composed of three adaptable, interconnected components: (1) a set of ratings; (2) a set of targets; and (3) the final

Chen et al. (2018) introduced a novel methodological framework for integrating social sensing and remote sensing data sources to conduct 'social functional' mapping of urban green spaces and land use structure.

Connection with SDGs

Goal 3	Goal 10	Goal 15
Goal 4	Goal 11	Goal 16
Goal 8	Goal 13	Goal 17
Goal 9	Goal 14	

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Original reference for indicator

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ratio determined for each parcel (Table 1). The first two are established by municipal planners and determine the scope and stringency of the metric (Keeley, 2011). Their development is time intensive, but then requires only periodic review (Keeley, 2011). The third value is generated by the property owner and involves a simple calculation of how each parcel meets these standards (Keeley, 2011).

Table 1. Descriptions of Green Area Ratio Components (Keeley, 2011)

Green Area Ratio components	Description
Environmental Performance Ratings	Planners rate the environmental services provided by each green technique; these numbers are used to weight or prioritise each technique
Greening Targets	Planners set the minimum percentage of each parcel to be comprised of green infrastructure
Parcel Achieved GAR	The weighted sum of green techniques actually implemented on a property

Some planning initiatives have set minimum targets for open (or green) space per resident e.g. 75 m2 green space per dwelling in the Netherlands. Other studies have shown that open space within the built-up city can be considerably more important to urban populations than open space at the urban fringe (Wagtendonk & Koomen, 2019).

To understand the impacts of urban development on the remaining open spaces within an area, rather than looking at urban sprawl, Wagtendonk & Koomen (2019) propose two spatial metrics:

- Open Space Ratio (OSR) = Open Area/Total Area; and
- Total Unit Density (TUD) = (Number of Built = up area units Number of Open Spaces) 100 + /Total Area - where Open Area represents the summed area of all open space units within the analysis area (both in km2) and Total Area the size of the analysis area in km2.

OSR is expressed as a dimensionless fraction, while TUD is presented as the number of units per 100 km2 to arrive at values ranging from 0 to 50 (depending on the characteristics of the area and applied data sets) and these can be used to show the temporal dynamics of open space and built-up areas at different spatial scales and shed light on different urban development processes (Wagtendonk & Koomen, 2019).
Scottish Natural Heritage have published a 'Wayfinder Guide' for the preparation of open space audits and strategies (https://www.nature.scot/wayfinder-guide-preparation-open-space-audits-and-strategies) that provides an overview on identification, classification and mapping of open spaces, and advice on developing accompanying open space strategies that take account of quantity, quality, value and accessibility of the open space resource . Glasgow City Council's Open Space Strategy (https://www.glasgow.gov.uk/CHttpHandler.ashx?id=47093&p=0) and accompanying Open Space Map (https://glasgowgis.maps.arcgis.com/apps/webappviewer/index.html?id=a968a2a7fa514eb1ac66abc571949c2e) provides an exemplar for setting out a long-term vision to ensure that urban open spaces meet the City's needs for years to come. As part of their open space assessment process, Glasgow City Council used a 'Quality Matrix' to evaluate whether a site could meet their quality standard considerations.

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Remote sensing methodologies are well-suited to detecting spatial-temporal changes at the urban scale, enabling the assessment of green space development and the outcome of the interplay between land-use policies focussing on densification and green space. Giezen et al. (2018) proposed the use of remote sensing technologies to monitor and analyse the resultant effects of opposing and conflicting urban policies for densification and protection and improving of urban green space in Amsterdam. High-resolution satellite images from 2003 and 2016 from Worldview 2 (0.46 m pixels) and Quickbird (0.64 m pixels) were used to measure land-use changes, which were assessed by applying landscape metrics for each land-use i.e. the percentage share of land use and their changes over the period measured (Giezen et al., 2018). This revealed a decrease of green space and an increase in the built-up environment, as well as strong fragmentation of green space, indicating that green space was increasingly available in smaller patches (Giezen et al., 2018). The findings highlighted that urban green space policies can be insufficient to mitigate the negative outcomes of a city's densification on urban green space, and that this should be looked at using more detailed metrics of changing spatial patterns, e.g. both "patch density" and "shape index" to indicate the overall level of fragmentation of the land-use and shape complexity (Giezen et al., 2018).

Krehl et al. (2016) underlined the analytical opportunities that recent remote sensing data offers with regard to an objective and transparent measurement of built density patterns of city regions.

Dennis et al. (2018) propose a new approach using open-source, high spatial and temporal resolution data with global coverage to measure and represent the landscape qualities of urban environments. The presented landscape approach employs remote sensing, GIS and data reduction techniques to map urban green infrastructure elements in a city region and how they relate to the built environment, and demonstrates considerable improvement in terms of coverage and thematic detail (Dennis et al., 2018). By going beyond simple metrics of quantity, such as percentage green and blue cover, it is possible to explore the extent to which landscape quality helps to unpick the mixed evidence from previous research on the benefits of urban nature to human well-being and provides a promising basis for developing further insight into processes and characteristics that affect human health and well-being in urban areas (Dennis et al., 2018).

Data on the ratio of open space to built form can be used to:

- Ensure that increasing density is not achieved at the expense of open/green space provision;
- Enhance the design of compact cities to ensure integration of nature-based solutions to deliver a balance of social, economic and environmental benefits;
- Track trends in open/green space provision and set targets for equitable provision and distribution;
- Prioritise areas with limited open/green space for nature-based solution initiatives.

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ENVIRONMENTAL INDICATORS - FEATURE

CONNECTING NATURE

Green space area

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Description

Measures green area (publicly or privately owned that is publicly accessible) in relation to population (e.g. ha/100k) as an indicator of environmental benefits provided by green areas in urban settings (reducing UHI and health benefits).

Methodology

Greenspaces provide a range of ecosystem services in urban areas including reducing the urban heat island, capturing particulates and social and health benefits through contact with nature. More green and blue space also reduces vulnerability to extreme weather events like flooding by heavy rainfall. Greenspace area can be used as an indicator of these environmental, social and economic benefits.

Level of expertise

Accessing the public datasets should be relatively straightforward. Experience of working with large datasets related to remotely sensed, climatic and environmental parameters as well as their statistical analysis using tools is important. Knowledge of GIS techniques such as multi-criteria evaluation and sensitivity analysis are also desirable.

Data collection

Cost

Some map datasets and satellite imagery are freely available online, others involve a licence fee and higher resolution imagery comes at increasing cost. There would be costs associated with acquiring GIS software if not already available, and GIS specialists if not available in-house.

Effort

Would depend on the level of in-house expertise available and the scale of area being analysed, availability of suitable data, and level of automation of analysis.

Data availability

There can be existing greenspace map data available (for example in the UK under licence - OS Mastermap Greenspace Layer) as well as in open-access format (OS Open Greenspace Layer), and international satellite data available online from the Copernicus Scientific Data Hub (scihub.copernicus.eu/dhus). There may be variation in terms of spatial resolution available.

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Scientific solid evidence

Relatively comprehensive and accurate greenspace datasets provide solid evidence, although there can be limitations in terms of capturing areas smaller than 0.25ha. It is important that a consistent methodology for evaluating greenspace area is used by a city to avoid overstating/underestimating actual greenspace availability. A weakness of this indicator is it does not capture the quality/health of the greenspace which would influence ES benefits.

Extended methodology

An important metric for evaluating urban green space is determining its area per capita, where population and urban area are the two main parameters. However, one of the difficulties in using the measure of square metres of green space per capita is that it can count all green space, including private green space which is largely inaccessible. The EU, through Eurostat and other agencies, has collected data on accessibility and green infrastructure gain/loss over time, which are also useful standards to apply.
Greenspace area information has typically been collected from high-resolution satellite images and then mapped and measured (area) in a GIS environment. Different urban green space (UGS) datasets are based on different definitions and parameters, which can result in large differences in the total amount of UGS depicted in cities (Feltynowski et al., 2018). A Polish study comparing data from five publicly available sources: 1) public statistics, 2) the national land surveying agency, 3) satellite imagery (Landsat data), 4) the Urban Atlas, and 5) the Open Street Map found that the most commonly used data source - public statistics (1) - excluded many types of greenspace (i.e. informal greenspaces and brownfields) creating inaccuracies in spatial extent, whereas the most comprehensive dataset was from their national land surveying agency (Feltynowski et al., 2018). Resources typically used for creating spatial datasets of urban green spaces include: Open Street Map (OSM); satellite imagery (Landsat, Sentinel etc.); orthophotomaps; LiDAR; Urban Atlas; and CORINE which are then typically geoprocessed in a GIS environment (Feltynowski et al., 2018).

Geographical scale

City-scale typically, due to the per capita component of the indicator, but also possible to use the data to monitor local-level changes in greenspace in relation to local population levels.

Temporal scale

Depending on the data available and the purpose of the exercise, could produce a current snapshot or a temporal view of change, although analysis of past trends can be a challenge if historical data is not available in a suitable resolution.

Participatory process

Citizen participation could be through a PPGIS tool such as the GLOBE app or a study such as Manchester's My Back Yard which can provide more detailed greenspace data to augment RS data.

Earth observation/remote sensing/modelling

The Feature indicator reviews are combined for applied metrics and earth observation/remote sensing/modelling approaches. However, this feature indicator can utilise metrics detailed for core indicator "Bluespace area" as well as methods described for other mapping/accessibility indicators such as "Greenspace accessibility".
For more detail on relevant earth observation, remote sensing and modelling approaches, including those used on past and current EU projects, see:
Blue space area - Remote Sensing Review.

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However, it is important to note, that extracting green space polygons from OSM using GIS software will be successful only if the case study area has been well drafted by OSM users. These polygons identify, generally, urban green public spaces, parks, pitches and their perimeters are not dependent on the availability of trees, grass and other vegetated surfaces. Core indicator review "Blue space area - Remote Sensing" has further detailed information on mapping using remotely sensed data. To differentiate private and public green space, data sources are again an important concern because, for instance, Landsat data cannot distinguish private from public UGS, while OSM data does not depict private UGS (Le Texier et al., 2018). It may therefore be necessary to undertake a manual exercise in order to evaluate and define public versus private greenspaces, for instance consulting land ownership maps (Feltynowski et al., 2018). Calculation of green space per capita depends on the spatial resolution of the data used (e.g. Landsat). With ArcGIS or QGIS it is possible to make a supervised classification. Another option is to use Normalized Difference Vegetation Index (NDVI), which is not as complicated as supervised classification, but provides useful data. When using open LANDSAT image gallery, NDVI is one of the simplest algorithms and enables calculation of green space in ArcGIS, where it is possible to extract surfaces having $0,3 < NDVI < 0,8$. This will define all the "vegetated surfaces", however permeable surfaces and unsealed soils not covered by trees, bushes and shrubs will not be identified as green spaces. An example method published by the European Commission (Pafi et al., 2016), extracts green areas >0.25ha in a city from the European Settlement Map (2016 release but a 2019 release is now available) at 10 metre resolution, and takes the total population of the city and number of inhabitants data from the 'EU 100m pop mosaic Global Human Settlement Layer' (GHSL), along with the best available input census data for a city. This data can then be used to estimate green area in relation to population. Greenspace per capita can be calculated as the total green area in hectares in the city divided by one 100,000th of the city's total population (Bosch et al., 2017; Wendling et al., 2019), or green area per capita in m2 (Pafi et al., 2016). Kabisch et al. (2016) undertake a number of greenspace availability analyses in relation to city population using the European Urban Atlas land cover dataset (https://www.eea.europa.eu/data-and-maps/data/urban-atlas).

Connection with SDGs

Goal 1	Goal 7	Goal 13
Goal 2	Goal 8	Goal 14
Goal 3	Goal 9	Goal 15
Goal 4	Goal 10	Goal 16
Goal 6	Goal 11	Goal 17

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Alternatively, the Integrated Landscape Map (ILM) methodology uses open-source, high spatial and temporal resolution data with global coverage (e.g. the OS Mastermap Greenspace layer (see link below) and Sentinel S2A data) to generate a composite spatial dataset that can classify land cover in a way that produces a more refined green infrastructure map for cities (Dennis et al., 2018). This method has the capacity to include public and private green (and blue) spaces and overcomes some of the shortcomings of the large minimum mapping units of other datasets (Dennis et al., 2018). ILM uses a classification system involving seven thematic land-use types coupled with five land cover values which can be used to more accurately investigate social-ecological relationships and measure and represent the landscape qualities of urban environments (Dennis et al., 2018). Examples of publicly available mapped greenspace data include UK public greenspace datasets, available (under licence) from https://www.ordnancesurvey.co.uk/business-and-government/products/os-mastermap-greenspace.html and Scotland's Greenspace Map (a mapping project of public greenspaces) available from https://www.greenspacescotland.org.uk/greenspace-map. Mears and Brindley (2019) provided several methodological recommendations for measuring green space distribution and provision, including taking steps to capture the relevant neighbourhood, as experienced by residents, as accurately as possible. They defined greenspace provision as the total area of greenspaces with at least one access point within a specified distance of each address point or population centroid. For their methodology, the whole area of greenspaces with an access point within the distance were included, rather than just the area within that distance, as the distance bands were determined considering how far people will travel to greenspaces, rather than within them. Provision was assessed at the same distance buffers and using the same buffer construction methods (network, straight-line) as for accessibility and the areal coverage provision measure was calculated using the area of the intersect between urbanised output levels and greenspaces (Mears and Brindley, 2019).

Public participation opportunities to engage with greenspace area mapping include the freely available GLOBE observer app https://observer.globe.gov/about/get-the-app. This enables citizen scientists to photograph the landscape with their smartphones, identify the kinds of land cover they see around them, and then match their observations to available satellite data. Users can also share the knowledge of the local environment around them and how it has changed. The "Adopt a Pixel" initiative is designed to fill in details of the landscape that are too small for global land-mapping satellites to see. Manchester City's citizen science project 'My Backyard Survey' http://mybackyard.org.uk/index.php was used to provide data on the extent of greenery in private residential gardens as part of a scheme to map citywide greenspaces. This involved an online questionnaire gathering data on the proportion of greenspace in gardens and how residents value their gardens. This improved estimates of actual greenspace in the city, although much of this would probably not be publicly accessible (a target for this indicator). Brown et al. (2018) provided an evaluation of participatory mapping methods to assess urban park benefits, designing an internet-based public participation GIS (PPGIS) survey and using household and volunteer sampling to identify the type and locations of urban park benefits.

Data on greenspace area collected in these ways can be used to:

- Quantify the distribution of greenspace across target areas and prioritise nature-based solutions implementation for areas deficient in public greenspace;
- Track trends in public greenspace availability in relation to nature-based solutions implementation;
- Support the equitable distribution of greenspace through urban planning for environmental, social and economic benefits;
- Provide underpinning data for other indicators such as ecosystem service mapping, stormwater management, biodiversity mapping, etc.

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ENVIRONMENTAL INDICATORS - FEATURE

CONNECTING NATURE

Local food production

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Description

A measure of the share of food consumption produced within a 100 km radius.

Methodology

Local food production is a provisioning ecosystem service in cities. Food production can take place in peri-urban fields, residential gardens, and in community gardens and allotments (Gómez-Baggethun et al. 2013). Though only a small proportion of food consumed is produced in cities, localising food production can make cities more sustainable and resilient (McPhearson et al. 2014). Urban agriculture (UA) and community gardening can potentially decrease food miles measured as the distance between production and consumption, thus lowering fossil fuel use and transportation costs (McClintock 2010).

Level of expertise

No specialist expertise for applied approaches is needed, unless GIS is used. The interpretation of remote sensing data requires knowledge of the spectral properties of different constituents of the Earth's surface as well as their variation caused by external factors. The spectral characteristics of different plant species must be known for accurate estimation of biophysical parameters such as biomass and productivity from remote sensing methods (Calvão and Pessoa, 2015; Camacho-De Coca et al., 2004). Training is an integral component to bridge the gap between remote sensing professionals and end users. Remote sensing involves sophisticated technology, and specialized training is required to process the data, convert it into information, and interpret the results. Many agencies and organizations either lack the financial resources to provide such training or do not understand the importance of periodic retraining for technical staff.

Data collection

Cost

For applied approaches costs are largely related to hiring someone to gather the data from various sources if this cannot be covered by staff in-house. Remote sensing techniques provide spatially consistent data sets and allow the current size of city farmlands to be rapidly determined and mapped at relatively low cost. Remote sensing can be less expensive than field-based mapping efforts, however, the cost of some high resolution remote sensed data can still be prohibitive.

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Scientific solid evidence

Figures based on Unalab's calculation represent a coarse estimation rather than solid scientific evidence. Apps such as MYHarvest can help quantify local food production. Nonetheless, Conner et al. (2013) highlight the difficultly of gathering more accurate 'actual' figures of consumption of locally produced foods. The extents of foodsheds used in foodshed analyses have often been constrained by data availability rather than being driven by key variables such as geography, distribution/transport or markets and can over-simplify networks of food production and consumption (Blum-evitts 2009; O'Sullivan 2012). Satellite remote sensing techniques have been widely used in detecting and monitoring land cover change, including urban farming, at various scales with useful results (Atzberger, 2013; Bégué et al., 2015; Brown and McCarty, 2017; Parece and Campbell, 2017; Saha and Eckelman, 2017; Schollaert et al., 2019; Stefanov et al., 2001; Russo et al., 2017). Recently, remote sensing has been used in combination with Geographical Information Systems (GIS) and Global Positioning Systems to assess land cover change more effectively than by remote sensing data only. It has already proved useful in mapping urban areas, and as data source for the analysis and modelling of urban growth and land use/land cover change (Herold et al., 2003). In the meantime changes in urban farming in developing nations can be quantified by coupling remote sensed data with available historic information from archival area photography and other sources in a GIS environment.

Extended methodology

Urban food production can also strengthen a sense of community, reconnect consumers with food producers, increase awareness of the environment and human health (McPhearson et al. 2014), and keep money circulating locally (McClintock 2010). Evidence of the value of own-grown fruit and vegetable production in terms of ecosystem services is increasing (e.g. Edmondson et al. 2014; Speak et al. 2015; Kortright & Wakefield 2010), although quantitative data to enable realistic estimates of the contribution own-grown food is lacking (Edmonson et al. 2019).
Granier 2016).

Effort

Trying to calculate actual consumption of locally produced food can be a fairly labour- intensive task. Remote sensing approaches must consider the technical limits on feature discrimination, the requirement of high levels of technical expertise, and the need for information to calibrate and verify remote sensing results, which can require effort and represent a limitation (Turner et al. 2003).

Data availability

Data availability on actual local food production/consumption is likely to be limited (Conner et al. 2013) and therefore based on data disaggregated from national/regional figures. A large volume of remotely sensed images at different temporal and spatial resolutions are available in many countries and international agencies (Huang et al., 2018). LiDAR and radar sensors pose other constraints to availability such as cost and lack of analytical monitoring standards. When classifying remote sensing data to produce a map of vegetation, the individual features belonging to a particular class of interest must be large with respect to the resolution of the imagery. For example, a stream that is 10 metres wide could not be detected in an image composed of cells of 1-kilometre spatial resolution. In addition, and crucially, the feature being observed must have a sufficiently unique spectral signature to be separated from other types of features. For example, it may be difficult to distinguish secondary from primary forest without additional supporting data.
Atmospheric phenomena, mechanical problems with sensors, and numerous other effects can distort the input data and therefore the results, although algorithms and models to correct these distortions are improving continuously. Cloud cover is the most common impediment to seeing the earth's surface with optical sensors and is particularly problematic in some regions of the world where cloud cover is common.

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Short food supply chains and local food systems have been gaining interest in the EU and one definition given states they are ‘a food system in which foods are produced, processed and retailed within a defined geographical area' (depending on the sources, within a 20 to 100 km radius approximately) (Augere-Granier 2016).

The CITYkeys indicators document defines local food production as ‘production within 100 km of the city to which the project is related’ and the recommended metric for measuring this is: (food produced in 100 km radius (tons) / total food demand within city (tons)) * 100. Food consumption values have been estimated as 770 kg per person a year in Europe (EEA, 2005). The food demand can then be calculated by multiplying the number of citizens with 770 kg. Food production values can be extracted from crop statistics and animal populations, but this is only available at NUTS2 level (Eurostat 2015) and has to be disaggregated from the database. There are overlaps with metrics for Env59, therefore if resources allow a city specific GIS analysis of UA land, as detailed in Env59, this could be used to provide a measure of food produced within 100 km radius.

Foodshed analyses attempt to capture the feasibility for a local region to be able to provide enough agricultural products to feed its population (Butler, 2013). The matrix below (Figure 1), taken from Butler (2013) provides an overview of attributes used in key research publications on conducting foodshed analysis (Blum-evitts 2009; Peters et al. 2008; Desjardins et al. 2010; Giombolini et al. 2011). A further method for estimating local food capacity proposes: 1) calculating local production and consumption for aggregated categories of food products, to determine overall local capacity, then 2) conducting more detailed assessments of local production of specific, locally significant foods (Timmons et al. 2008). A criticism of the foodshed analyses approach is the tendency to simplify understanding of localization feasibility to matching supply with demand within an area, without considering mediating factors like trade and transportation linkages (O’Sullivan 2012).

Haze and thin clouds are less problematic, but can result in distortions of feature spectral signatures, resulting in greater error or more expensive and complex processing.

Geographical scale

Applied methods typically examine patterns at the city scale, although these approaches could be carried out on a neighbourhood scale if there was reason to target a specific development or area. Remote sensing allows the acquisition of data in areas difficult to reach and at different resolutions (Calvão and Pessoa, 2015; Wang et al., 2013), and agricultural monitoring from space has historically been extensively utilized (as early as the 1930s) over a wide range of geographic locations and spatial scales (Atzberger, 2013). Thus, remote sensing can provide a detailed insight into the spatial dynamics of the processes of urban growth and land use change.

Temporal scale

Applied methods can be used to generate a snapshot (baseline) ads well as monitoring change over time following nature-based solution implementation. Remote sensing can provide consistent historical time series data. Future repeated observations will, over time, allow detailed quantification of changes in farmland sizes and types of crops produced. Thus, remote sensing can also provide a detailed insight into the temporal dynamics of the processes of urban growth and land use change.

Participatory process

Engagement with ‘locavores’ could be embedded into the indicator to deliver a form of public participation that could data on locally produced and consumed food. The MYHavest app engages local own-growers.

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	Peters et al.	Giombolini et al.	Blum-Evitts	Desjardins et al.
Area of Study	New York State (1 state)	Willamette Valley, OR (1 watershed)	Pioneer Valley, MA (3 counties)	Waterloo Region, Canada (1 regional municipality)
Goal of Study	Determine the *potential* ability of NYS agriculture to feed NYS pop.	Determine the *current* ability of WV agriculture to feed WV pop.	Determine current and potential ability for PV agriculture to feed PV pop.	Estimate capacity to improve nutrition of pop. through local agriculture
Measure of Food Production	Model using soil and landuse data	Last 5 years of agricultural yields (OSU Extension)	Current production: Census of Agriculture (USDA) Potential production: model using soils and landuse data	Estimate based on soil, climate, amount of available land
Measure of Food Consumption	Complex equation accounting for 42 different diets to produce per capita area of land required	USDA "Dietary Guidelines for Americans"	Consumer Expenditure Survey (stats on household purchasing habits)	Optimal food consumption based on Canada's Food Guide (Health Canada). Focus on foods currently under-consumed
Calculation of Distance travelled	Euclidean Distance between production zones and population centers	none	none	none

Figure 1. Matrix of attributes of the Foodshed Analysis studies taken from Butler, 2013.

A Metropolitan Foodshed and Self-sufficiency Scenario (MFSS) model has been developed, which combines regional food consumption and agricultural production parameters in a data-driven approach to assess the spatial extent of foodsheds, as well as the theoretical self-sufficiency of the communities they serve (Zasada et al., 2019). The model differentiates between food groups, food production systems, levels of food loss and waste as well as food origin. The authors propose that the tool enables the ex-ante assessment of the consequences of spatial changes within metropolitan food systems, on both demand and supply sides.
To more accurately quantify yields achieved by own-growers, Edmonson et al. (2019) have proposed a citizen science approach, in conjunction with Geographic Information Systems (GIS) and fieldwork. This involves mapping allotments/potential allotment space using GIS, ground-truthing for food cultivation, and development of a citizen science app called MYHarvest (https://myharvest.org.uk/) to collect yield data. This will provide the first comprehensive UK dataset on own-grown production for use by research scientists, policy-makers and the public.

Hodbod et al. 2019 propose an approach for combining participatory methods with remote sensing to provide a more holistic understanding of ES change, including local food production. Participatory mapping in focus group discussions can identify traditional ecological knowledge regarding what ES were present, where, and their value to communities. Obtained traditional ecological knowledge can then be integrated with satellite imagery to extrapolate to the landscape-scale.

Earth observation/remote sensing/modelling

The Feature indicator reviews are combined for applied metrics and earth observation/remote sensing/modelling approaches.

Connection with SDGs

Goal 1
Goal 2
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Goal 8
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Original reference for indicator

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Questionnaires followed by face-to-face interviews have been used to gather qualitative data on food growing in residential gardens to assess how edible backyards can contribute to community food security (Kortwright and Wakefield 2010).
Bristol City carried out a baseline study of the food systems that serve Bristol, including 'local food supply' – how much food comes from within a 50-mile radius (Carey 2011). This includes a detailed account of the data used to assess local food provision.
Methodologies for gathering accurate data on local food consumption are limited. Conner et al. (2013) collect data from a variety of sources to estimate current local consumption of food (e.g. U.S. Census non-employer data for food manufactured in Vermont by small-scale businesses, USDA National Agricultural Statistics Service figures measuring food sales direct to consumers, and direct inquiries to several types of stakeholders to fill data gap) but they acknowledge a lack of data from certain sources was a significant constraint in their study.
In order to reveal the spatial distribution of urban farming in cities, remote sensing provides spatially consistent data sets that cover large areas with both high spatial detail and high temporal frequency. Remotely sensed satellite data can provide an alternative to more limited traditional ground-based systems of production estimation and offer timely, objective, economical, and synoptic information for crop monitoring (Calvão and Pessoa, 2015). Remote sensing to estimate vegetation quantity and condition for the development of physiology-based plant growth models can be used, however the lack of available data means this has had limited application at scales larger than field scale. Instead, remote sensing vegetation characterization has developed using empirical or semi-empirical relationships between plant biophysical parameters and arithmetic combinations of reflectance from different spectral bands into a single metric, the so called "vegetation indices" (Calvão and Pessoa, 2015). Vegetation indices (VIs) have been found to be related to a number of vegetation biophysical parameters such as biomass, Leaf Area Index (LAI, the total one-sided area of photosynthetic tissue per unit of ground surface area), percent vegetation cover, fraction of absorbed photosynthetically active radiation and crop yield (Brown and McCarty, 2017). A major weakness of VIs is that relationships are often site-specific and thus their extrapolation to new areas is not always feasible or recommended.

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Nonetheless, remote sensing provides an efficient tool to monitor long term farmland changes in urban/ peri-urban areas, while the GIS environment provides a framework for spatial analysis and modelling based on geographic principles and seeks to integrate the analytical capabilities to broaden the understanding of the real-world system.
Some of the metrics in indicator "Cultivated crops" may overlap with this indicator.

Data on the performance of nature-based solutions in relation to local food production collected in these ways can be used to:

- Quantify the amount of food production within a city;
- Quantify the proportion of food consumption in a city produced locally (within a set distance);
- Assess performance in relation to targets for increasing the proportion of food consumed from local sources;
- Assess local food production potential to reduce carbon footprints associated with transport costs;
- Assess social equality in relation to locally produced food;
- Support the development of new food growing sites to support local food sourcing.

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ENVIRONMENTAL INDICATORS - FEATURE

CONNECTING NATURE

Cultivated crops

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Description

Vegetables produced by urban allotments and in the commuting zone (ton or per kg/ha-1/year-1).

Methodology

Cultivated crops offer a provisioning ecosystem service in cities. Fruit and vegetables can be produced in urban allotments, on green roofs, and in the rural-urban fringe (Gómez-Baggethun et al., 2013). Metrics typically measure the surface area of allotments and food production statistics, most often yield (Maes et al., 2016). Cultivated crops produced in cities are broadly defined in Maes (2016) as 'vegetables produced by urban allotments and in the commuting zone', and the service providing units include crop fields, fruit trees, private and public gardens. Recommended metrics in Maes (2016) are:

- production of food in tons or kilograms (kgs) per hectare (ha)/year
- surface of community gardens/small plots for self-consumption (ha)

Level of expertise

Participatory approaches typically require expertise in relation to development of an online platform and experience in organising community engagement projects. GIS expertise is needed for remote sensing approaches as well as technical expertise in handling and interpreting remotely sensed data. Managing even small quantities of satellite imagery requires specialized software, hardware, and training. The expertise and equipment often exist in-country, but not necessarily within the agencies interested in undertaking a monitoring programme. Fortunately, new software tools are making remote sensing data more accessible to non-specialists, and the possibilities for training are growing rapidly. Some remote sensing platforms (for example, hyperspectral, LiDAR, and radar) are largely or exclusively in the research phase of development and may not be in common use for some years. The number of experts who can work with these platforms is likely to grow in the future.

Data collection

Cost

Some map datasets and satellite imagery are freely available online, but the comprehensive data needed for network-based measures potentially can involve a licence fee. Higher resolution satellite imagery can have a cost associated. There also would be costs associated with acquiring GIS software if not already available, and GIS specialists.

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Scientific solid evidence

For more applied methods, the robustness of evidence will be biased by how detailed existing data is on CGs in a city and the accuracy of census data. Similarly the accuracy of distance to CGs will vary based on the distance measure used. They can however represent a useful indicator basis for urban planning. Using ground-based survey methods to map urban farmlands can be inherently problematic and prohibitively expensive, influencing accurate assessment of the future role of urban farming in enhancing food security. Remote sensing, however, allows areas being used as urban farmlands to be rapidly determined at relatively low cost. Due to the propensity for multi-cropping/polyculture practices in urban farming, remote sensing approaches such as NDVI may not accurately discriminate such fine-scale heterogeneity, but can provide a time series analysis over growing seasons (As-syakur et al., 2010; Parece and Campbell, 2017), although the accuracy of this can be impacted by atmospheric artefacts and reliable reference data for labelling and classification (Belgiu et al., 2018; Gómez et al., 2016; Matton et al., 2015; Nduati et al., 2019). Both remote sensing and participatory approaches will have inaccuracies based on the quality and resolution of aerial photos and level of participation. A combination of the two approaches may provide the most reliable data.

Extended methodology

Manual analysis of high-resolution images in Google maps in conjunction with GIS can be used to identify and map public and private spaces of food production (Taylor & Lovell, 2012). This involves two strategies: (1) the visual analysis of aerial images of previously documented allotments and community gardens; and (2) the manual extraction and classification of undocumented sites from high-resolution aerial images of the city in Google Earth. Known sites can be geocoded and reference images used to identify and digitise previously undocumented food growing sites. Visual markers - orthogonal garden layout, vegetation planted in rows or in beds separated by paths, bare earth or mulch between individual plants or rows of plants – provide indicators of food production (this was confirmed by ground-truthing a large number

The analysis of satellite remote sensing data can be a cost-effective way to generate up-to-date crop classification maps for larger areas at various scales (Atzberger, 2013; Waldner et al., 2015), however if this needs reliable reference data from in-situ field observations, the acquisition of this data can be expensive (Matton et al., 2015).

Effort

Manual feature extraction and classification required approximately 40 minutes per square kilometer of land area, and mapping the entire city of Chicago required approximately 400 hours of effort (Taylor & Lovell, 2012). Time-series analysis and classification for cropland mapping requires timely a priori knowledge of the cropland landscape for labelling of clusters (in the case of unsupervised classification), and derivation of the signature files needed to guide supervised classification models (Belgiu et al., 2018; Gómez et al., 2016; Matton et al., 2015; Nduati et al., 2019). In-situ field observations can be the most reliable data and necessary for calibrating/validating remote sensing approaches, but the acquisition of this data can be time-consuming (Matton et al., 2015).

Data availability

Some greenspace map data is freely available for mapping distance within a commuting zone. Spatio-temporal data on crop types and on crop rotations at the field level for regional scales are rarely available. A rare example of multiannual crop maps are the Cropland Data Layers (CDL) for the Unites States, provided by the National Agricultural Statistics Service (NASS) of the US Department of Agriculture (Boryan et al., 2011). However, in most European countries, such information is not available to the general public, due to data protection laws. The lack of this information is a major drawback for regional agro-ecosystem modelling, since large uncertainties concerning management and site-specific matter fluxes arise.

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of accessible sites). Once all sites have been digitised as polygons in Google Earth, they can be imported into a GIS environment for calculation of food production area in m2 or ha. Formal institutions such as the Food and Agriculture Organization (FAO) of the United Nations and the U.S. Department of Agriculture (USDA) are using online, self-registration techniques to gather information about urban agriculture across different cities. Data mining techniques can be used to identify UA locations in cities and then remote sensing techniques such as NDVI, NDWI and EDI, once UA locations are known, can be used to monitor UA, but RS data alone can have limitations in terms of accurately detecting UA from other vegetation types (Brown & McCarty, 2017). A free platform called OneSoil was recently launched online, providing an interactive digital map of agriculture data detected using AI. The map provides data on hectarage, crop and field score for the three years between 2016 and 2019 for 55 countries in Europe and USA. On a smaller scale, initiatives like Fruit City can provide a more informal mechanism for community mapping of city food production.

The National Society of Allotment and Leisure Gardeners Ltd (NSALG) states an expected yield value of 31.28 tonnes of vegetable per ha on an average allotment plot (based on average size of an allotment plot being 30 x 100 feet, or 0.0278 ha for 259 days growing season), although a more labour-intensive study suggested a yield of 40 tonnes per ha can be achieved (Tomkins, 2006). Once spatial data has been collated, these metrics could be used as a proxy for yield in the UK. A modelling study in Boston in North America used more conservative average yield values of 13.5 tonnes/ha-1/year1 for conventional urban garden food growing and 195 tonnes/ha-1/year1 for hydroponic rooftop food growing (Saha & Eckleman, 2017). Research for Oakland California in the US used calculations based on average yields under three different management practices: conventional at 24.71 tons/ha); low-biointensive at 37.07 tons/ha; and medium-biointensive at 61.78 tons/ha (McClintock et al., 2013).

Weidner et al. (2019) give the following yield figures: average by community gardens 12-26 t/ha; horticulture in developed countries 25-33 t/ha; professional and intensive UA 54-71 t/ha. A new citizen science app called MYHarvest (https://myharvest.org.uk/) was developed and launched to enable the collection of more accurate yield data from own-grown food.

To reduce these uncertainties, usually only a few different prototype crop rotations are considered, which are based on expert-knowledge or designed according to good farming practice. By combining the precise multiannual crop type data, a database for the spatio-temporal identification of crop sequences and crop rotations can be built. For crop mapping on a regional scale (larger than 1000 km2), usually multispectral remote sensing data of moderate spatial resolution (ca. 10–30 m) is still the most reasonable choice. Nevertheless, many studies also demonstrate the potential of satellite-borne synthetic aperture radar (SAR) data (Bargiel and Herrmann, 2011, Hütt et al., 2016, Koppe et al., 2013, McNairn et al., 2014) and their combination with optical data (Blaes et al., 2005, Forkuor et al., 2014, McNairn et al., 2009, Lussem et al., 2016) for land use/land cover mapping.

Geographical scale

Typically analyses would be carried out at a city-scale, but could potentially be targeted at other administrative/neighbourhood scales. Remote sensing provides spatially consistent data sets that cover large areas with both high spatial detail and high temporal frequency to analyse the spatial distribution of urban farming in cities. Satellite remote sensing techniques have been widely used in detecting and monitoring land cover change, including urban farming, at various scales with useful results.

Temporal scale

Ideally assessment should be carried out before and after nature-based solution implementation. Following this, assessment should be carried out a regular intervals (e.g. annual, 5 yearly). Remote sensing provides spatially consistent data sets that cover large areas with high temporal frequency to analyse the spatial distribution of urban farming in cities. Remote sensing can also provide consistent historical time series data.

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Knowing where food is grown and in what form can help planners and local authorities identify gaps in the spatial distribution of existing food growing sites, where urban agriculture is not occurring but possibly should be because of poverty, lack of food access, or public health problems and can also help to identify valuable local resources for the development of new sites and the enhancement of existing sites (Taylor & Lovell, 2012).

Metrics that only concern measuring yield in weight/surface area of plots may not necessarily be capturing the quality of the food produced or the quality of the allotment system producing the food (for instance in environmental terms management practices such as pesticide/fertiliser use and emissions, water use, soil erosion, and biodiversity etc). Moreover, there might be strong links with social and health & wellbeing indicators that are missed by adopting a yield-only approach.

In terms of evaluating a city's capacity for UA, a study of vacant lots, open space, and underutilized parks with agricultural potential using GIS and aerial imagery can be undertaken to calculate the potential contribution of these sites to a city's vegetable production needs (McClintock et al., 2013). Other city level estimations can be undertaken looking at various other urban landcovers, including rooftops (Kremer & Liberty, 2011; Ackerman et al., 2014 and Grewal & Grewal, 2012). A geospatial methodology can be used for estimating maximum food crop production capacity (MFCPC) of a city using remote sensed data and Object-Based Image Analysis (Richardson & Moskal, 2016). A study of urban agriculture in the city of Milan (Italy) provides an example of a spatiotemporal quantification for assessing food self-provisioning potential (Pulighe & Lupia, 2019).

Recent developments in remote sensing technologies coupled with GIS have significantly increased the capability of conducting farmland mapping. There are a variety of methods used for farmlands mapping that could potentially be applied to urban food production (Table 1).

Remote sensing techniques can also be used to distinguish between farmlands and farmlands use. Satellite images facilitate the estimation over a wide area the impact of farmlands change on nearby facilities. Land-cover classification can be derived through remote sensing for all allotments in the city and show structural and morphological diversity for allotment gardens. A study by Dongus and Drescher (2006) used remote sensing and GIS to map out vegetable production in open spaces.

Future repeated observations will, over time, allow detailed quantification of changes in the farmland sizes and types of crops produced. Thus, remote sensing provides a detailed insight into the spatial and temporal dynamics of the processes in urban growth and land use change.

Participatory process

Online portals for voluntary mapping of urban allotment distribution represent a potential participatory approach. Complementing remote sensing analysis using participatory mapping can help provide information for an initial land cover assessment (including food production), gain better understanding of how local land use might affect changes, and provide a way to engage local communities. Jacobi et al. 2019 and Zaehringer et al. 2018 propose an approach for combining participatory methods with remote sensing to provide a more holistic understanding of local food production by cultivated crops. Participatory mapping in focus group discussions can identify traditional ecological knowledge. Obtained traditional ecological knowledge can then be integrated with satellite imagery to extrapolate to the landscape-scale.

Earth observation/remote sensing/modelling

The Feature indicator reviews are combined for applied metrics and earth observation/remote sensing/modelling approaches.

Connection with SDGs

Goal 1	Goal 8	Goal 12
Goal 2	Goal 9	Goal 13
Goal 3	Goal 10	Goal 16
Goal 4	Goal 11	Goal 17
Goal 6		

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Table 1. Summary of farmlands mapping methods (Source: Addo, 2010; Seto et al., 2002)

Methods	Types	Data sources	Advantages	Disadvantages
Photogrammetric	Analog/ Analytical	Aerial photos	Relatively fast	Expensive
	Digital	Aerial photos/ Multispectral imagery	Accurate Wide coverage	Photo distortions
Digitising	Manual/Scanning	Historic maps	Ability to correct errors Correct distortions Reliable	Labour intensive Slow Depend on map accuracy
Physical survey	Planetable	Field measurement	Higher accuracy	Very tedious Time consuming Expensive

Studies (Addo, 2010; Clinton et al., 2018; Nduati et al., 2019) show advances in the use of remote sensing technology to develop an integrated monitoring technique for urban farmlands.

Normalized Difference Vegetation Index (NDVI) can be used as an environmental metric to track changes in vegetation phenology, assess vegetation stress and health, and, in urban areas, to separate vegetation from impervious surfaces. NDVI has a positive relationship with net primary production. Parece and Campbell (2017) used NDVI product from U.S. satellites (Landsats 5, 7, and 8) to assess urban community garden sites. They confirmed that this approach can be applied by conducting a time series analysis over the growing seasons (May–September) for several cities in the USA.

Their results show that establishment of community gardens alter seasonal NDVI trajectories, sometimes with initial declines, but then increasing over time.

Furthermore, NDVI profiles reveal the vigorous character of urban agriculture.

Nduati et al. (2019) show that daily MODIS 250 m NDVI and intermittent Landsat NDVI images can be fused, to generate a high temporal frequency synthetic NDVI data set. In their study, the identification and distinction of upland croplands from other classes (including paddy rice fields), within the year, was evaluated on the temporally dense synthetic NDVI image time-series, using Random Forest classification. As result, they achieved overall classification accuracy of 91.7%, with user and producer accuracies of 86.4% and 79.8% respectively, for the cropland class. Cropping patterns were also estimated, and classification of peanut cultivation based on post-harvest practices was assessed. Image

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spatiotemporal fusion provides a means for frequent mapping and continuous monitoring of complex urban and peri-urban agriculture in a dynamic landscape.

As vegetables and fruits are the most commonly grown crops in urban and peri-urban agriculture (UPA). Mapping of major staples such as rice, wheat, maize, and soybeans using remote sensing has been successful due to the spatial scale of production and the relatively uniform regional cultivation and management practices. However, varied crop types, crop varieties, tillage practices, and planting times characterize UPA crop production, resulting in misaligned phenological development and thus necessitating multi-temporal classification approaches which utilize time-series data. Cropland mapping approaches that use time-series data have been shown to perform better than single-date methods. Nonetheless, one of the main challenges of time-series analysis and classification for cropland mapping requires timely a priori knowledge of the cropland landscape for labelling of clusters (in the case of unsupervised classification), and derivation of the signature files to guide supervised classification models (Belgiu et al., 2018; Gómez et al., 2016; Matton et al., 2015; Nduati et al., 2019). Generally, satellite images are, for most applications, processed and analyzed retrospectively unless the data acquisition and processing are real-time or near real-time, as is the case for meteorological monitoring and prediction applications. The most reliable source of reference data is in-situ field observations, collected through farmer surveys and field campaigns (Matton et al., 2015). However, the acquisition of this data, especially for large areas and heterogeneous croplands, is an expensive and time-consuming exercise (Matton et al., 2015).

The collection of ground-truth information for urban and peri-urban agriculture croplands, therefore, remains a daunting task that requires an investigation into the application of novel approaches, such as crop-specific post-harvest practices, for reference data acquisition.

Another challenge of time-series analysis is missing data due to atmospheric artefacts, which results in an irregular sampling frequency of the phenomena of interest (Belgiu et al., 2018; Gómez et al., 2016). At any one time, approximately 35% of the global land surface is under cloud cover, thus limiting information retrieval and meaningful interpretation of optical satellite data (Shen et al., 2015). Various techniques have been developed to deal with cloud

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cover and other causes of missing data, such as sensor failures (Gómez et al., 2016). Shen et al. (2016) broadly classified these methods into spatial, spectral, temporal, and hybrid categories, which vary by the type of images they can be applied to, and the sources of information used to fill the missing data. The synthesis of multisource data with complementary information; data integration in the spatial, spectral, and temporal domains; and development of efficient, accurate, and task-oriented algorithms are areas of potential improvement for missing data reconstruction. The last decade has seen a proliferation in the development of multi-sensor image fusion or blending methods that exploit redundant and complementary information in the spatial and temporal dimensions of remote sensing data, to enhance interpretation and classification accuracy (Zhao et al., 2018). Fusion of high spatial–low temporal resolution images (e.g., Landsat 30 m) with low spatial–high temporal resolution satellite images (e.g., MODIS 250 m or 500 m), to generate synthetic high spatial–high temporal resolution data, can enable mapping of small, fragmented, and spatially and temporally heterogeneous UPA croplands at a regular frequency (e.g., seasonally or annually). In any case, the generation of comprehensive crop classification maps is usually hampered by limits in the technical capabilities of remote sensing systems (e.g. spectral or radiometric resolution), with regard to high spectral similarities of certain crop types (Waldhoff et al., 2017). Varying crop development (e.g. winter/summer crops) or weather conditions (Whitcraft et al., 2015) are additional aspects, which hinder the crop differentiation. These factors necessitate multitemporal observations to capture and differentiate all crop types. Such approaches are often enhanced by integrating expert-knowledge in the form of production rule-based methods.

As-syakur et al. (2010) have also used NDVI from remotely sensed imagery to quantify primary production in an urban area, but again the spatially fine-scale and heterogeneous nature of urban agriculture plots adds complexity to NDVI (As-syakur et al., 2010; Parece and Campbell, 2017). In large agriculture plots, an individual pixel will typically represent a single crop species but urban agriculture generally involves polyculture, i.e. multi-cropping, and intercropping. Multi-cropping is defined as two or more crop species cultivated within the same unit area and intercropping as two or more species grown at the same time in

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close proximity (Parece and Campbell, 2017). Such practices are commonly used in community gardens as documented in studies by Yadav et al. (2012) and Li et al. (2013). Thus, any application of remote sensing to examine urban agriculture will likely encounter multi-cropping and intercropping, and record plots as mixed pixels (pixels representing integration of several different spectral features), preventing direct application of conventional remote sensing analyses.
Some of the metrics in indicator "Food production" may overlap with this indicator.

Data on the performance of nature-based solutions in relation to food production collected in these ways can be used to:

- Quantify the amount of food production within a city;
- Support the identification of existing sites with potential to support urban agriculture;
- Assess local food production potential to reduce carbon footprints associated with transport costs;
- Assess social equality in relation to access to grow-your-own schemes;
- Support the targeting of urban allotments to the communities with the greatest need.

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ENVIRONMENTAL INDICATORS - FEATURE

CONNECTING NATURE

Intensity of landuse

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Description

Measure of artificial area per inhabitant (m2/person) - implement nature-based solutions to minimise artificial areas.

Methodology

The land take assessment produced by the European Environment Agency (2017) for 2006–2012 reports that "based on the average for the EU-28, 52% of all areas that changed to artificial surfaces were arable land or permanent crops in 2006". This means that several land cover types change to impervious cover, which in turn compromises the provision of important services provided by vegetation and soils, namely the storage and filtering of water, and the transformation of nutrients and contaminants —a direct call for the phenomenon to be monitored at proper spatial and temporal scales (European Environment Agency, 2017).

Level of expertise

Expertise in relation to mapping and modelling/statistical analysis will be necessary and knowledge regarding applicable data sources (especially those related to remote sensing and GIS) and appropriate methods/measures for processing data will be needed.

Data collection

Cost

Increasingly high resolution, high-quality data is becoming freely available (i.e. Open Street Map (OSM)) and the main costs would be associated with employing suitably experienced specialists/technology to analyse data if this is not available in-house. See indicator review for "Land use change and greenspace configuration - Remote Sensing" for some commercial costs for newly acquired high resolution RS imagery.

Effort

More detailed land use intensity studies will be more data-intensive and time-consuming and effort will be directly related to the level of expertise available. Much of the effort associated is required up front, however. Once automated methods such as NDVI have been developed, re-running them on new aerial photos can be relatively low effort. Similarly, once a land use intensity map has been developed, updating it can be relatively low effort if links to good processes are established with planning departments.

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Scientific solid evidence

Accuracy will be influenced by the quality of land use and land cover data that is used and the mix of measures that are used, but can provide robust and useful data on land use intensity (Siedentop & Fina, 2010).

Extended methodology

Moreover, the latest assessment of Maes et al. (2019) revealed that now 22% of the surfaces in European cities are sealed; if only soil sealing in artificial areas is considered, 58% of urban surfaces are sealed (average values, in many cities the proportion of the impermeable surfaces is higher). This measure provides a state indicator of urban ecosystems in terms of built infrastructure intensity and can be used as an indicator of the condition of urban ecosystems by determining the ratio of built and green infrastructure (Maes et al., 2016). This includes metrics that quantify urban sprawl. Methods will largely concern identification of land cover and land use, therefore, the same metrics outlined for feature indicator Env63 (Land use mix) will apply here and should be reviewed in the first instance. Also relevant is core indicator Env81 (Soil sealing).

From mapping land use and land cover, land use intensity calculations can be derived as set out in the MAES Urban technical report (Maes et al., 2016):

- artificial area per inhabitant (m2/person using latest city population statistics) or artificial surfaces as a percentage of the total municipal area;
- land annually taken for built-up areas per person (m2/person);
- proportion of urban green space (%) (synergies with support of human health and well-being as well as connectivity of urban green infrastructure);
- proportion of impervious surface (%) (synergies with flooding – infiltration capacity, UHI);
- proportion of natural area (%) (synergies with support of urban biodiversity);
- proportion of protected area (%) (synergies with support of urban biodiversity);
- proportion of agricultural area (%); and
- proportion of abandoned area (%).

Although various land cover classification approaches are available (Doustfatemeh and Baleghi, 2016; Le and Wan, 2015; Faridatul and Wu, 2018), the selection of the best classifier is difficult because each of the methods has its own strengths and limitations and requires the related expert knowledge.

Data availability

Land use and land cover data is widely available in the EU, depending on the resolution required (e.g. CORINE Land Cover data).

Geographical scale

Most studies reviewed examine data at the city scale, however more fine-scale analyses are possible for local planning contexts.

Temporal scale

Suitable for various temporal scales, although the availability of high-resolution historical data can sometimes be a barrier to studying past trends.

Participatory process

As described in Feature Indicator Review "Landuse mix", projects such as OSM and LandSense offer a mechanism for community participation recording land use.

Connection with SDGs

Goal 3	Goal 10	Goal 15
Goal 4	Goal 11	Goal 16
Goal 8	Goal 13	Goal 17
Goal 9	Goal 14	

References

Original reference for indicator

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Other calculations related to land use that may be significant attributes for measuring urban form in relation to land use intensity include (from Wendling et al., 2019):

- Residential density: number of residents divided by their residential area (number/km2) based upon population (census) and land use data (EEA, 2006; Siedentop & Fina, 2010);
- Percent of built-up area to describe urban sprawl pattern: built up area divided by total urban area, based on land use data (EEA, 2006; Siedentop & Fina, 2010);
- Share of low/dense residential areas (low density areas are areas with less than 80% of built-up areas i.e. buildings, roads and other structures): calculate as dense (low density) area / total residential areas using land use data with dense and low density areas specified (EEA, 2006; Siedentop & Fina, 2010);
- Scattering Index to differentiate urban sprawl from compact urban expansion and characterize how urban patches are dispersed in the landscape (patches = urban areas laying less than 200 m apart): measure as number of patches / total area or number of patches / number of inhabitants using land use data with the urban patches delimited (Arribas-bel et al., 2011).

Loss of environmentally fragile land or gain due to nature-based solutions adding ecologically valuable spaces to cities can also be derived from land use data (Johnson, 2001).
The European Commission provide a database: UDP – artificial areas per inhabitant, 2010 – 2050, JRC LUISA Trend Scenario (European Commission, 2016) that includes an index measuring the surfaces of artificial area per inhabitant (in square meters) for a specific year, comprising built-up areas, which correspond to land classified as urban, industrial and abandoned urban and industrial. In addition to built-up areas, artificial areas include infrastructure and green urban leisure land classes which also should be included in the assessment of this indicator. The increased quality and availability of satellite map data has given a better view of the form and extent of artificial areas, for example there are a number of algorithms and indices which can be used to distinguish the colours and patterns on maps, to discern between built-up areas and natural ground cover or water-covered surfaces (e.g. suggested by Faridatul and Wu, 2018). Moderate Resolution Imaging Spectroradiometer (MODIS) provides medium resolution maps (with resolutions of about 500m) that can be used to map urban built-up areas across regions.

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Higher resolution maps such as Quickbird (around 2m or less and) can be used at the city level to estimate different land use types, based on the colours, shapes, and ground cover. Alternative maps do not even necessarily rely on daylight, for instance night-time light data using Defense Meteorological Satellite Program Optical Line Scanner (DMSP-OLS) at a higher resolution and greater electromagnetic spectrum coverage, Visible Infrared Radiometer Suite (VIIRS), allow for distinguishing the form and brightness of built-up areas by recording ambient light. These maps have not only been used to track urban form and expansion, but also to estimate the intensity and location of economic activity within cities.

In order to classify urban land covers, various image classification approaches can be used (Doustfatemeh and Baleghi, 2016; Le and Wan, 2015; Faridatul and Wu, 2018). Use of different spectral indices has proved to be an effective alternative means of mapping land covers. For example, the normalized difference vegetation index (NDVI), developed by Rouse et al. (1973), extracts vegetation and biomass information. The soil-adjusted vegetation index (SAVI) proposed by Huete (1988) separates vegetation and water in urban areas. The normalized difference water index (NDWI) developed by McFeeters (1996) delineates open water features in remote sensing images. The modified normalized difference water index (MNDWI) (Xu, 2005) enhances accurate water detection. And finally, the normalized difference built-up index (NDBI), developed by Zha et al. (2003) is widely used to map built-up urban areas. The indexed-based built-up index (IBI) (Xu, 2008; Zhang et al., 2016) delineate urban built-up features. In addition to the individual indices, different combinations of indices or modified indices have been developed and used to map land covers and define artificial areas (Li et al., 2015; Patel and Mukherjee, 2015). However, as confirmed by Faridatul and Wu (2018), the existing approaches have limitations in terms of classifying urban land covers, for instance separating impervious and bare land is still a challenge. Thus, they proposed three novel indices: the modified normalized difference bare-land index (MNDBI), tasseled cap water and vegetation index (TCWVI), and shadow index (ShDI) and addressed the above-mentioned limitations of existing methods and enabled automated classification of land cover.
Population-based estimates of urban artificial areas aim to refine the application of available population census data. This approach uses known population centres and applies a grid across administrative boundaries (usually of about 1 km2). It enables an estimated distribution of the population within built-up and non-built-up areas within each grid cell.

Evaluating the intensity of land use can generate data on:

- Patterns of urban densification/sprawl;
- Changes in relation to loss/increase of permeable surfaces;
- The importance of land use configuration for shaping urban climate conditions;
- The design of cities to ensure integration of nature-based solutions to deliver a balance of social, economic and environmental benefits.
- Targeting of nature-based solutions in areas with greatest land use intensity.

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ENVIRONMENTAL INDICATORS - FEATURE

CONNECTING NATURE

Landuse mix

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Description

Mapping the diversity of land uses in an area by measuring urban morphology and composition. This can include using a 'self-organising map' algorithm to visualise and map urban form and mix of land uses.

Methodology

Land use mix refers to the heterogeneity of land uses in urban areas, with land use often simplified into categories such as residential, commercial, industrial, recreational, and agricultural uses (Croucher et al., 2012). Complementary land use in cities has been regarded as a sustainable development model that limits urban sprawl and can potentially benefit health and wellbeing by encouraging active travel. Nonetheless, as cities densify this can pose a threat to greenspace (ergo nature-based solutions) provision (Fuller & Gaston, 2009).

Level of expertise

Expertise in relation to mapping (especially those based on remote sensing and GIS techniques) and modelling will be necessary and knowledge regarding applicable data sources and appropriate methods/measures for processing data will be needed.

Data collection

Cost

Increasingly high resolution, high-quality data is becoming freely available (i.e. OSM) and the main costs would be associated with employing suitably experienced specialists/technology to analyse data if this is not available in-house. The resolution needed to capture land use mix in very high density areas and accurately characterise small land pockets can be expensive. See indicator review for "Land use change and greenspace configuration - Remote Sensing" for some commercial costs for newly acquired high resolution RS imagery.

Effort

More detailed land use mix studies will be more data-intensive and time-consuming and effort will be directly related to the level of expertise available.

Data availability

Land use and land cover data is widely available in the EU, depending on the resolution required..

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Scientific solid evidence

Remote-sensing techniques on satellite images have been effective at capturing land cover patterns and high-resolution aerial and satellite images can provide accurate land use maps when augmented with detailed and up-to-date auxiliary data on land use. Methodological inconsistencies in measuring land use mix have hindered generation of more generalizable and comparable results and imperfect conceptual assumptions can result in misunderstandings regarding true associations between land-use mixing and, for instance, travel behaviour (Gehrke & Clifton, 2016). Selection of appropriate measures for the study project is critical (see Song, Merlin & Rodriguez, 2013). There can be missing data to some degree with remotely-sensed and crowd-sourced tools such as OSM, however it is of sufficient quality for most cities (Gervasoni et al., 2016).

Extended methodology

Whilst a number of strategies to overcome this have been identified (Haaland & van Den Bosch, 2015), ensuring provision of sufficient, well-functioning greenspace/nature-based solutions as part of urban land use mix remains a major challenge. For this indicator to adequately address this challenge, it is crucial that greenspace/nature-based solutions are accounted for as accurately as possible when using metrics to measure land use mix. Some of the studies set out below use a very simplified range of land use categories that do not always explicitly include a greenspace category (for instance transport related studies) but have been included here as they provide indicative methodologies for evaluating land use mix.

A mixture of land uses has been shown empirically to encourage non-automobile-based modes of travel such as walking and bicycling, which in turn are seen as having a positive impact on public health and well-being (Tallen, 2008). Land use diversity is a key component of compact liveable communities where everything is within reasonable distances. This can range anywhere between 5 to 20 minutes of walking distance to a park, public space or a cluster of services. Exploring land use data supports the process of determining access to public spaces and institutions, parks or even vacant land for future development.

Geographical scale

Most studies reviewed examine data at the city scale, however more fine-scale analyses are possible for local planning contexts.

Temporal scale

Suitable for various temporal scales, although the availability of high-resolution historical data can sometimes be a barrier to studying past trends.

Participatory process

Volunteered Geographic Information Projects such as OSM and LandSense offer a mechanism for community participation in the process of recording land use mix, contributing not only to road network distribution information but also to the potential for using these data to justify and delineate land patterns.

Connection with SDGs

Goal 3	Goal 10	Goal 15
Goal 4	Goal 11	Goal 16
Goal 8	Goal 13	Goal 17
Goal 9	Goal 14	

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Original reference for indicator

UnaLab

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This is helpful for establishing the number of potential destinations in a neighbourhood and for drawing a more general conclusion on walkability. While public spaces and local centres act as anchors that allow people to meet and socialize, housing is the key to population density that actually brings people together. The input data sets for land use/land cover classification studies typically use aerial data such as remotely sensed images acquired by sensors such as Landsat. The European Urban Atlas service offers a high-resolution land use map of urban areas (https://land.copernicus.eu/local/urban-atlas). In the UK, Digimap offers a collection of Ordnance Survey Products for free to academic institutions, and the land cover data can be supplemented with government land use data for instance via the Generalised Land-Use Database (GLUD), which allocates all identifiable land features on Ordnance Survey's OS MasterMap® into nine simplified land categories: domestic buildings, domestic gardens, non-domestic buildings, roads, paths, rail, greenspace, water, other land uses (largely hardstanding) and unclassified (DCLG, 2007). OpenStreetMap (OSM https://www.openstreetmap.org/) is a freely-licensed, global geospatial database built by a community of volunteer mappers that can provide an up-to-date Land Use Land Cover (LULC) resource free, and that for some cities can be considered as complete as a commercial data set (Gervasoni et al., 2016). Where data coverage is incomplete, it can be merged with a high-resolution product such as GlobeLand 30 (GL30) to generate LULC maps that are more accurate and up-to-date and have a more detailed nomenclature (e.g. more detailed urban classes) (Fonte et al., 2017). OSM provides a community driven participatory process to LULC mapping processes. Yang et al. (2017) in their study of mapping land-use and management practices, developed a robust regional land-use mapping approach by integrating OSM data with earth observation remote sensing imagery. This novel approach incorporates a vital temporal component to large-scale land-use mapping while effectively eliminating the typically burdensome computation and time/money demands of such work.
High-resolution remotely sensed images have the spectral and textural properties suitable to extract urban land use maps, using, for instance, object-based (Voltersen et al., 2014) or scene classification (Zhong et al., 2015) methods, although it can still be difficult to distinguish urban land use mix accurately using classification algorithms based on physical characteristics alone.

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For example, remotely sensed spectral and spatial features of business and commercial land uses are similar, consequently a combination of remote and socially sensed data can be advantageous in terms of distinguishing ‘social’ land use classes (Jia et al., 2018). Using high-resolution remotely sensed data and social features data derived from mobile phone positioning data (MPPD), Jia et al. (2018) generated a ‘fused’, six-class land use map of Beijing to increase accuracy: 1) residential, 2) business; 3) entertainment; 4) scenic areas; 5) open (including parks, outdoor locations etc.); 6) other (areas with limited human activities). The method was applied in two steps: first, a support vector machine was adopted to classify the RSI and MPPD; second, classification results were fused using a decision fusion strategy to generate the land use map. This method is also helpful for analysing the activity density in key zones during day-time and night-time to illustrate the volume and variation of people working and living across different regions.

Gervasoni et al. (2016) present a GIS-based land use mix analysis framework for urban planners using OpenStreetMap crowd-sourcing data and Kernel Density Estimation, with the degree of land use mix measured using the Entropy Index calculation. In terms of potential land use mix measures, the literature is extensive, particularly in relation to active transport (Manaugh & Kreider, 2013). Whilst a variety of different approaches are available, most contain two concepts either implicitly or explicitly – distance and quantity – and reflect how the quantity and proximity of one type of land use influences the utility of another (Song, Merlin & Rodriguez, 2013). Song, Merlin & Rodriguez (2013) reviewed a range of common measures of urban land use mix to understand their differences and identify their strengths and limitations, including landscape ecology metrics such as Percent/Proportion; Balance Index; Entropy Index; Herfindahl-Hirschman Index and so on. They categorise these as:

- ‘integral’ measures – which measure area-wide totals of land use types tend to reflect land use balance, or whether various land uses are present in equal proportion in the area as a whole (e.g. Percentages, the Balance Index, the Entropy Index and the Herfindahl–Hirschman Index); or
- ‘divisional’ measures – that examine at the finer level of district and tend to reflect evenness, or whether one district tends to look like another (Song, Merlin & Rodriguez, 2013).

Whilst integral measures are relatively easy to compute and understand, they have some significant limitations in terms of masking micro-scale variation and being sensitive to the size of area under analysis (Song, Merlin & Rodriguez, 2013). Divisional measures are sensitive to variations of land use patterns within an area, but not to variations of land use pattern within district boundaries, or typically to the spatial arrangement of districts relative to each other, and depending upon the geography of the division (i.e. the size and shape of the districts), the same mixed use measure will produce different measurement results (Song, Merlin & Rodriguez, 2013). The results of applying 14 mixed use measures to both simulated and real-world data suggest that integral mixed-use measures provide measures of overall land use balance, whereas divisional measures provide measures of evenness (Song, Merlin & Rodriguez, 2013). Selection of the appropriate mixed-use measure requires knowledge of the number of land use dimensions of interest and the approximate scale(s) at which land use mix influences the outcome of interest (Song, Merlin & Rodriguez, 2013).

Manaugh & Kreider (2013) provide a novel land use interaction method for measuring land use mix that accounts for the extent to which complementary land uses adjoin one another, and which can potentially improve the explanatory power of land use mix when modelling walking and cycling. The results of this study suggest that the focus that the entropy index places on the balance of land uses is misplaced, and that equal proportions of land uses are somewhat arbitrary in predicting travel outcomes.

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Moreover, the authors concluded that area-based measures of land use mix do not adequately capture the subtleties of land use mix. Thus, the degree to which an area shows fine-grained patterns of land use is shown to be more highly correlated with behaviour outcomes than indices based solely on the proportions of land use categories (Manaugh & Kreider, 2013). Gehrke & Clifton (2016) identify some of the conceptual and methodological shortcomings of current land-use interaction and geographic-scale representations, and outline why a mix measure that includes a spatial-temporal element is needed to better understand land-use mixing and travel behaviour. As a method for measuring different aspects of urban sprawl, Arribas-Bel et al. (2011) propose measuring:

- 'urban morphology' - which includes variables such as the scattering of urban development, the connectivity of the area, and the availability of open space, and
- 'internal composition' - which includes density, decentralisation and land-use mix (measured using the Simpson's Index (Torrens, 2008)).

Using land cover data derived from EEA datasets (Urban Audit, Corine, and UMZ), the above indices were calculated for a sample of European cities and the information analysed using a 'self-organising map' algorithm, that can visualise and map urban form and the mix of land uses and be used to differentiate urban sprawl from compact development and identify hot-spots of urban sprawl in Europe (Arribas-Bel et al. 2011). Local policy makers may find the approach useful to view their cities or regions in the supra-national context and in comparison with other European areas (Arribas-Bel et al. 2011).

LandSense (https://landsense.eu/) is an EU project that aims to engage citizens in monitoring change in the urban landscape that can be integrated into local authorities databases to improve urban planning (Olteanu-Raimond et la., 2018). The LandSense observatory collects data both actively (through citizens) and passively (from authoritative, open access, and other citizen-based initiatives) and integrates them into an open platform that provides valuable quality-assured in-situ data for SMEs, larger businesses, government agencies, NGOs and researchers. The LandSense Engagement Platform will become a marketplace where citizens can participate in Land Use and Land Cover (LULC) campaigns and can register new or reuse existing services. Citizens use a mobile app to validate current land use and add new information for land use changes (under the name PAYSAGES in France). Campaigns can be opportunistic or guided, and contributors would typically either: edit a feature, add new information about a feature, report of change or an error in existing data, take pictures of features depicted on the map (Olteanu-Raimond et la., 2018).

At a site or project level, a Green Space Factor score (between 0 and 1) can be calculated based on score assigned (by a planning authority) to any particular surface-cover type (e.g. asphalt, lawn, green roof etc) as a measure of land use mix at a microscale. The area for each surface cover type is calculated and multiplied by its factor, and the overall total score is divided by the total area of the project. The project score can then be compared to targets set by local authorities.

GSF can provide certainty for developers regarding expectations for urban greening for new developments. It can identify planning proposals with insufficient quantity and functionality of greening, encourage improvements in greening, and compare and evaluate proposals for a site. Examples are Malmo's Green Space Factor and Green Points system (Kruuse (2011), the City of London's Urban Greening Factor Study (Grant, 2018)and Southampton City Council's GSF guidance available at: https://www.southampton.gov.uk/policies/green-space-factor-guidance-notes-2015_tcm63-371696.pdf.

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Evaluation of land use mix can be used to:

- Ensure better urban design in the context of scarce land resources and the potential benefits of using nature to address the challenges of cities (European Commission, 2018);
- Enhance the design of compact cities to ensure integration of nature-based solutions to deliver a balance of social, economic and environmental benefits;
- Address the challenge of urban sprawl, limit land take and help build compact liveable;
- Support ‘no net land take by 2050’ targets (European Commission, 2016).

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ENVIRONMENTAL INDICATORS - FEATURE

CONNECTING NATURE

Air quality change

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Description

Measurement of change in air quality through nature-based solution implementation. Typically, such evaluation will be linked to the strategic planning of nature-based solutions to intercept atmospheric pollutants through the use of street trees, urban woodlands, green walls, green roofs, hedgerows, etc. Scale and location are critical components of this indicator as, whilst localised nature-based solution interventions could reduce overall air pollution on a city-scale, poorly planned nature-based solutions have been reported to exacerbate localised air pollution by vegetation releasing volatile organic compounds (VOCs) and/or disrupting wind flows and trapping poor quality air increasing public exposure (Vos et al. 2013; Shaneyfelt et al. 2017). This localised effect should be considered, particularly when adopting spatial modelling-based metrics for this indicator.

Methodology

Urban nature-based solutions can affect local and regional air quality through several different mechanisms (Escobedo and Nowak 2009).

Level of expertise

Some expertise required for installation of equipment and/or sampling methodology. Expertise required for sample analysis depends on the level of automation of the sampling equipment. For example, samplers that include automated analysis generally only require calibrating. Samples than are not automatically analysed generally require specialist analytical methods, these are typically carried out through an accredited laboratory. Biological monitoring methods can be simpler, sometimes only requiring species identification skills. Data analysis/interpretation against statutory guidelines can be very basic once systems are in place. Applying remote sensing technique requires expert knowledge. According to Martin (2008), aerosol remote sensing at visible wavelengths exhibits high sensitivity to boundary layer concentrations. Although atmospheric scattering and surface emission of thermal radiation generally reduce instrument sensitivity to trace gases near the surface, a strong boundary layer signal in NO2 arises from its large boundary layer concentrations relative to the free troposphere. Recommendations are presented including (1) additional dedicated validation activities, especially for tropospheric NO2 and HCHO; (2) improved characterization of geophysical fields that affect remote sensing of trace gases and aerosols; (3) continued development of comprehensive assimilation and inversion capabilities to relate satellite observations to emissions and surface concentrations;

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Scientific solid evidence

Robustness of evidence depends upon the precision and accuracy of the method adopted. Frequency and design of sampling is also linked to the strength of evidence. For example, regular interval sampling may provide long-term and seasonal patterns but may miss significant short-term events. Modelling impacts of nature-based solutions might be the most cost-effective mechanism for generating usable data but there may be a trade-off with accuracy if local context is not incorporated. The properties of satellite data are highly complementary to ground-based in-situ measurements, and whilst remotely sensed data have distinct benefits, the interpretation is often less straightforward compared to traditional in-situ measurements. Integrated approaches using satellite data, ground-based data and models combined with data assimilation, could provide improved characterisation of air quality. Maps of air pollution measured from space can have a strong impact on the general public and the policy makers (Veefkind et al. 2007).

Extended methodology

This includes:
·Removing atmospheric pollutants (Dochinger et al. 1980; Scott et al. 1989);

- Emitting atmospheric chemicals from the vegetation and emissions through nature-based solutions maintenance (Calfapietra et al. 2013);
- Lowering urban microclimate temperatures through shading and evapotranspiration (Nowak et al. 2000; Moss et al 2019);
- Changing wind patterns (Wang et al. 2001; Shaneyfelt et al. 2017);
- Modifying boundary layer heights (Beckett 1998);
- Reducing building energy use and consequent emissions from power plants (Castleton et al. 2010; Lee and Jim 2019).

Due to this diversity of potential impacts of nature-based solution implementation on air quality, the first step to establishing evaluation indicators is to determine those that are relevant to the specific project. For this, it is important to consider which air quality impacts the nature-based solution project is being implemented to deliver (benefits), and which other impacts are likely to be delivered incidentally (co-benefits). It is also useful to consider any negative impacts that might occur (disbenefits).

(4) development of satellite instruments and algorithms to achieve higher spatial resolution to resolve urban scales, facilitate validation, and reduce cloud contamination that increases remote sensing error; and (5) support for the next generate of satellite instrumentation designed for air quality applications.

Data collection

Cost

Can be low cost, but this is very dependent upon the level of sophistication, frequency of sampling, and automation of the equipment. The financial requirements associated with this indicator tend to be associated with a sliding scale of cost. Cost increases with: greater numbers of air quality parameters; greater numbers/frequency of sampling; and greater levels of precision and accuracy. Cheapest solutions are generally represented by the use of citizen science, particularly in relation to monitoring biological indicators. In-situ continuous monitoring equipment can have relatively large up-front costs, but can represent value for money compared to repeated laboratory analysis for long term studies and costs for labour for collecting/changing samples.
Remote sensing data for monitoring air quality in cities and countries can provide a wide territorial coverage at relatively low cost, but typically the use of RS data necessary to conduct complex work requires verification and comparison with ground-based measurement tools. The following are freely accessible RS data that can be used for air quality assessment:
·Glovis - Global Visualization Viewer, with easy-to-go navigation tools (http://glovis.usgs.gov/);
·NASA (http://reverb.echo.nasa.gov);
·Hyperspectral Unmixing, Ground Truths (http://www.escience.cn/people/feiyunZHU/Dataset_GT.html);
·http://openremotesensing.net provides access to MATLAB codes of different remote sensing fields, and other invaluable free data;

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By identifying these, it is possible to develop a theory of change to determine which aspects of air quality are most relevant and should be evaluated.

Basic measurements in relation to air quality have tended to either focus on measuring change in local air quality before and after an nature-based solution intervention, improvement in air quality behind or within the nature-based solution (Yin et al. 2011), or measurement of the pollutants directly absorbed or intercepted by the vegetation. The difference between absorption and interception is a critical factor in relation to air quality improvement. Absorption corresponds to a direct reduction in pollutants like sulphur dioxide (SO_2), nitrogen dioxide (NO_2), and ozone (O_3) through leaf stomata and the dissolving of water-soluble pollutants on moist leaf surfaces (Nowak, 1994).

Interception represents a more temporary removal of particulate matter from the air through sedimentation/impaction on leaves (Beckett et al. 1998). This comprises temporary removal as, unless the particulates are washed off the vegetation and locked away in soils or storm drain systems, the possibility of resuspension still exists (Przybysz et al. 2014).

A strong link has been established between particulate air pollution and poor health. As a result of this, the PM10 value is typically used as a measure of particulate matter pollution in relation to causing illness (Beckett et al. 1998).

Other parameters used to measure air quality have included:

- PM2.5/PM0.2 (Sæbø et al. 2012);
- Total Suspended Particles (TSP) (Monn et al 1995)
- Ozone (O_3) (Cardelino and Chameides 1990)
- Sulphur dioxide (SO_2) (Zhan et al. 2018)
- Nitrogen dioxide (NO_2) (Zhan et al. 2018)
- Volatile organic compounds (VOCs) (Calfapietra 2013)
- CO (Zhan et al. 2018)
- Lead (Pb) (Mage et al. 1996)
- Carbon flux (See "Carbon storage OR carbon sequestration in vegetation/soil")

Selection of pollutants to evaluate in relation to nature-based solutions implementation tends to be related to the local/regional problems in relation to air quality where the nature-based solution is being implemented and the type of nature-based solution being implemented.

-http://freegisdata.rtwilson.com provides a categorised list of links to over 300 sites providing freely available geographic datasets all ready for loading into GIS.

For downloading users have to register. The images are provided as jpg for a quick preview, but also as the complete spectral-data set. There are the manuals to explain how to use the portal.

Effort

Automated in-site data-gathering and analysis is very low effort, with installation, data analysis and equipment maintenance the only inputs required. The only onerous aspect can be the volume of data generated. If samples are taken manually, or auto-sampling does not include analysis, effort can be substantially more with container preparation and site visits required plus post-collection analysis. Effort under this scenario will be strongly linked with frequency of sample collection. Effort can also be linked to the duration of the monitoring, with short-term analysis of impact relatively low effort compared to long term monitoring schemes that evaluate change in nature-based solution performance over time (linked to changing performance with maturation/management of the nature-based solution). For remote sensing approaches, the level of effort involved would be dependent on the scale and amount of data to be analysed, the level of automation of data processing, and the level of technical expertise already available. With the availability of high-resolution remote sensing images and multi-source geospatial data, there is a great need to transform Earth observation data into useful information necessary for urban planning and decision making related to air quality improvement.

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To measure change in local air quality, quantification of pollution reduction is typically done using system modelling combining hourly meteorological data and air pollutant concentrations, with canopy cover data (Scott et al. 1998). Direct sampling to quantify air pollution concentrations typically uses either passive sampling (based on diffusion) or active sampling using pumps. Generally, in-situ continuous monitoring is used to generate averages over set time periods (IARF 2016a). A comprehensive review of measurement methods for different pollutants has been carried out by IARF (2016b). This includes information on practicality, precision, and costs of different methods for each pollutant. Such monitoring is commonly carried out formally across populated areas in many cities to comply with air quality standards. These monitoring networks are typically implemented across a series of fixed points covering the city to continuously measure key pollutants: SO_2 (sulfur dioxide), NOx (nitrogen oxides), CO (carbon monoxide), O_3 (ozone), PM10 (coarse particles) and PM2.5 (fine particles), C_6H_6 (benzene), and Pb (lead) (Năstase et al. 2018). If nature-based solution projects are located in the vicinity of such monitoring stations, or are implemented on a scale considered sufficient to have wide-ranging impact across cities or city regions, these data sources can be used to monitor nature-based solution impacts before and after implementation.

If accurate measurements are required but with greater flexibility on location (e.g. at a finer spatial scale to fixed point monitoring stations), stationary portable monitors are available that retain a relatively high level of accuracy, but that can be easily moved between locations. A comprehensive literature is now available in relation to the systems available and the opportunities for implementation (Morawska et al. 2018). Miniaturisation of these systems through the development of microsensors is enabling greater flexibility in terms of monitoring location. Such sensors have greater flexibility than fixed stations and stationary portable monitors in terms of where they can be placed, including being carried by subjects (Marć et al., 2012; McKercher et al. 2017). This enables more effective assessment of exposure levels. Such sensors provide an opportunity for more personal monitoring, enabling exposure in more precise locations related to nature-based solution implementation to be monitored, and also providing an excellent opportunity for citizen science approaches (McKercher et al. 2017).

Data availability

Many ground-based measurement approaches generate new data, or it is possible to use existing city-wide air quality monitoring station data if available. Baseline data prior to intervention is not always necessary as it may be possible to measure air quality across the nature-based solution (from pollution source to leeward side) to get a measure of air quality change. If comparison to a previous green or grey space is required, establishing baseline data prior to installation can be of benefit. Alternatively, a control space without a nature-based solution but with a high likelihood to be experiencing the same air pollution levels as the nature-based solution site could also be used for comparative purposes. Remote sensing data is widely available free of charge (see Cost section above for examples). According to Vatseva et al. (2016), recently available Sentinel-2A (S2A) multispectral satellite imagery are provided free of charge in the frame of European Copernicus Earth observation program, and the target minimum mapping unit presents a five-fold improvement compared to Urban Atlas, i.e. 500 m^2 as well as more frequent and timely data updates compared to Urban Atlas.

Geographical scale

Implementation scale can be very different depending on indicator metrics used. Direct sampling tends to be focused on a component or site scale. Spatial modelling can be carried out on all scales including city and region scales. Evaluating over a range of scales can be critical as local impacts can vary substantially compared to larger-scale impacts. Both low and medium spatial resolution remote sensing products have been be applied to the identification of vegetation types and their role for air quality improvement at the city and regional scale.

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It has been recognised, however, that such democratisation of air quality monitoring can lead to issues related to comparability of data when common protocols are not adopted for data collection across studies (Hubbell et al. 2018; Morawska et al. 2018). This should be a critical consideration when planning air quality evaluation indicators across and between cities.

Examples of use of low-cost monitoring methodologies to promote community participation include:

- Wearable sensors for monitoring PM levels in London Underground stations (Zhang et al. 2017);
- Crowd sourced air quality monitoring programmes (Thompson 2016);
- Personal ozone monitoring (Cao and Thompson 2016);
- Use of smartphones to collect air quality data (Pereira et al. 2018);
- Use of low-cost sensors to cover new pollutants and new areas (Commodore et al. 2017);
- Toolboxes of monitoring systems to support citizen science (Barzyk et al 2016);
- Nitrogen dioxide passive diffusion tubes for ambient measurement (Kirby et al. 2000).

Such studies have demonstrated that low-cost sensors can make a valuable contribution to understanding and awareness-raising in relation to air pollution exposure (Jerrett et al. 2017).
Biological monitoring of air quality using plant/lichen growth patterns in relation to the presence of air pollutants has also been used as a mechanism for assessing air quality (Matos et al. 2019, Limo et al. 2018), including for promoting a participatory approach (Nali and Lorenzi 2007).
For the measurement of the pollutants directly absorbed or intercepted by the vegetation, methods adopted have focused on the physical removal and analysis of samples of vegetation, or the 'washing' of material from foliage (Dzierzanowski et al. 2011; Weerakkody et al. 2017). For air pollution deposition sampling over known time periods, vegetation is washed at the beginning of the study to establish a baseline (Weerakkody et al. 2018). Once samples are obtained, standard laboratory analytical methods and/or scanning electron microscopy are used to identify accumulation rates (Weerakkody et al. 2017).

Temporal scale

Monitoring methods can be adopted for short-term snapshots associated with impacts immediately following implementation. However, long-term in-situ monitoring is generally more effective in terms of capturing a more comprehensive overview of the performance of the nature-based solution over a range of environmental conditions. Long-term monitoring is also recommended as nature-based solution performance could be expected to change over time.
Existing satellite applications can suffer from poor temporal resolution. Pollution clouds e.g. gas, smoke from a fire or invisible gas, move at (roughly) the same speed as normal clouds and therefore remote sensing is not always appropriate if there are scattered clouds but is better if cloud cover is consistent. A long-term daily average will give typical background levels, however, air quality (i.e. short-term exposure) is more concerned with the magnitude and duration of temporal maxima during air quality events. The trade-off is usually between temporal and spatial resolution, and the size of the domain. Using high temporal resolution remote sensing images together with vegetation phenological features can achieve more accurate identification of vegetation types and thus better predict the effects of urban green for air improvement through implementation of particular nature-based solutions.

Participatory process

Participatory processes represent a key part of air quality monitoring as they are directly linked to assessing exposure, raising awareness, and behaviour change. Air quality analysis can be linked to local schools/universities through the use of microsensors, and biological indicators. Automated sampling and analysis equipment offer less opportunity for such participation with participation limited to observing and/or processing the data produced.

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Results from these absorption/interception studies, combined with more controlled studies under laboratory conditions (Blanus et al. 2015), has typically been fed into the development of a series of modelling tools designed to predict the impact of nature-based solution implementation on air quality level (e.g. Hirabayashi et al. 2012). These include iTree (Hirabayashi et al. 2012), UFORE (Nowak et al. 1998) and the FRAME models (MacDonald et al. 2007). Examples of the implementation of such tools are widespread (Nowak et al. 2016; Rogers et al. 2018) with numerous resources listed on the iTree website (https://www.itreetools.org/resources/reports.php). Recent studies have, however, questioned the reliability of some of the long-held assumptions behind these models (Xing and Brimblecombe 2019), including the lack of consideration of disservices of nature-based solution implementation (Pataki et al. 2011).

In addition to direct sampling of air pollutants, various methods have been employed that use modelling or remote sensing methods to quantify the impact of nature-based solutions on air quality. This includes the use of emerging predictive tools such as iTree (2019) and long-established multilayer models (e.g. for sulphur dioxide) (Baldocchi 1967). Open-access tools such as i-Tree (Tools for Assessing and Managing Community Forests; https://www.itreetools.org/tools) provide a valuable database on tree species, as well as options to quantify benefits and ecosystem services of community trees and forests. While the chemistry is fairly well understood, the quantification of emissions generated by nature-based solutions in specific cities and their contribution to airborne particles is still a grey area in research. In addition, the World Urban Database and Access Portal Tool (WUDAPT; http://www.wudapt.org/wudapt/) is another type of complementary database that provides climate-relevant information on urban centres across the world in the form of local climate zones using remote sensing imagery (Hammerberg et al., 2018; Kumar et al., 2019). It also captures variations across urbanised landscapes (Hammerberg et al., 2018). Such a database could complement dispersion modelling, which together with the deposition component in the i-Tree model, could support the multidisciplinary assessment of nature-based solutions impact on pollutant concentrations at a city scale. Remote sensing can be used to measure the scattering and absorption of infrared, visible, and ultraviolet radiation at different wavelengths along a sight path.

Several studies revealed the success of incorporating remote sensing and citizen's perception of green space and especially their role for air quality improvement (Chen et al., 2018; Schöpfer et al., 2005).

Earth observation/remote sensing/modelling

The Feature indicator reviews are combined for applied metrics and earth observation/remote sensing/modelling approaches.

Connection with SDGs

Goal 3	Goal 10	Goal 14
Goal 4	Goal 11	Goal 15
Goal 6	Goal 12	Goal 16
Goal 8	Goal 13	Goal 17
Goal 9		

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Original reference for indicator

Eklipse; Baró et al., 2014

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Path lengths may range from a few metres, used for in-plume monitoring, to thousands of kilometres for geostationary satellites (Hidy et al., 2009; Hoff & Christopher, 2009). Satellite remote sensing estimates for PM, NO2, SO2, and some other pollutants often correspond to urban and industrial areas, but spatial resolution is limited to about 10 km.

As stated by Martin (2008), satellite remote sensing of air quality has evolved dramatically and global observations are now available for a wide range of parameters including aerosols, tropospheric O3, tropospheric NO2, CO, HCHO, and SO2. Satellite retrievals can add synoptic and geospatial context to ground-based air quality measurements and can be applied to qualitative, quantitative and numerical modelling analyses of events that affect air quality (Martin 2008). Nonetheless, the review highlights the need for improvements in the capability for satellite remote sensing of air quality in the boundary layer, particularly in relation to focusing on pollution gradients within cities, because spatial resolution of satellite observations can be insufficient to resolve intra-urban scales (Martin 2008).

In the study of Bagheri et al. (2017), land use maps including 6 classes of green space, urban areas, roads, river, agriculture lands, and barren land were produced using maximum likelihood algorithm and the landscape metrics were analyzed using FRAGSTATS software. Then, a partial least square (PLS) model was applied to assess the effects of changes in the pattern of green space on air pollution. The model results indicated that reduction in the area of large green space patches promote air pollution, suggesting that there is a direct relation between increases in the area of large green space patches and air pollution reduction. Similarly, Vatseva et al. (2016) mapped urban green spaces based on remote sensing data and confirmed the positive impact of urban green spaces on air quality. Schöpfer et al. (2005) present an approach that uses remote sensing data sets and GIS layers to provide spatially disaggregated information of green space. Their approach is to combine image processing, GIS and spatial analysis tools to quantify urban structures in terms of greenness, generating a spatially disaggregated 'green index' from classified orthophotos (with additional weighting factors), which can form part of an indicator set for Salzburg city and can be used for assessing impacts to air quality.

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Other studies using remote sensing techniques for air pollution assessment include:

- regression models to analyse and map the relationship between Air Pollution Index (API) indicators, remote sensing and ground-based measures of NO2 and PM2.5 in several cities of Ukraine (Putrenko and Pashynska, 2017);
- an algorithm to provide a reliable and cost effective technique for estimating and mapping PM10 using Landsat satellite images (Lim et al. 2009)
- estimating air quality in the form of aerosol optical depth (AOD) from Landsat ETM+ images as part of a study to develop an integrated index of urban environmental quality (UEQ) which can be used by planning and environmental authorities as an objective measure of environmental quality over a whole city, for comparisons between places and cities and for monitoring changes over time (Nichol and Wong, 2009).

Microscale simulations are also becoming more commonly employed for street-scale evaluation (Wania et al. 2012), with software such as ENVI-MET (Bruse 2007) commonly being adopted (Simon et al. 2019).
Further detail on current understanding on the links between nature-based solutions and urban air quality can be found in recent reviews (e.g. AQEG 2018, Ferranti et al. 2019).
Data on the air quality performance of nature-based solutions collected in these ways can be used to:

- Quantify the benefits of nature-based solutions in terms of air quality improvement;

- Assess any negative impact on air quality of implementing nature-based solutions;

- Underpin evaluation of the health impacts of air quality;

- Assess compliance with Ambient Air Quality Directives;

- Provide easily accessible data to communities and decision-makers to promote the uptake of nature-based solutions to provide clean air spaces.

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ENVIRONMENTAL INDICATORS - FEATURE

CONNECTING NATURE

Tree shade for local heat change

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Description

Trees as nature-based solutions to create shade in neighbourhoods measured by °C or K per spatial unit (m2).

Methodology

Thermal comfort in cities has increased in importance due to impacts from global warming and high-density urbanisation. Metrics to measure the shading services provided by trees are largely based on quantifying differences in local air temperature from unshaded areas. The effect of tree shade on local temperature may be upscaled to a citywide impact if modelled and assessed cumulatively. This indicator principally concerns measuring how tree shade effects urban microclimates, in particular by intercepting solar radiation preventing warming of the ground and thereby reducing surface temperature.

Level of expertise

Some expertise may be required in relation to appropriately designing studies and with respect to the selection/use of specialist instrumentation and software such as ENVI-met. Expertise in relation to mapping (especially those based on remote sensing and GIS techniques) and modelling will be necessary.

Data collection

Cost

Cost would be linked to the scale of monitoring and the complexity of equipment used. Basic digital thermometers and thermocouples are relatively cheap, but cost increases when these are linked to dataloggers. However, this could be offset by decreased staff costs for data collection. Overall cost also tends to be linked to the level of precision of equipment and the number of sampling points. Li et al.'s (2018) study provides a fully automatic workflow for quantifying the shade provision of street trees without much cost and computational burden.

Effort

With field measurements, effort is related to frequency of visits and number of sampling points/measurements. If feasible, automated in-situ data gathering is very low effort, with installation, data analysis and equipment maintenance the only inputs required. Li et al. (2018) state that the datasets required in their proposed method of study are easily accessible for most cities, and that all the data collection and image processing procedures could be done on a personal computer.

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Scientific solid evidence

Robustness of evidence depends upon the level of precision of the equipment, the spatial design of the monitoring and the duration of temperature recording. Generally, direct measurement in the field can provide greater confidence than microclimate simulations, and it can be hard to accurately scale-up local measurements to the whole city. Photographic methods yield good results, but they typically require manual acquisition and processing of fisheye images, which is time consuming and not feasible at the neighborhood or city-scale (Middel et al., 2018). To accurately simulate the thermal performance benefits that trees provide, it is necessary to account for growth and phenological changes in tree shade amount and quality and the influence of street canyon geometry.

Extended methodology

Other basic measures of air temperature covered in Env03 (Air temperature reduction) such as apparent temperature (the temperature equivalent perceived by humans – based on air temperature, relative humidity and wind speed), and Physiological Equivalent Temperature (thermal perception of an individual including thermal physiology) can also be used to evaluate the human thermal comfort conditions associated with tree shade (e.g. Kàntor et al., 2018). Various factors such as tree species (size, shape, leaf type, seasonality etc), tree age, distance between trees, type of surface beneath the tree, surrounding environment and climate will impact the degree of shade provided.

The classical methodical approach for measuring tree shading was developed by Barlow and Harrison (1999) and considered different factors affecting shading, such as topography, time of day and year and geographical location. They provided mathematical descriptions and procedures used to calculate the length of the shadow and its duration (Barlow & Harrison, 1999).
The shade from tree canopies can generate significant surface cooling in cities, particularly over impervious surfaces such as asphalt, where a temperature reduction of about 6°C has been recorded (Rahman et al., 2019).

In this study, for all 11,451 GSV panoramas in Boston, it took about 48 h to collect all GSV panoramas, process synthetic hemispherical images, and generate the shade estimation result on a 64-bit desktop computer with 8G RAM and 3.7 GHz processor (Li et al., 2018).

Data availability

This indicator mostly involves generating new data. However, it is also possible to use publicly available data such as Google Street View to estimate canopy cover. Baseline data prior to intervention is not always necessary as it may be possible to measure temperature at increasing distances away from nature-based solutions to quantify effect. If comparison to a previous green or grey space is required though, establishing baseline data prior to installation can be of benefit.

Geographical scale

Typically, tree shade effects on temperature are measured in terms of the local microclimate impact. Wang et al. (2018) propose a modelling framework for the shading effect of trees that can be used at the city and regional scale with moderate accuracy.

Temporal scale

Monitoring methods tend to be adopted for short-term snapshots, for instance to show benefits on days of extreme heat. Monitoring should be undertaken at repeated intervals to capture a more comprehensive overview of the performance of trees and account for change over time and under different climatic conditions. Establishing a network of sensors across the city could provide a useful baseline as tree-planting is upscaled across the city to a scale that impacted city-wide temperatures, if this was planned.

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This study examined the vertical temperature gradient beneath two common urban street tree species Tilia cordata and Robinia pseudoacacia, recording a range of morphological measurements (e.g. diameter at breast height (DBH), tree height, crown projection area (CPA) and leaf area index (LAI) derived from hemispherical photographs), as well as air and surface temperature and various other meteorological data, collected using a combination of temperature loggers at 3 different heights and weather stations installed at the study sites (Rahman et al., 2019). Surface cooling was strongly correlated with LAI, and the relationship was found to be stronger over asphalt than grass, indicating therefore that tree species with higher canopy density might be preferential when planted over asphalt surfaces in cities, but low water using species with lower canopy density could be chosen over grass surfaces (Rahman et al., 2019).

In a meta-analysis of the characteristics of urban tree species that influence cooling potential, a total of 13 studies were analysed that reported on cooling by shading (as measured by surface temperature difference ΔST), and consensus from the review in terms of surface cooling was that the following parameters contributed to ΔST in order of relative importance: climate > below canopy surface > growing size > leaf thickness > LAI > crown shape > plant functional type > habitat > wood anatomy > leaf shape > leaf colour (Rahman et al., 2020). LAI was again reported as the most influential driver of cooling benefits in terms of human thermal comfort, although vertical leaf area densities can also be influential, and species with higher leaf density at the lower crown may ensure better cooling benefits (Rahman et al., 2020). Studies reviewed in the meta-analysis used various methods for gathering data on tree shade effects on surface temperature, for example:

- Field measurements: empirical microclimate measures using for instance temperature sensors attached to dataloggers, infrared thermometers/thermal cameras, globe thermometers (to measure radiant temperature as a determinant of physiological equivalent temperature (PET) which is used to assess human thermal comfort), in combination with weather station data and tree species morphology (i.e. height, canopy spread and LAI (using a LAI analyser/ceptometer or hemispherical images) (Lin & Lin, 2010; Armson et al., 2012 & 2013; Devia & Torres, 2012; Berry et al., 2013 (building walls rather than ground level); Millward et al., 2014; Gillner et al., 2015; Napoli et al., 2016; Rahman et al., 2018; Stanley et al., 2019); also leaf colour (using colorimeter), leaf thickness

Participatory process

Opportunities are available for participatory processes in relation to collecting temperature measurements using mobile dataloggers or wearable sensors (Shandas et al., 2019), as well as collecting very basic information such as tree locations, or updating existing inventories to determine where trees have been planted or removed (as based on the findings of Berland et al. (2019).

Earth observation/remote sensing/modelling

The Feature indicator reviews are combined for applied metrics and earth observation/remote sensing/modelling approaches.

Connection with SDGs

Goal 1	Goal 9	Goal 15
Goal 3	Goal 10	Goal 16
Goal 4	Goal 11	Goal 17
Goal 6	Goal 13	
Goal 8	Goal 14	

References

Original reference for indicator

Haase et al. (2014), Andersson et al. (2014), Kremer et al. (2018)

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(using thickness gauge) canopy coverage area (using handheld GPS and walking a transect round the tree canopy edge) and canopy thickness from photographs of individual trees (Lin & Lin, 2010); hemispherical photographs to measure tree shade cover on walls (Berry et al; 2013);

- statistical/modelling techniques: linear mixed model and/or regression analyses of field data (Lin & Lin, 2010; Armson et al., 2012; Milward et al., 2014; Gillner et al., 2015; Rahman et al., 2018; Stanley et al., 2019), shade area analysis (Armson et al., 2013), vertical shading coefficient of walls (Berry et al., 2013); a heat transfer model, which was found to be effective at predicting surface temperatures of pavements and lawn under different trees (Napoli et al., 2016);

Rötzer (2019) presents different techniques for greening cities, particularly through planting trees in all climate zones, as effective tools to mitigate climate change and the Urban Heat Island (UHI), and provides empirical as well as modelling studies of urban tree growth and their services and disservices in cities worldwide, including the dynamics, structures, and functions of urban trees, as well as the influence of climate and climate change on urban tree growth, urban species composition, carbon storage, and biodiversity.
Stanley et al. (2019) analysed urban tree growth and regulating ecosystem services along an urban heat island (UHI) intensity gradient in Salzburg (Austria). For the phenological monitoring in spring March – May (and later verification in autumn), they used the well-established method presented by Wesolowski and Rowinski (2006). They developed a scale of point values from 0 to 2 for assessing the development status of a leaf bud. For each observation day, ten randomly selected apical buds in the upper, south-exposed part of the crown are evaluated and their sum is calculated. The monitoring starts when all buds are closed and thus evaluated as having zero points. As soon as all ten leaves are completely developed and each scores two points, the monitoring is finished. Moreover, for all observation trees, the height, trunk circumference at breast height, and leaf area index (LAI) were measured. Using these data, the tree age, crown area, and crown volume were further calculated. The tree height was measured using a Leica DISTOTM D810 Touch (Leica Geosystems); LAI was determined based on LAI-2200C Plant Canopy Analyzer from LI-COR (Lincoln, NE, USA). The measured values were then edited in the FV2200 software from LI-COR (2.1.1, Lincoln, NE, USA).

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The microclimate was measured using the difference of the surface temperatures between the crown-shaded area and the full sun-exposed area using an Infrared Radiometer, Model MI-220. Data were assessed using statistical analysis similar to those applied by Gillner et al. (2015). They found out, after leaves have developed, trees cool the surface throughout the whole growing season by casting shadows. On average, the surfaces in the crown shade were 12.2 ◦ C cooler than those in the sun. Thus, the tree characteristics had different effects on the cooling performance. In addition to tree height and trunk circumference, age was especially closely related to surface cooling. They conclude, if a tree's cooling capacity is to be estimated, tree age is the most suitable measure, also with respect to its assessment effort. Practitioners are advised to consider the different UHI intensities when maintaining or enhancing public greenery. The cooling capacity of tall, old trees is needed especially in areas with a high UHI intensity. Species differences should be examined to determine the best adapted species for the different UHI intensities. The results of such studies can be the basis for modelling future mutual influences of microclimate and urban trees.

An alternative methodology to those above used a high-resolution thermal imaging camera to record the crown temperature of trees from above (using a helicopter), and determined that urban tree temperatures are species-specific due to traits such as leaf size, stomatal conductance and canopy structure, and that foliage temperature was mostly influenced by the location of the tree (i.e. park or pavement) (Leuzinger et al., 2010). Generally small-leaved trees were cooler, but this trend did not always hold at temperature extremes (40°C), indicating that the cooling effect of urban trees could be species and context specific, which may be useful information for future urban tree planning projects (Leuzinger et al., 2010).

Thermal imaging (in combination with a range of other field measurements and photographic records) has also been used to record the surface temperatures of three common urban surfaces – asphalt, porphyry, and grass – in the shade of 332 single tree crowns, of 85 different species, during the peak temperature period of summer days, to evaluate which tree traits play an important role in cooling (Speak et al., 2020).

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Measurements at three locations within the shadow of individual trees revealed higher cooling in the centre and at the western edge and cooling was related to a multitude of tree traits, of which Leaf Area Index estimate (LAIcept) and crown width were the most important (Speak et al., 2020). Median average cooling of 16.4, 12.9 and 8.5 °C was seen in the western edge of the tree shade for asphalt, porphyry and grass, respectively (Speak et al., 2020). Tree traits recorded were modelled using descriptive and predictive multiple linear regression models and were able to predict cooling with some success from several of the predictor variables (LAIcept and gap fraction), which has implications for the selection of trees within urban design schemes by altering the weight given to certain tree traits if high shade provision is a desired outcome (Speak et al., 2020).

ENVI-met (a three dimensional microclimate simulation software) can be used to generate a microscale model simulating various tree canopy scenarios under various climate conditions and investigate the relationship between percentage tree canopy cover and temperature reduction at the neighborhood scale (Middel et al., 2015). The study findings suggested the relationship between percent canopy cover and air temperature reduction was linear, with 0.14 °C cooling per percent increase in tree cover for the neighborhood under investigation, although they highlight Envi-met has various shortcomings, for instance in terms of estimating nocturnal cooling under trees and accounting for anthropogenic heat (Middel et al., 2015). Beyond the local scale, the Weather Research and Forecasting (WRF) model has been coupled with urban land surface processes parameterized by urban canopy models (UCMs) to investigate the radiative shading effect of trees over the contiguous United States (Wang et al., 2018). This WRF-urban modelling framework can be informative to researchers and policy makers, but as it omits other biophysical functions of trees such as evapotranspiration, more work is needed to produce a more comprehensive and realistic representation of urban tree shade cooling effects (Wang et al., 2018).

Remotely sensed tree canopy cover has been widely used to estimate the amount of trees in an area. However, where this is limited to two-dimensional calculations, it may not fully evaluate the shading service of trees as the vertical structure and density of trees can also influence the solar radiation reaching ground level (Li et al., 2018). Google Street View (GSV) provides publicly available, high spatial resolution photographs of vegetation along streetscapes, which can be used to quantify the degree of shading under street trees (Richards & Edwards, 2017).

The GSV panoramas can be transformed into hemispherical images and pixels classified into classes (i.e. sky, trees, buildings), and combined with remotely sensed data (i.e. LiDAR) to enable estimation of canopy cover provided by street trees (Li et al., 2018). A sky view factor (SVF) calculation - the ratio of sky hemisphere visible from the ground that is not obstructed by buildings, trees and terrain - can been applied to these images to quantify the shading effectiveness of street trees alone (SVF ranges from 0 to 1, indicating totally enclosed and totally open street canyons respectively) (Li et al., 2018). The quantitative information and spatial distribution of shade provision by street trees generated by this method can be used as a reference for urban planners and city officials for urban greening projects, for instance so they can target critical areas for urban heat island (UHI) mitigation (Li et al., 2018).

The influence of vertical and horizontal tree canopy structure on land surface temperature (LST) can also be measured using a combination of a high-resolution vegetation map, Light Detection and Ranging (LiDAR) data and various statistical analysis methods (Chen et al., 2020). Results from this method indicated that composition, configuration and vertical structure of tree canopy were all significantly related to both daytime LST and night-time LST, highlighting the important contribution measuring the vertical structure of tree canopies can have in determining LST in cities (Chen et al., 2020).

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The influence of patch size of trees (from 500 m2 – 80,000 m2) on shading has been modelled, using a variety of field measurements (e.g. DBH, distance between trees, temperature, weather etc) and simulated using the solar radiation tool embedded in ArcGIS, and found that multiple small patches can provide more total area of shade than a single large one (Jiao et al., 2017). However, they also found a non-linear relationship between patch size and transpiration, both of which are key cooling services provided by trees, therefore there may be a trade-off between shading and transpiration at certain patch sizes, and with different tree species (Jiao et al., 2017).
A study of the effects of street trees in three contrasting street canyon environments found the cooling and human thermal comfort benefits of street trees were localised and highly variable both spatially and temporally, based on factors such as the amount of shading, street geometry, and the local meteorological conditions (Coutts et al., 2015).
Thus, depending on their position in the street canyon, the prevailing conditions, and time of day, trees can have either a cooling or warming effect, highlighting the importance of strategic placement of trees to maximize their shade area whilst spacing them sufficiently to allow some nocturnal longwave cooling and ventilation, and reduce potentially detrimental impacts on urban cooling at night (Coutts et al., 2015).
i-Tree Canopy (https://canopy.itreetools.org/) is a web browser application that offers a quick and easy way to produce a statistically valid estimate of land tree canopy cover using aerial images available in Google Maps. This can be used as an easy to understand concept for communicating messages about tree cover to policy makers and the public, and can be linked to shading provision in terms of percentage cover/m2 gained/lost in an area being an index of potential shading benefits gained/lost. i-Tree Canopy could also be used to map existing canopy cover in order to determine tree-less areas that may benefit from shade.
The package i-Tree Design (https://design.itreetools.org/) can be used to evaluate the cooling benefits of shade from individual trees on building energy demand.

Mobile sensors (a fast-response, high-accuracy temperature probe, GPS device and data logger) mounted to bicycles have been used to measure temperature variability along urban transects in relation to tree canopy and impervious cover, both of which can interact to influence both daytime and nighttime summer air temperature (Ziter et al., 2019). In this study, generalised additive models were used to test the effect of percentage canopy and impervious cover and distance to nearest lake at 4 scales (10-90 metre radius) surrounding each temperature measurement (Ziter et al., 2019). This fine-scale method detected that canopy cover >40% can counter the warming effect of impervious surfaces during the daytime within a radius of 60-90 m (the scale of a city block). However, the impact at night-time was much less pronounced, indicating that reducing impervious cover as well as tree planting could be key to reducing UHI (Ziter et al., 2019). This method may also be suitable for citizen science projects (Ziter et al., 2019). Citizen science has also been successfully used to collect temperature data in cities using vehicle-mounted temperature sensors and global positioning system devices (GPS), with volunteers undertaking one-hour 'traverses' through study areas in a city to provide a snap-shot of temperatures, which can then be modelled against land use and land cover data to evaluate the role of trees in reducing/amplifying local temperatures and create a heat map for city planners (Shandas et al., 2019).
Other participatory methods include the use of wearable sensors to detect human thermal stress (Sim et al. 2018), which could potentially be used to deliver a citizen science project on the effects of urban tree shade.

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Berland et al. (2019) also confirmed that inventories relying on citizen scientists or virtual surveys conducted remotely using street-level photographs may greatly reduce the costs of street tree inventories since those ones conducted in the field by trained professionals are expensive and time-consuming. However, they pointed here several fundamental uncertainties regarding the level of data quality that can be expected from these emerging approaches to data collection. In particular, 16 volunteers were asked to inventory street trees in suburban Chicago using Google Street ViewTM imagery, and later this was assessed by comparing their virtual survey data to field data from the same locations conducted by experts. The findings suggest that virtual surveys may be useful for documenting the locations of street trees within a city more efficiently than field crews and with a high level of accuracy. However, tree diameter and species identification data were less reliable across all expertise groups, and especially analysts. Based on this analysis, virtual street tree inventories are best suited to collecting very basic information such as tree locations, or updating existing inventories to determine where trees have been planted or removed.
It should be noted that measuring shade alone will not fully capture cooling services provided by trees, since evapotranspiration also plays a role in regulating temperatures. Also, if tree planting is poorly designed, it can lead to disruption of airflows, causing trade-offs such as localised increases in air pollution concentrations (e.g. Vos et al., 2013) and night-time temperatures (Bowler et al., 2010; Coutts et al., 2015).

Data on the reduction of air temperature by tree shade collected in these ways can be used to:

- Quantify the benefits of trees as nature-based solutions in terms of cooling the local microclimate, reducing building energy use and providing thermal comfort zones for residents (synergies with "Air temperature - Energy demand");

- Target tree planting in areas prone to temperature extremes/UHI and/or to provide optimal shade benefit to commuting pedestrians (see also Langenheim et al., 2020);

- Contribute towards other environmental and health and well-being indicators linked to temperature, air pollution, carbon storage, flooding and biodiversity.

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ENVIRONMENTAL INDICATORS - FEATURE

CONNECTING NATURE

Community garden area per child capita and in a defined distance

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Description

A measure of per child capita garden area per target distance - public community gardens provide places of active learning in nature and opportunities for healthy play.

Methodology

Measuring community gardens as part of the greenspace network in cities provides evidence on a wide range of services provided by such spaces. This includes: accessible greenspace provision and preservation, diversity of land use for humans and biodiversity, sustainable use of vacant land, climate regulation (cooling, stormwater, reduced GHG emissions associated with food transportation), food security, physical activity, access to healthy food/fruit and vegetable consumption, community cohesion and empowerment.

Level of expertise

Some mapping/GIS expertise is likely to be needed, in particular when: using remotely sensed imagery and field observations to identify community gardens; applying geographic mapping software to analyse data layers; understanding how the distribution of community gardens relates to children as well as demographic data on race, ethnicity, and socio-economic conditions.

Data collection

Cost

Some map datasets and satellite imagery are freely available online, more comprehensive data needed for network-based measures potentially can involve a licence fee. Could be additional costs associated with acquiring GIS software and specialists if not already available in-house.

Effort

The level of effort involved would be dependent on the amount of data already recorded by the city on community garden distribution, and the expertise available in terms of GIS. Public participation in organised research efforts (citizen science) could be beneficial in terms of reducing the amount data collection needing to be undertaken by in-house personnel.

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Scientific solid evidence

Robustness of evidence will be determined by how detailed existing data is on CGs in a city and accuracy of census data in relation to child capita. Similarly, the accuracy of distance to CG will vary based on the distance measure used. They can, however, represent a useful indicator basis for urban planning.

Extended methodology

Community gardening projects promote healthy lifestyles with educational initiatives such as a community garden club, exercise and nutrition lessons, and environment and recycling education which encourage and enable children and parents to learn collectively about sustainable living in cities. Ultimately, community gardens deliver a social function. In addition to mapping evidence, mapping exercises can also be used to identify areas where future community garden (CG) projects should be targeted (i.e. need for CGs).
Metrics will largely concern identification of CGs as part of the city's greenspace provision and then quantification in relation to population census data and an assessment of accessibility in relation to proximity measures. This indicator differs from Env89 (Community garden area per capita and in a defined distance) in that it is specifically in relation to per child capita. Therefore, the same metrics as for "Community garden area per capita and in a defined distance" are provided below, but census data would need to be interrogated to extract figures relating to the population of children (typically under 16 years old) in the survey area.
Identification of CGs within a city will involve data gathering from land use plans on location, extent and characteristics, analysing official websites to identify additional CGs not included in planning documents, interrogating available satellite imagery provided on regional geoportals, and ground truthing by field observation/surveys (Senes et al., 2016). The collated data can then be entered into a GIS database for digitisation. From this, it would be possible to generate metrics regarding average CG area within the city (m2), and distance from urban centres by overlaying a land use map and mapping buffer areas of 330 and 660 m (which correspond to a walking distance of 5 and 10 min respectively at a speed of 4km/h) (as outlined in Senes et al, 2016).

Data availability

Some GS map data is freely available for mapping distance, aerial data is increasingly available but the quality and resolution can still be variable. This indicator can also be used to generate new data, for instance CG per child capita before and after nature-based solutions project implementation.

Geographical scale

Typically used at city-scale, but other scales such as region/neighbourhood scale are possible.

Temporal scale

Can provide a snapshot or a temporal view of change over time if adequate historical data is available.

Participatory process

The project Incredible Edible Lambeth demonstrates it may be possible to validate CG distribution using a PPGIS-type citizen science exercise. The studies by Ramirez-Andreotta et al. (2015) and Pollard et al. (2017) show that establishing a community-academic partnership, and building a co-created citizen science program in urban community gardens can confirm the role of local knowledge in scientific research.

Earth observation/remote sensing/modelling

The Feature indicator reviews are combined for applied metrics and earth observation/remote sensing/modelling approaches.

Connection with SDGs

Goal 1	Goal 7	Goal 13
Goal 2	Goal 8	Goal 14
Goal 3	Goal 9	Goal 15
Goal 4	Goal 10	Goal 16
Goal 6	Goal 11	Goal 17

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Alternative metrics that have been calculated in a GIS environment include: stratified spatially diverse and representative sampling design based on measuring the district area (ha) and the area of CGs (ha) and calculating a CG area proportion for the city as a % of the overall district area (Speak et al., 2015). Measuring the proportion of households within 0.25 miles of a CG, or a measure of the acreage used for CG per 1,000 residents as measures of accessibility and density (Jakubowski & Frumkin, 2010). Metrics outlined in the indicator review for Env41 (Accessibility of greenspaces) can also be applied here, to provide a 'defined distance' measure for this indicator. For instance La Rosa's (2014) 'simple distance indicators' which measure the Euclidean distance or Network distance to a greenspace, in this case CGs, at a fixed threshold distance of 300 m or 600 m. Within GIS, the total population present (taken from census data) within the considered distance thresholds can be calculated in relation to each CG.

In general, GIS analysis of urban gardens needs the following data to be utilized: community garden outlines (by City Municipality), biotope and land-use survey, and authoritative topographic-cartographic information systems. City-wide VHR hybrid remote sensing comprising Digital Orthophotos (DOP) at 20 cm resolution and LiDAR elevation data at 2 m resolution can be applied. From this, distance to roads, distance to edge of built-up area (urbanity), as well as types and proportion of surrounding structure types can then be analysed. Moreover, it is essential to consider here to the concept of 'walkability' as a measure of how safe/friendly an area is for walking, in particular when evaluating use of community gardens by children. Thus, the following factors influencing walkability should additionally be analysed: the presence or absence and quality of footpaths, sidewalks or other pedestrian rights-of-way, traffic and road conditions, land use patterns, building accessibility, and safety, among others (Speck, 2012). Another important issue to reflect is to analyse how 'child-friendly' is the particular community garden, as it has been confirmed by several studies (ACT, 2013; Shallue 2014) that community gardens can play a powerful role in shaping a child-friendly city. In a physical context, CGs provide children with the opportunity to engage with and explore their natural environment, and the chance to learn about flora, fauna and gardening. Children can also develop new skills and learn about healthy lifestyle choices and nutrition through helping to grow food.

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Original reference for indicator

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This indicator has direct relevance to the objectives of the 'Child Friendly Cities Initiative' of UN Habitat II (https://childfriendlycities.org/), where it was declared "...the well-being of children is the ultimate indicator of a healthy habitat, a democratic society and good governance". In this regard not only provision per child capita, but also the ability of community gardens to give children the opportunity for exploring and learning nature, to connect with their community and foster a sense of belonging should be evaluated. Additionally, community gardens can be assessed from the perspective of how, through playing an active role in the tending of the gardens, children can develop a sense of responsibility, self-confidence and cooperation, all important parts of their social development (ACT, 2013).

As well as providing metrics for calculating existing CG provision, Senes et al. (2016) also provide a methodology for identifying possible sites suitable for CG projects. They identify areas potentially suitable for new CGs on the basis of the following criteria: i) proximity to residential road network, because the accessibility to the CGs is a fundamental requirement for a public service (considers only the residential road network, usually not characterized by heavy traffic); ii) compatible land-use, in order to exclude areas with a land-use that doesn't allow a future transformation to CG; iii) identify areas with soils with land capability class 1 and 2 and exclude from the possible conversion into CG to allow the preservation of agriculture. The data is mapped in a GIS environment to generate a plan of potentially suitable and available areas for new CGs (Senes et al., 2016).

'Incredible Edible Lambeth' (IEL) have created an online map of community garden projects in the borough https://www.incredibleediblelambeth.org/map/ which can be updated by citizens who become a member (for free) online. As well as connecting citizens to CGs in the borough, this also provides a public participation mechanism for generating a comprehensive map of CGs in an area.

A study by Ramirez-Andreotta et al. (2015) illustrates the benefits of a community-academic co-created citizen-science program in addressing the complex problems that can arise for community garden projects neighbouring a contaminated site.

This place-based, community-driven project was designed where academics and community members maintained a reciprocal dialogue, and together: 1) defined the question for study, 2) gathered information, 3) developed hypotheses, 3) designed data collection methodologies, 4) collected environmental samples (soil, irrigation water, and vegetables), 5) interpreted data, 6) disseminated results and translated results into action, and 7) discussed results and asked new questions (Ramirez-Andreotta et al., 2015). Such a project can increase the community's involvement in communication and decision-making, which ultimately has the potential to help mitigate environmental exposure, reduce associated risks and increase the provision of community gardens. It also demonstrates that community members can successfully participate in environmental science investigations. Pollard et al. (2017) also demonstrates that a citizen science approach offers a unique method to investigate provision as well as the inputs (labour, costs and water use) and outputs (produce yields and value) of urban community gardens. Citizen science enables a large cohort of gardeners to identify and measure urban agriculture, notably the sheer number of geographically separated gardens, the enormous diversity of garden sizes and types, as well as highly variable cultivation and management techniques (Pollard et al., 2017).

Mapping community garden accessibility in these ways can be used to:

- Identify deficits and inequalities in relation to community garden access specifically for children;
- Assess changes in access for children in relation to new projects/sites;
- Inform strategic planning decisions in relation to community garden provision for children;
- Assess different types of accessibility;
- Set targets in relation to community garden provision for children and monitor progress towards targets.

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INDICATOR REVIEWS

HEALTH AND WELLBEING

The indicators included in this category form a wide spectrum that allow evaluating the impacts of Nature-based solutions on the physical and mental health of citizens. Indicators related to mental health not only focus on the absence of disorders, but also on the measurement of well-being and the restorative capacity of green spaces. Regarding the physical health indicators, their measurement would provide valuable information on the incidence of chronic diseases, obesity, as well as levels of daily physical activity. Together, this set of indicators allows cities to know the main NBS expected outcomes in the health of adults and children.

INDICATOR REVIEWS

CORE

- General wellbeing and happiness
- Prevalence, incidence, morbidity, and mortality of cardiovascular diseases
- Perceived chronic stress
- Mental health and wellbeing
- Enhanced physical activity
- Perceived restorativeness of public green space

FEATURE

- Sustainable nutrition/adoption
- Life expectancy and healthy life years expectancy
- Prevalence and incidence of chronic autoimmune diseases
- Prevalence, incidence, morbidity, and mortality of respiratory diseases
- Incidence of obesity /obesity rates (adults and children)
- Heat reduced mortality
- Perceived chronic loneliness
- Improvement of behavioural development and symptoms of attention-deficit/hyperactivity disorder (ADHD)
- Exploratory behaviour in children

HEALTH AND WELLBEING INDICATORS - CORE

CONNECTING NATURE

General wellbeing and happiness

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Description

MacKerron and Maurato (2013) distinguish three categories of SWB: evaluative SWB, in which people are asked for global assessments of their lives – for example, their 'satisfaction with life as a whole'; eudemonic SWB, based on reports concerning 'flourishing', purpose and meaning in life, and the realization of one's potential; and hedonic or experienced SWB, based on reports of mood, affect or emotion, and representing the Utilitarian view of wellbeing as pleasure and pain. The authors note that answers across the three categories of SWB or happiness tend to be positively correlated – and also related to other account of wellbeing – but they may respond differentially to different external factors, such as income (MacKerron & Maurato, 2013).

Life satisfaction (Diener, Emmons, Larsen, & Griffin, 1985) is a cognitive, judgmental process based on a comparison of one's current state of affair with a standard that each individual sets for him or herself (i.e., not externally imposed). Diener et al. (1985) developed the Satisfaction with Life Scale (SWLS) around the idea that one musk ask subjects for an overall judgment of their life in order to measure the concept. Life satisfaction belongs to the category of evaluative subjective WB, as organized by current literature (Dolan & Metcalfe, 2012; MacKerron & Maurato, 2013).

Level of expertise

. Methodology and data analysis requires high expertise in psycho-social research

. Quantitative data collection requires no expertise

Data collection

Required data

. Essential: NBS characteristics for each city/site, more specifically nature of activities one can get involved into while engaging with nature, opportunities for social interaction and for physical exercise, etc.

. Essential: Data on "Place Attachment"

. Desirable: Data on symbolic/affective meanings assigned to NBS (case studies, participatory data collection methods) – see also indicator "Place Attachment"

Data input type

Quantitative

Data collection frequency

After NBS implementation or aligned with timing of targeted (especially long-term) objectives

Participatory process

No opportunities identified

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Methodology

Quantitative Procedure:
Scale/Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)

Selective Tool:
Satisfaction with Life Scale (Diener et al., 1985)

Extended description

Cross-disciplinary literature operates with a variety of concepts to delineate general wellbeing (WB) and happiness, such as (subjective) wellbeing (SWB), happiness, life satisfaction (LS), experienced utility, and quality of life (Larson, Jennings, & Coutier, 2016; MacKerron & Mourato, 2013). Cervinka, Röderer, and Hefler (2012) categorize WB as an umbrella-term that includes experiences of positive emotional states and processes ranging from short-term to long-term, from current positive feelings (positive affect) to habitual dispositions (personality-factors), and that encompasses pleasurable affect as well as general life satisfaction. A growing body of empirical evidence documents the otherwise intuitive notion that people who are more connected with nature and engage in nature's beauty (i.e., experience positive emotional responses when witnessing nature's beauty) report more subjective well-being (Frumkin, Bratman, Breslow, Cochran, Kahn Jr., Lawler, Levin, Tandon, Varanasi, Wolf, & Wood, 2017; ; Howell, Dopko, Passmore, & Buro, 2011; Howell & Passmore, 2013; Larson et al., 2016; Pritchard, Richardson, Sheffield, & McEwan, 2019; Zhang, Howell, & Iyer, 2014). MacKerron and Maurato (2013) document theoretical and empirical evidence for at least three reasons for thinking that experiences of natural environments will be positively related to health, wellbeing and happiness:

1. The existence of direct pathways by which such experiences affect the nervous system, bringing about stress reduction and restoration of attention;
2. Natural environments may be lower in environmental 'bads' that have significant negative impacts on physical and mental wellbeing, which in turn could affect happiness;
3. Natural environments might increase happiness by facilitating and encouraging – for practical, cultural and/or psychological reasons – behaviours that are physically and mentally beneficial, including physical exercise, recreation and social interaction.

Connection with SDGs

Goal 3
Goal 11

References

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Research on complex/multi-dimensional relationship between nature connectedness/nature affiliation (i.e., affective, cognitive and experiential factors related to our belonging to the natural world) and wellbeing indicate that exposure to elements of the natural world affects our wellbeing by boosting our positive affect, by eliciting feelings of ecstasy, respect, and wonder, by fostering feelings of comfort and friendliness, by heightening our intrinsic aspirations and generosity, and by increasing our vitality (Capaldi, Dopko, & Zelenski, 2014; Howell & Passmore, 2013).

Strengths and weaknesses

+ Reliable indicator of a global assessment of an individual's satisfaction with own life

+ Empirical evidence as to relationship between subjective wellbeing and connectedness to nature

- Multidimensional and complex construct whose relationship with exposure to nature is mediated/moderated by numerous of variables, like engagement with natural beauty (Zhang et al., 2014), meaning in life (Howell, Passmore, & Buro, 2013), mindfulness (Howell et al., 2011), presence of natural elements (Ryan, Weinstein, Bernstein, Brown, Mistretta, & Gagné, 2010)

Extended methodology

Satisfaction with Life Scale (SWLS – Diener et al., 1985)

It is a 7-point scale comprising 5 items that measure individual's general satisfaction with own life as a cognitive-judgmental process (i.e., based on a comparison with a standard that individual had set for him/herself).
Instructions: Below are five statements with which you may agree or disagree. Using the 1-7 scale below, indicate your agreement with each item by placing the appropriate number on the line preceding that item. Please be open and honest in your responding.
The 7-point scale is: 1- strongly disagree, 2-disagree, 3-slightly disagree, 4-neither agree nor disagree, 5-slightly agree, 6-agree, 7-strongly agree:

1. In most ways my life is close to my ideal.
2. The conditions of my life are excellent.
3. I am satisfied with my life.
4. So far I have gotten the important things I want in life.
5. If I could live my life over, I would change almost nothing.

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HEALTH AND WELLBEING INDICATORS - CORE

CONNECTING NATURE

Prevalence, incidence, morbidity, and mortality of cardiovascular diseases

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Description

Cardiovascular diseases (CVD) generally refers to conditions that involve narrowed or blocked blood vessels that can lead to a heart attack, chest pain (angina) or stroke (Heart Disease, n.d.). They include: high blood pressure, hypertension, arrhythmias (abnormal heart rhythms), heart failure, heart valve disease, cardiomyopathy (heart muscle disease), vascular disease (blood vessel disease).

Prevalence is a measure of the burden of disease in a population in a given location and at a particular time, as represented in a count of the number of people affected (Ward, 2013). Prevalence is a function of both the incidence and duration of disease. In turn, duration is affected by the availability and effectiveness of curative treatments and by survival times of afflicted individuals (National Institutes of Health. Autoimmune diseases coordinating committee—Autoimmune diseases research plan, n.d.).

Level of expertise

. Methodology and data analysis requires high expertise in psycho-social research

. Quantitative data collection requires no expertise

Data collection

Required data

. Essential: NBS characteristics for each city/site

Data input type

Quantitative

Data collection frequency

Before and after NBS implementation (longitudinal)

Participatory process

No opportunities identified

Connection with SDGs

Goal 3
Goal 11

References

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Incidence represents how quickly new cases occur relative to population size and the passage of time. Incidence is calculated as the ratio of the number of new cases of a disease occurring within a population during a given time to the total number of people in the population (National Institutes of Health. Autoimmune diseases coordinating committee—Autoimmune diseases research plan, n.d.). While the prevalence represents the existing cases of a disease, the incidence reflects the number of new cases of disease within a certain period and can be expressed as a risk or an incidence rate (Noordzij, Dekker, Zoccali, & Jager, 2010).

Morbidity refers to the state of being diseased and the severity and impact of disease. Like prevalence, measures of morbidity represent the burden that a disease places on a population. In contrast to prevalence, morbidity estimates use more complex approaches that are potentially more informative than a simple count of cases (National Institutes of Health. Autoimmune diseases coordinating committee—Autoimmune diseases research plan, n.d.).

Mortality measures deaths caused by a specific disease, deaths resulting from treatment for a specific disease, or deaths in which a specific disease is a contributing factor, but not the primary cause. Mortality is the number of deaths due to a disease during a specific time divided by the number of persons in that population at the beginning of the time period. Hence, mortality is a rate in the sense that it represents how quickly deaths occur relative to population size and the passage of time. It can be interpreted as reflecting the risk of death from a particular cause faced by persons within the population being studied (National Institutes of Health. Autoimmune diseases coordinating committee —Autoimmune diseases research plan, n.d.).

Methodology

Quantitative Procedure:

Epidemiological data (Health Data Administration/Cities)

Extended description

Accumulating evidence supports the notion that ecological features such as the diurnal cycles of light and day, sunlight exposure, seasons, and geographic characteristics of the natural environment such as altitude, latitude, and green spaces are important determinants of cardiovascular health and CVD risk (Bhatnagar, 2017).

Dadvand, P., Bartoll, X., Basagaña, X., Dalmau-Bueno, A., Martinez, D., Ambros, A.,Cirach, M., Triguero-Mas, M., Gascon, M., Borrell, C., & Nieuwenhuijsen, M.J. (2016).Green spaces and general health: roles of mental health status, social support, and physical activity. Environment International, 91, 161–167. doi: 10.1016/j.envint.2016.02.029
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Some of the beneficial cardiovascular effects of greenery might relate to a decrease in the levels of local air pollution, increased proximity to walking spaces, or lower levels of mental stress (Bhatnagar, 2017). Recent studies and systematic reviews of empirical evidence have found support for the association between access and use of green spaces, and the prevalence and mortality of cardiovascular disease and risk, as well as for improved rates of recovery from cardiovascular disease (Gascon, Triguero-Mas, Martínez, Dadvand, Rojas-Rueda, Plasència, & Nieuwenhuijsen, 2016; Grazuleviciene, Vencloviene, Kubilius, Grizas, Dedele, Grazulevicius,Ceponiene, Tamuleviciute-Prasciene, Nieuwenhuijsen, Jones, & Gidlow, 2015a; Kuo, 2015; Pereira, Foster, Martin, Christian, Boruff, Knuiman, & Giles- Corti, 2012; Tamosiunas, Grazuleviciene, Luksiene, Dedele, Reklaitiene, Baceviciene, Vencloviene, Bernotiene, Radisauskas, Malinauskiene, Milinaviciene, Bobak, Peasey, & Nieuwenhuijsen, 2014; Villeneuve, Jerrett, Su, Burnett, Chen, Wheeler, & Goldberg, 2012).

Tamosiunas et al. (2014) brought forth evidence for the fact that distance from and use of urban green spaces are associated to lower risk of cardiovascular disease and improved chances of recovery from coronary artery disease in a study conducted on a sample of more than 5000 people which indicated that park users living at a distance of less than 350 meters away from a park had a significantly lower risk of fatal and non-fatal CVD.

Living in a city presents numerous health hazards that contribute to CVD by constituting major obstacles to physical activity (i.e., lack of exercise, sedentary lifestyle), like heavy environmental pollution, high traffic, no sidewalks, fewer “green spaces,” or open land for public use (Laslett, Alagona, Clark, Drozda, Saldivar, Wilson, Poe, & Hart, 2012). Walking in a green environment for 30 minutes on seven consecutive days, as compared to walking on a busy city street, has been found to improve recovery from coronary artery disease (Grazuleviciene et al., 2015a). For pregnant women, increase in distance to green spaces was associated to an increase in blood pressure, risk of preterm birth, and decrease of gestational age (Grazuleviciene, Danileviciute, Dedele, Vencloviene, Andrusaityte, Uždanaviciute, & Nieuwenhuijsen, 2015b).

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A recent study on a sample of almost 250.000 American senior adults, aged 65 and older, found that higher neighbourhood greenness was associated with reduced heart disease risk independent of socio-demographic status and neighbourhood income, although the relationship was weaker when adding in cardio-metabolic risk factors (Wang, Lombard, Rundek, Chuanhui Dong, Marinovic Gutierrez, Byrne, Toro, Nardi, Kardys, Li Yi, Szapocznik, & Brown, 2019).

Pereira et al. (2012) found that those living in neighbourhoods that had a high variability in greenness had a lower risk of stroke than those in either high overall greenness or low overall greenness. Gascon et al. (2016) conducted a systematic review of research concerning the relationship between residential green spaces and mortality in adults (stroke SMR, circulatory causes SMR, lung cancer, respiratory disease, diabetes, heart disease), and concluded on support for the hypothesis that living in areas with higher amounts of green spaces reduces mortality, mainly CVD.

Strengths and weaknesses

+ Many recent studies indicating that even in modern urban environments of sprawling metropolises and congested conurbations, residential proximity to vegetation is associated with lower levels of stress, diabetes mellitus, stroke, and CVD (Dadvand, Bartoll, Basagaña, Dalmau- Bueno, Martinez, Ambros, Cirach, Triguero-Mas, Gascon, Borrell, & Nieuwenhuijsen, 2016; James, Banay, Hart, & Laden, 2015)

- Limited empirical evidence as to the contribution of mechanisms involved in the beneficial cardiovascular effects of greenery (i.e., decrease in the levels of local air pollution, increased proximity to walking spaces, lower levels of mental stress) (Bhatnagar, 2017)

Extended methodology

Incidence of CVD relevant for measurement, along prevalence, as it indicates the number of new cases of disease within a certain period (for example, since the implementation of the NBS), and can be expressed as a risk or an incidence rate.

Recommended variables for CVD:

- Prevalence/incidence/morbidity/mortality of CVDs (coronary artery disease/coronary heart disease/narrowing of the arteries; heart attack; abnormal heart rhythms, or arrhythmias; heart failure; heart valve disease; congenital heart disease; heart muscle disease/cardiomyopathy; pericardial disease; aorta disease and Marfan syndrome; vascular disease/blood vessel disease)
- Blood pressure/hypertension HBP
- Stroke/cerebrovascular accident CVA
- CRP (C-Reactive protein) levels (blood test)

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HEALTH AND WELLBEING INDICATORS - CORE

CONNECTING NATURE

Perceived chronic stress

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Description

Stress is the process by which an individual responds psychologically, physiologically, and often with behaviors, to a situation that challenges or threatens well-being (Baum, Fleming, & Singer, 1985 as cited in Ulrich et al., 1991, p. 202). The psychological component includes cognitive appraisal of the situation, emotions such as fear, anger, and sadness, and coping responses (Ulrich et al., 1991). Psychological stress occurs when an individual perceives that environmental demands tax or exceed his or her adaptive capacity (Cohen, Kessler, & Gordon, 1995 as cited in Cohen et al., 2007).

Methodology

Quantitative Procedure:
Scale/Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)

Selective Tool:
Perceived Stress Scale (Cohen, Kamarck, & Mermelstein, 1983)

Level of expertise

. Methodology and data analysis requires high expertise in psycho-social research

. Quantitative data collection requires no expertise

Data collection

Required data

. Essential: NBS characteristics for each city/site, more specifically nature of activities one can get involved into while engaging with nature, opportunities for social interaction and for physical exercise, etc.

. Essential: Data on Place Attachment; General wellbeing and happiness; Mental health and wellbeing

. Desirable: Data on symbolic/affective meanings assigned to NBS (case studies, participatory data collection methods) – see also indicator Place Attachment

Data input type

Quantitative

Data collection frequency

After NBS implementation and aligned with timing relevant to biochemical assessments (e.g., 2-3 months after implementation for hair cortisol levels)

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Quantitative Procedure:
Biochemical assessments of diurnal cortisol secretion (hair, blood, salivary cortisol)

Selective Tool:
E.g., saliva sampling devices; morning blood samples; cortisol levels extracted from a 3 cm sample of scalp hair (Gidlow et al., 2016)

Extended description

Numerous authors emphasize that modern urban wellbeing challenged by chronic stress and insufficient physical activity can be healthily nurtured by natural environment exposure which promotes mental and physical health and reduces morbidity and mortality in urban residents by providing psychological relaxation and stress alleviation, enhancing immune function, stimulating social cohesion, supporting physical activity, and reducing exposure to air pollutants, noise and excessive heat (Braubach, Egorov, Mudu, Wolf, Ward Thompson, & Martuzii, 2017; Hartig, Mitchell, de Vries, & Frumkin, 2014). The psychological pathways to the beneficial effects of exposure to/engagement with nature have been founded on two complementary theoretical frameworks. Attention Restoration Theory (ART) emphasizes the role of nature in relieving mental fatigue and proposes that nature allows restoration from directed attention fatigue and enable more effective cognitive performance (Kaplan, 1995). Stress Recovery Theory (SRT) emphasizes the role of nature in relieving physiological stress and posits that natural environments influence affective states by promoting recovery from stress, and diminishing arousal and negative thoughts through psycho-physiological pathways (Ulrich, Simons, Losito, Fiorito, Miles, & Zelson, 1991).
Psychological Stress is thought to be a significant factor in the onset, course and exacerbation of various diseases, like depression, cardiovascular diseases, immune-related disorders, and it has been related to higher overall mortality (Cohen, Janicki-Deverts, & Miller, 2007; Hammen, 2005; Klein, Brähler, Dreier, Reinecke, Müller, Schmutzer, Wölfling, & Beutel, 2016).

Participatory process

No opportunities identified

Connection with SDGs

Goal 3
Goal 11

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The psychological approach to stress brings forth the role of subjective perception of stressful situations in coping and resilience, and focuses on the person's appraisal of the significance of the stressor (primary appraisal) and the individual coping abilities (secondary appraisal) within a person environment transaction (Klein et al., 2016).
Given the complex psychophysiological pathways of stress, measurement is usually approached holistically through collection of both subjective psychological (i.e., subjective rating scales, self-report measures) and objective physiological data (most frequently, salivary analysis due to the validity, reliability and ease of collection of salivary data) (Beil & Hanes, 2013).

For instance, van den Berg and Custers (2011) measured salivary cortisol levels and selfreported mood to demonstrate that gardening alleviated acute stress faster than reading. Beil and Hanes (2013), Roe, Thompson, Aspinall, Brewer, Duff, Miller, Mitchell, and Clow (2013), and Ward Thompson, Roe, Aspinall, Mitchell, Clow, and Miller (2012) used diurnal cortisol to demonstrate that exposure to green space reduced chronic stress in adults living in deprived urban neighborhoods.
Hair cortisol was used as a biomarker of chronic stress in research documenting similar relationships between green space and stress reduction (Gidlow, Randall, Gillman, Smith, & Jones, 2016; Wippert, Honold, Wang, & Kirschbaum, 2014).

Strengths and weaknesses

+ Reliable indicator of physical and mental health, wellbeing, and satisfaction with own life (Braubach et al., 2017; Frumkin et al., 2017; Klein et al, 2016)

+ Solid empirical evidence as to relationship between levels of stress/perception of stress and exposure to nature and urban green space (parks, playgrounds, and residential greenery)

- Complex psychophysiological pathways of stress – construct cannot be measured via a single marker, and both psychometric and physiological data need to be collected

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Extended methodology

Perceived Stress Scale (Cohen, Kamarck, & Mermelstein, 1983)

It is a self-report measure intended to capture the degree to which persons perceive situations in their life as excessively stressful relative to their ability to cope. To date, there are three standard versions of the PSS: the original 14-item form (PSS-14), the PSS-10, and a four-item form (PSS-4) Cohen et al., 1983). Cohen and Williamson (1988) suggested that the PSS-10 is the best form of the PSS and recommended the PSS-10 be used in future research (as cited in Taylor, 2015, p. 90).
The questions in this scale ask you about your feelings and thoughts during the last month. In each case, you will be asked to indicate how often you felt or thought a certain way. Although some of the questions are similar, there are differences between them and you should treat each one as a separate question. The best approach is to answer each question fairly quickly. That is, don't try to count up the number of times you felt a particular way, but rather indicate the alternative that seems like a reasonable estimate.

For each question choose from the following alternatives:

0. never
1. almost never
2. sometimes
3. fairly often
4. very often

In the last month, how often...

1 ...have you been upset because of something that happened unexpectedly?
2 ...have you felt that you were unable to control the important things in your life?
3 ...have you felt nervous and “stressed”?
4 ...have you felt confident about your ability to handle your personal problems? (R)
5 ...have you felt that things were going your way? (R)
6 ...have you found that you could not cope with all the things that you had to do?
7 ...have you been able to control irritations in your life? (R)
8 ...you felt that you were on top of things? (R)
9 ...you been angered because of things that were outside your control?
10 ...have you felt difficulties were piling up so high that you could not overcome them?

Biochemical assessments of diurnal cortisol secretion (hair, blood, salivary cortisol)

- Saliva sampling devices
- Morning blood samples
- Cortisol levels extracted from a 3 cm sample of scalp hair can reflect the past 3 months of cortisol secretion, offering a stable and feasible measure of long term stress exposure, where higher HCC reflects higher chronic stress levels (Gidlow et al., 2016)

CONNECTING NATURE

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HEALTH AND WELLBEING INDICATORS - CORE

CONNECTING NATURE

Mental health and wellbeing

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Description

Depression is a mood disorder (also called major depressive disorder or clinical depression) that causes a persistent feeling of sadness and loss of interest, affecting how one feels, thinks and behaves, and leading to a variety of emotional and physical problems (e.g., trouble doing normal day-to-day activities, sometimes feeling as if life isn't worth living, etc.) ("Depression (Major Depressive Disorder), n.d.").

Anxiety disorders (e.g., generalized anxiety disorder, social anxiety disorder or social phobia, specific phobias, separation anxiety disorder) are mood/emotional disorders characterized by intense, excessive and persistent worry and fear about everyday situations, often involving repeated episodes of sudden feelings of intense anxiety and fear or terror that reach a peak within minutes (i.e., panic attacks) ("Anxiety Disorders", n.d.).

Level of expertise

. Methodology and data analysis requires high expertise in psycho-social research

. Quantitative data collection requires no expertise

Data collection

Required data

. Essential: NBS characteristics for each city/site, more specifically nature of activities one can get involved into while engaging with nature, opportunities for social interaction and for physical exercise, etc.

. Essential: Data on Place Attachment; General wellbeing and happiness; Perceived chronic stress

. Desirable: Data on symbolic/affective meanings assigned to NBS (case studies, participatory data collection methods) – see also indicator Place Attachment

Data input type

Quantitative

Data collection frequency

After NBS implementation and aligned with timing of Perceived chronic stress study (i.e., relevant to biochemical assessments; e.g., 2-3 months after implementation for hair cortisol levels)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

Methodology

Quantitative Procedure:
Scale/Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)

Selective Tool:
General Health Questionnaire (GHQ-12) (Goldberg, Gater, Sartorius, Ustun, Piccinelli, Gureje, & Rutter, 1997)

Extended description

A decrease in experienced nature is one aspect of urbanization that has drawn researchers' attention with the purpose of developing methodologies to explore the affective and cognitive benefits of nature experience, and demonstrate the psychological benefits of our exposure to/engagement with nature (Bratman, Hamilton , Hahn , Daily, & Gross, 2015). The mental health benefits of urban green space have been highlighted by a growing body of knowledge and empirical evidence attesting to the complex interplay among stress responses, neighborhood conditions, and health outcomes (Beyer, Kaltenbach, Szabo, Bogar, Nieto, & Malecki, 2014; Hartig et al., 2014; Frumkin et al., 2017). A meta-analysis by Bowler, Buying-Ali, Knight, and Pullin (2010) identified effect sizes and significant levels indicative of improvement in energy, anxiety, anger, fatigue and sadness with exposure to natural environments, with less evidence of an impact on attention, tranquility, blood pressure or cortisol. Greater surrounding greenness has been linked to improved physical and mental health in all socioeconomic strata and in both sexes in Spain (Triguero-Mas, Dadvand, Cirach, Martínez, Medina, Mompart, Basagaña, Gražulevičienė, & Nieuwenhuijsen, 2015). More greenery in the neighborhood was linked to lower levels of depression, anxiety, and stress (Beyer et al. 2014; Pope, Tisdall, Middleton, Verma, Ameijden, Birt, Macherianakis, & Bruce, 2015). In a prospective study in the United Kingdom, moving to greener residential areas has been linked with persistent mental health improvements (Alcock, White, Wheeler, Fleming, & Depledge, 2014).

Participatory process

No opportunities identified

Connection with SDGs

Goal 3
Goal 11

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As documented under indicator HW 10 (Prevalence, incidence, morbidity of chronic stress), two complementary theoretical perspectives explain the psychological pathways of beneficial effects of nature on health, wellbeing, and mental states, namely Attention Restoration Theory (ART - Kaplan, 1995) and Stress Recovery Theory (SRT - Ulrich et al., 1991). Mental restoration and relaxation from leisure activities (e.g., walks in parks vs. walks in urban settings, gardening) pursued in the nature and green space have been studied as strong evidence of mental health benefits consequent to nature experience (Aspinall, Mavros, Coyne, & Roe, 2013; Bratman et al., 2015; Braubach et al., 2017; Hartig et al., 2014; van der Berg & Custers, 2011). Further studies of the relationship between NBS and mental health is of particular importance, as it has been long proven that there is a significant comorbidity (co-occurrence) of mental disorders, particularly mood disorders (i.e., depression, anxiety), with chronic physical conditions (Scott, Bruffaerts, Tsang, Ormel, Alonso, Angermeyer, Benjet, Bromet, Girolamo, de Graaf, Gasquet, Gureje, Haro, He, Kessler, Levinson, Mneimneh, Oakley Browne, Posada-Villa, Stein, Takeshima, & Von Korff, 2007).

Strengths and weaknesses

+ Reliable indicator of well-being and satisfaction with own life (Braubach et al., 2017; Frumkin et al., 2017; Klein et al, 2016)

+ Previous empirical evidence as to relationship between mental health (Alcock et al., 2014; Beyer et al., 2014; Pope et al., 2015) and vitality (van den Berg et al., 2016), as well as between perceived risk of poor mental health (Triguero-Mas et al., 2015) and exposure to nature and urban green space

- Methodological inconsistencies (operationalization of mental health, psychometrics used) in environmental study of relationship between mental health and green spaces

Extended methodology

General Health Questionnaire (GHQ-12) (Goldberg, Gater, Sartorius, Ustun, Piccinelli, Gureje, & Rutter, 1997)

It consists of 12 items, each one assessing the severity of a mental problem over the past few weeks using a 4-point Likert-type scale (from 0 to 3).

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It is a self-report instrument used to aid diagnosis of disorders such as anxiety and depression; respondents report how they have felt in the “past few weeks” compared to “usual” for six positive mood states, such as being able to concentrate and make decisions, and six negative mood states, such as feeling under strain and lacking confidence (Alcock et al., 2014).

Information about GHQ (all available versions) and on how to obtain permission to use the instrument in research studies https://www.gl-assessment.co.uk/products/general-health-questionnaire-ghq/

GHQ-12 items (as cited in Sánchez-López and Dresch, 2008):

01. Able to concentrate

02. Loss of sleep over worry

03. Playing a useful part

04. Capable of making decisions

05. Felt constantly under strain

06. Couldn’t overcome difficulties

07. Able to enjoy day-to-day activities

08. Able to face problems

09. Feeling unhappy and depressed

10. Losing confidence

11. Thinking of self as worthless

12. Feeling reasonably happy

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HEALTH AND WELLBEING INDICATORS - CORE

CONNECTING NATURE

Enhanced physical activity

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Description

Schipperijn et al. (2013) defined:

- Outdoor Physical activity as self-reported participation in organized or unorganized sport or exercise, outdoors, at least once a week.
- Physical activity in urban green space (UGS) as the selfreported participation in sport or exercise taking place in the nearest UGS at least once a week.

UGS can be replaced by NBS, as defined by current project, to apply the same definition to further measurements.

Methodology

Quantitative Procedure:
Scale/Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration).

Selective Tool:
International Physical Activity Questionnaire (IPAQ) (International Physical Activity Questionnaires, n.d.)

Level of expertise

. Methodology and data analysis requires high expertise in psycho-social research

. Quantitative data collection requires no expertise

Data collection

Required data

. Essential: NBS characteristics for each city/site, more specifically nature of activities one can get involved into while engaging with nature, opportunities for physical exercise, etc.

Data input type

Quantitative

Data collection frequency

After NBS implementation and aligned with timing relevant to "Enhanced physical activity" and synergies with other indicators.

Participatory process

No opportunities identified

Connection with SDGs

Goal 3
Goal 11

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

Extended description

The outdoor environment may influence how physically active an individual is by offering suitable spaces for certain types of activities. It may also attract people outdoors because of the experiences it offers. Such outings ordinarily entail some form of physical activity, usually walking (Hartig, Mitchell, de Vries, & Frumkin, 2014). Numerous studies in various countries have shown that access to, and use of, urban green space contributes to increased physical activity, higher rates of recreational walking and reduced sedentary time (Almanza, Jerrett, Dunton, Seto, Pentz, 2012; Schipperijn, Bentsen, Troelsen, Toftager, & Stigsdotter, 2013; Lachowycz and Jones, 2014; Sugiyama et al., 2014; Braubach et al., 2017; Sallis et al., 2016). This has been proven valid for all age categories, including children, working age adults and senior citizens. For example, a comprehensive study conducted by Schipperijn et al. (2013) has demonstrated positive associations between urban green space and both physical activity and positive affect. Greater surrounding greenness has been linked to improved physical and mental health in all socioeconomic strata and in both sexes in Spain (Triguero-Mas et al., 2015). As documented under indicator HW 10 (Prevalence, incidence, morbidity of chronic stress), two complementary theoretical perspectives explain the psychological pathways of beneficial effects of nature on health, wellbeing, and mental states, namely Attention Restoration Theory (ART - Kaplan, 1995) and Stress Recovery Theory (SRT - Ulrich et al., 1991). Mental restoration and relaxation from leisure activities (e.g., walks in parks vs. walks in urban settings, gardening) pursued in the nature and green space have been studied as strong evidence of mental health benefits consequent to nature experience (Aspinall, Mavros, Coyne, & Roe, 2013; Bratman et al., 2015; Braubach et al., 2017; Hartig et al., 2014; van den Berg & Custers, 2011).

Strengths and weaknesses

+ Reliable indicator of physical and mental health, wellbeing, and life expectancy (Braubach et al., 2017; Frumkin et al., 2017; Klein et al, 2016).

+ Solid empirical evidence as to relationship between physical and mental health, and wellbeing, and physical activity in nature and urban green space (parks, playgrounds, and residential greenery).

+ Robust empirical evidence for the role of physical activity in cardiovascular disease and obesity.

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CONNECTING NATURE

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Extended methodology

International Physical Activity Questionnaire (IPAQ) (International Physical Activity Questionnaires, n.d.)

IPAQ (both long - 27 items, and short form - 7 items) assesses physical activity undertaken across a comprehensive set of domains including:

- Leisure time physical activity
- Domestic and gardening (yard) activities
- Work-related physical activity
- Transport-related physical activity

International Physical Activity Questionnaire (IPAQ – short/7 items) (International Physical Activity Questionnaires, n.d.)

See website for the International Physical Activity Questionnaire (IPAQ) for information about the use of the questionnaire and links to the questionnaire itself, in multiple languages:

https://sites.google.com/site/theipaq/questionnaire_links

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives.
The questions will ask you about the time you spent being physically active in the last 7 days. Please answer each question even if you do not consider yourself to be an active person.
Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport. Think about all the vigorous activities that you did in the last 7 days. Vigorous physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

1. During the last 7 days, on how many days did you do vigorous physical activities like heavy lifting, digging, aerobics, or fast bicycling? _____ days per week

No vigorous physical activities Skip to question 3.

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2. How much time did you usually spend doing vigorous physical activities on one of those days? _____ hours per day _____ minutes per day.
Don't know/Not sure: Think about all the moderate activities that you did in the last 7 days. Moderate activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

3. During the last 7 days, on how many days did you do moderate physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking. _____ days per week.

No moderate physical activities: Skip to question 5.

4. How much time did you usually spend doing moderate physical activities on one of those days? _____ hours per day _____ minutes per day.
Don't know/Not sure: Think about the time you spent walking in the last 7 days. This includes at work and at home, walking to travel from place to place, and any other walking that you have done solely for recreation, sport, exercise, or leisure.

5. During the last 7 days, on how many days did you walk for at least 10 minutes at a time? _____ days per week.

No walking: Skip to question 7.

6. How much time did you usually spend walking on one of those days? _____ hours per day _____ minutes per day.
Don't know/Not sure: The last question is about the time you spent sitting on weekdays during the last 7 days. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

7. During the last 7 days, how much time did you spend sitting on a week day? _____ hours per day _____ minutes per day.
Don't know/Not sure.

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HEALTH AND WELLBEING INDICATORS - CORE

CONNECTING NATURE

Perceived restorativeness of public green space

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Description

Restoration can be seen as a sequential, interactive process that begins with physiological relaxation and results in affective and attention restoration and broader life reflection (Pasanen et al., 2018).

Methodology

Quantitative Procedure:
Scale/Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)

Selective Tool:
Perceived Restorativeness Scale (the short, PRS - 11) (Pasini et al., 2014)

Level of expertise

. Methodology and data analysis require high expertise in psycho-social research

. Quantitative data collection requires no expertise

Data collection

Required data

. Essential: NBS characteristics for each city/site, more specifically nature of activities one can get involved into while engaging with nature

. Desirable: Data on symbolic/affective meanings assigned to NBS (case studies, participatory data collection methods) – see also indicator Place Attachment

Data input type

Quantitative

Data collection frequency

After NBS implementation or aligned with timing of targeted (especially long-term) objectives

Participatory process

No opportunities identified

Connection with SDGs

Goal 3
Goal 11

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Extended description

In recent decades a growing body of environmental psychology research has demonstrated the psychological benefits of interacting with natural environments, especially green spaces (Joye & Dewitte, 2018). There is strong evidence that experiencing nature through leisure activities pursued in green spaces (i.e., walking in parks, gardening) has benefits in mental health, creativity and mental relaxation (Aspinall et al., 2013; Bratman et al., 2015; Braubach et al., 2017; Hartig et al., 2014; Van der Berg & Custers, 2011; Williams et al., 2018).

Natural physical settings play an important role in coping with stress, as there are robust links between exposure to natural environments and recovery from physiological stress and mental fatigue (Berto, 2014). Two complementary theoretical perspectives explain the psychological pathways of beneficial effects of nature on health, wellbeing, and mental states, namely Attention Restoration Theory (ART - Kaplan, 1995) and Stress Recovery Theory (SRT - Ulrich et al., 1991).

Regarding ART, the theory suggests that concentration capacity is a limited resource and susceptible to fatigue by overuse, but that it can be restored by exposure to natural environments (Ohly et al., 2016; Zhang et al., 2017). These environments are a healthy resource, which allows and promotes the restoration of individuals within it from their state of directed attention fatigue (Zhang et al., 2017). Although this theory has been widely cited, there is uncertainty regarding which attentional aspects are affected by exposure to natural environments (Ohly et al., 2016). It is hypothesized that the restorative effect of these environments derives from its soft fascinating characteristics; these can set an individual in an effortless mode of attention, thereby giving directed attention to a relative opportunity to rest and replenish itself (Joye & Dewitte, 2018). Softly fascinating stimuli not only requires little effort, but also leaves mental space for reflection (Basu et al., 2019).

In turn, exposure to nature can boost an individual's sense of connectedness (i.e., emotional or cognitive bonds to the natural world), as there is a bidirectional relationship between connectedness and restoration (Wyles et al., 2019). Both the connection with nature and nature restorativeness are an alternative source of motivation, to reinforce the relationship between environmental knowledge, environmental attitudes and engagement in pro-environmental behaviour (Berto & Barbiero, 2017; Whitburn et al., 2019).

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Much of recent research in the restorative process of natural environments has focused on knowing how cities can incorporate elements that facilitate attentional restoration, since this process can be affected both positively and negatively by different urban factors (Zhang et al., 2017). Cities can be potentially restorative, improving urban designs to offer psychological benefits to citizens (San Juan et al., 2017), since urban nature environment fosters mental health as a natural therapy intervention to improve pro-environmental behaviour for urban communities (Othman et al., 2020).

Specifically, the restorative potential of an urban area can be reinforced by the design and proper selection of landscape types and elements (Deng et al., 2020). These authors stress that the elements that promote the optimal restorative environment are water features and the appearance of natural forest. In fact, urban gardens are an essential source for the psychological restoration, as well as urban biodiversity or ecosystem services (Young et al., 2020). Biodiversity, or ecological quality of environments (number of species, integrity of ecological processes) has numerous benefits to human health and well-being (Meyer-Grandbastien et al., 2020; Wood et al., 2018). In addition, there are other factors that contribute to increasing the restorative power offered by urban environments, such as the presence of sounds characteristic of nature as opposed to noise sounds related to traffic (Zhang et al., 2017), or the amount vegetation and perceived safety (Tabrizian et al., 2018).

In conclusion, exposure to natural scenes mediates the negative effects of stress reducing the negative mood state, and above all enhancing positive emotions and wellbeing (Berto, 2014), that ́s why city planners and designers should seriously attend to restorativeness effects in urban areas.

Strengths and weaknesses

+ The indicator allows to know the restorative potential of a nature-based solution

- Understanding the relationship of the indicator with well-being involves knowing the intermediate attentional mechanism

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Extended methodology

Perceived Restorativeness Scale (the short, PRS - 11) (Pasini et al., 2014)

A shorter, parallel version of the Perceived Restorativeness Scale (PRS – 26) (Hartig et al., 1997), developed to address original psychometric limitations; PRS is based on the Attention Restoration Theory (ART; Kaplan, 1995) and its short version measures an individual's perception of 4 restorative factors assumed to be present to a greater or lesser extent in the environment, namely physical and/or psychological "being-away" from demands on directed attention, "fascination" a type of attention assumed to be effortless and without capacity limitations, the "coherence" and "scope" perceived in an environment. Participant's judgments are made on a 0 to 10-point scale, where 0 = not at all, 6 = rather much, and 10 = completely.

We are interested in how you experience this environment. To help us understand your experience, we have provided the following statements for you to respond to. Please read carefully, then ask yourself: "how much does this statement apply to my experience there?". To indicate your answer, circle only one numbers on the rating scale beside the statement. A sample of the rating scale is given below and at the top of each subsequent page. So, for example, if you think that the statement does not at all apply to your experience of the environment, then you would circle "0" (not at all), if you think it applies rather much, then you would circle "6" (rather much), but if you think that it applies very much, you would circle 10 (very much).

1. Places like that are fascinating (Fascination)

2. In places like this my attention is drawn to many interesting things (Fascination)

3. In places like this it is hard to be bored (Fascination)

4. Places like that are a refuge from nuisances (Being Away)

5. To get away from things that usually demand my attention I like to go to places like this (Being Away)

6. To stop thinking about the things that I must get done I like to go to places like this (Being Away)

7. There is a clear order in the physical arrangement of places like this (Coherence)

8. In places like this it is easy to see how things are organized (Coherence)

9. In places like this everything seems to have its proper place (Coherence)

10. That place is large enough to allow exploration in many directions (Scope)

11. In places like that there are few boundaries to limit my possibility for moving about (Scope)

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HEALTH AND WELLBEING INDICATORS - FEATURE

CONNECTING NATURE

Sustainable nutrition/adoption

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Description

World Health Organization (WHO) guidelines with respect to what constitutes a healthy diet (Healthy diet - WHO, 2018) include the following:

For adults

- Fruit, vegetables, legumes (e.g. lentils and beans), nuts and whole grains (e.g. unprocessed maize, millet, oats, wheat and brown rice).
- At least 400 g (i.e. five portions) of fruit and vegetables per day (2), excluding potatoes, sweet potatoes, cassava and other starchy roots.
- Less than 10% of total energy intake from free sugars (2, 7), which is equivalent to 50 g (or about 12 level teaspoons) for a person of healthy body weight consuming about 2000 calories per day, but ideally is less than 5% of total energy intake for additional health benefits (7). Free sugars are all sugars added to foods or drinks by the manufacturer, cook or consumer, as well as sugars naturally present in honey, syrups, fruit juices and fruit juice concentrates.

Level of expertise

. Methodology and data analysis requires high expertise in psycho-social research

. Quantitative data collection requires no expertise

Data collection

Required data

. Essential: NBS characteristics for each city/site, more specifically nature of activities one can get involved into while engaging with nature, opportunities for sustainable food production, etc.

. Essential: Data on Place attachment and Enhanced physical activity

. Desirable: Data on symbolic/affective/social meanings assigned to NBS (case studies, participatory data collection methods) – see also indicator Place Attachment; quantitative data on Incidence of obesity /obesity rates (adults and children)

Data input type

Quantitative

Data collection frequency

Before and after NBS implementation or aligned with timing of targeted (especially long-term) objectives

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- Less than 30% of total energy intake from fats (1, 2, 3). Unsaturated fats (found in fish, avocado and nuts, and in sunflower, soybean, canola and olive oils) are preferable to saturated fats (found in fatty meat, butter, palm and coconut oil, cream, cheese, ghee and lard) and trans-fats of all kinds, including both industrially-produced trans-fats (found in baked and fried foods, and pre-packaged snacks and foods, such as frozen pizza, pies, cookies, biscuits, wafers, and cooking oils and spreads) and ruminant trans-fats (found in meat and dairy foods from ruminant animals, such as cows, sheep, goats and camels). It is suggested that the intake of saturated fats be reduced to less than 10% of total energy intake and trans-fats to less than 1% of total energy intake (5). In particular, industrially-produced trans-fats are not part of a healthy diet and should be avoided (4, 6).
- Less than 5 g of salt (equivalent to about one teaspoon) per day (8). Salt should be iodized.

For infants and young children

In the first 2 years of a child's life, optimal nutrition fosters healthy growth and improves cognitive development. It also reduces the risk of becoming overweight or obese and developing NCDs later in life.

Advice on a healthy diet for infants and children is similar to that for adults, but the following elements are also important:

- Infants should be breastfed exclusively during the first 6 months of life.
- Infants should be breastfed continuously until 2 years of age and beyond.
- From 6 months of age, breast milk should be complemented with a variety of adequate, safe and nutrient-dense foods. Salt and sugars should not be added to complementary foods

Methodology

Quantitative Procedure:

Scale/Scale inventory/Questionnaire/Index (survey procedure, paper-and-pencil administration, computer-based administration)

Selective Tool:

Healthy Eating Index (HEI) (e.g., HEI 2015)

Participatory process

No opportunities identified

Connection with SDGs

Goal 3
Goal 11

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Extended description

Research on the effects of engagement with nature-based solutions on the adoption of more sustainable, healthy diets is scarce. Healthy eating habits are not correlated to green space in the limited number of studies available, but to other demographic and quality of life variables (Yuen et al., 2019), although this might be due to the type and functionality of green space. Traditionally, it is thought that deprived neighborhoods have less accessibility to healthy food. This has been called the deprivation amplification hypothesis – poorer places have poorer access to resources for healthy diets and physical activity. However, a review of evidence on food deserts in the UK,found very little evidence in support of this hypothesis (Macintyre, 2007).

One NBS that shows results is school gardens, both for physical activity and dietary behaviour (but not attitudes). Studies show gardeners and their children eat healthier diets than non-gardeners, and that school gardening increases knowledge of children on edible plants and their preference for vegetables (Jasper et al., 2018).

Edible forest gardens have also been proposed as nature-based solutions that could reinforce positive health effects and pro-environmental behaviours, through provision of ecologically sustainable and healthy food, social cohesion, and psycho-physiological reductions of stress (Stoltz & Schaffer, 2018).

In a systematic analysis of public health implications of urban agriculture, Brown and Jameton (2000, p. 26) assert that economic factors (i.e., profits, income) are "undeniably the single most powerful predictors for food security", which prompts the authors to infer that successful urban gardens could lead to nutritional benefits throughout the community by means of providing employment opportunities to low-income households, thus enabling them to purchase a healthy diet.

Strengths and weaknesses

+ Reliable indicator of general risks to health (e.g., malnutrition, noncommunicable diseases, such as diabetes, heart disease, stroke and cancer) (Healthy diet - WHO, 2018)

- Limited empirical evidence as to relationship between healthy eating habits and connectedness to nature

Nishida, C., Uauy, R., Kumanyika, S., & Shetty, P. (2004). The joint WHO/FAO expert consultation on diet, nutrition and the prevention of chronic diseases: process, product and policy implications. Public Health Nutrition, 7(1a), 245-250.

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- Complex indicator (healthy diet, sustainable diet, food security) that ties into individual (e.g., age, gender, physical activity), social (e.g., social justice) and economic variables (e.g., level of income); according to WHO, the make-up of a diversified, balanced and healthy diet will vary depending on individual characteristics (e.g. age, gender, lifestyle and degree of physical activity), cultural context, locally available foods and dietary customs (Currie, Levin, Kirby, Currie, van der Sluijs, & Inchley, 2011; Healthy diet - WHO, 2018)

Extended methodology

Healthy Eating Index (HEI)

(e.g., HEI 2015), namely adaptations of this tool developed by the United States Department of Agriculture and the National Cancer Institute to evaluate the extent to which diets are consistent with the Dietary Guidelines for Americans (Healthy Eating Index, n.d.) based on region/country-specific food-based dietary guidelines (FBDGs) (Joint F. A. O. & World Health Organization, 1998)

- National food-based dietary guidelines (FBDGs) provide context-specific advice and principles on healthy diets and lifestyles, which are rooted on sound evidence, and respond to a country's public health and nutrition priorities, food production and consumption patterns, sociocultural influences, food composition data, and accessibility, among other factors (Food-based dietary guidelines, n.d.).
- Food-Based Dietary Guidelines in Europe to be found at https://ec.europa.eu/jrc/en/health-knowledge-gateway/promotion-prevention/nutrition/food-based-dietary-guidelines
- HEI is recommended in epidemiologic research and as a tool to evaluate nutrition interventions (e.g., in the context of NBS). The HEI is a scoring metric that can be used to determine overall diet quality as well as the quality of a range of dietary components (Overview & Background of the Healthy Eating Index, n.d.).

Adaptation from Environmental behaviors: Reducing emissions. (Brick & Lewis, 2016).

How often do you eat meat?
How often do you eat dairy products such as milk, cheese, eggs, or yogurt?
How often do you eat organic food?
How often do you eat local food (produced within 100 miles)?
How often do you eat from a home vegetable garden (during the growing season)?

1 Never; 2 Rarely; 3 Sometimes; 4 Often; 5 Always

See also Kirkpatrick, Reedy, Butler, Dodd, Subar, Thompson, and McKinnon (2014), Kirkpatrick, Reedy, Krebs-Smith, Pannucci, Subar, Wilson, Lerman, and Tooze (2018), Nishida, Uauy, Kumanyika, and Shetty (2004), Thompson, Kirkpatrick, Krebs-Smith, Reedy, Schap, Subar, and Wilson (2015), Thompson and Subar (2017)

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HEALTH AND WELLBEING INDICATORS - FEATURE

CONNECTING NATURE

Life expectancy and healthy life years expectancy

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(2) West University of Timisoara, Romania

Description

Life expectancy at birth is defined as the mean number of years that a new-born child can expect to live if subjected throughout his life to the current mortality conditions (age specific probabilities of dying) (Eurostat). Average years of life a person is expected to live, normally divided by gender.

Healthy life years, abbreviated as HLY and also called disability-free life expectancy (DFLE), is defined as the number of years that a person is expected to continue to live in a healthy condition. This statistical indicator is compiled separately for men and women, at birth and at ages 50 and 65. It is based on age-specific prevalence (proportions) of the population in healthy and unhealthy condition and age-specific mortality information. A healthy condition is defined as one without limitation in functioning and without disability.

Level of expertise

. Methodology and data analysis requires high expertise in psycho-social research

. Quantitative data collection requires no expertise

Data collection

Required data

. Essential: NBS characteristics for each city/site, more specifically nature of activities one can get involved into while engaging with nature, opportunities for sustainable food production, etc.

Data input type

Quantitative

Data collection frequency

Before and after NBS implementation or aligned with timing of targeted (especially long-term) objectives

Participatory process

No opportunities identified

Connection with SDGs

Goal 3
Goal 11

References

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Methodology

Quantitative Procedure:
Objectives measures (Administrative data)

Approaches to developing tools:
Life table, abridged life table, adjusted Chiang II methods (see Boothe, Fierro, Laurent, & Shih, 2018)

Extended description

A limited number of studies have focused on the relationship between green space exposure, and life expectancy and healthy life years expectancy. A recent study has documented a modest relationship between both the quantity and the perceived quality of urban green on both life expectancy and healthy life expectancy and found no relationship with the average distance to the nearest public green space (Jonker et al., 2014).

Furthermore, a longitudinal study carried out in Hong Kong revealed that a 10 % increase in coverage of green space was significantly associated with a reduction in all-cause mortality, circulatory system-caused mortality and stroke-caused mortality, independent of age, sex, marital status, years lived in Hong Kong, education level, socioeconomic ladder, smoking, alcohol intake, diet quality, self-rated health and housing type. These associations became weaker when variability in physical activity and cognitive function were considered (Wang et al., 2017). Finally, a recent systematic review of evidence found consistent negative associations between urban green space exposure and mortality (Kondo et al., 2018).

Thus, although evidence does show overall reductions in mortality, an increase in life expectancy and healthy life years expectancy, these relationships tend to be weak, as they are mediated by actual engagement with green spaces, suggesting the importance of developing indicators for engagement with nature-based solutions.

Strengths and weaknesses

- Limited empirical evidence as to relationship between life expectancy and connectedness to nature

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HEALTH AND WELLBEING INDICATORS - FEATURE

CONNECTING NATURE

Prevalence and incidence of chronic autoimmune diseases

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Description

AID is a condition which is triggered by the immune system initiating an attack on self-molecules due to the deterioration of immunologic tolerance to auto-reactive immune cells. The initiation of attacks against the body's self-molecules in AIDs, in most cases is unknown, but a number of studies suggest that they are strongly associated with factors such as genetics, infections and /or environment (Page, du Toit, & Page, 2011). For most AIDs, cure is unusual, and survival is generally measured in years or decades. Hence, the chronicity of autoimmune disease leads to a high prevalence despite a relatively low annual incidence (National Institutes of Health. Autoimmune diseases coordinating committee—Autoimmune diseases research plan, n.d.). Most prevalence surveys are limited by their reliance on self-reporting of disease status rather than a physician-confirmed diagnosis. Self-reporting of AIDs can result in misclassification and underreporting (National Institutes of Health. Autoimmune diseases coordinating committee—Autoimmune diseases research plan, n.d.).

Level of expertise

. Methodology and data analysis requires high expertise in psycho-social research

. Quantitative data collection requires no expertise

Data collection

Required data

. Essential: NBS characteristics for each city/site

Data input type

Quantitative

Data collection frequency

Before and after NBS implementation (longitudinal)

Participatory process

No opportunities identified

Connection with SDGs

Goal 3
Goal 11

References

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Prevalence is a measure of the burden of disease in a population in a given location and at a particular time, as represented in a count of the number of people affected (Ward, 2013). Prevalence is a function of both the incidence and duration of disease. In turn, duration is affected by the availability and effectiveness of curative treatments and by survival times of afflicted individuals (National Institutes of Health. Autoimmune diseases coordinating committee—Autoimmune diseases research plan, n.d.).

Incidence represents how quickly new cases occur relative to population size and the passage of time. Incidence is calculated as the ratio of the number of new cases of a disease occurring within a population during a given time to the total number of people in the population (National Institutes of Health. Autoimmune diseases coordinating committee—Autoimmune diseases research plan, n.d.). While the prevalence represents the existing cases of a disease, the incidence reflects the number of new cases of disease within a certain period and can be expressed as a risk or an incidence rate (Noordzij, Dekker, Zoccali, & Jager, 2010).

Methodology

Quantitative Procedure:

Epidemiological data (Health Data Administration/Cities)

Incidence of AID relevant for a measurement, along prevalence, as it indicates the number of new cases of disease within a certain period (for example, since the implementation of the NBS), and can be expressed as a risk or an incidence rate.

Extended description

Numerous authors stress the relevance of immuneregulatory mechanisms in the manifestation of the generally expected beneficial effects of exposure to nature (Hanski et al, 2012; Kuo, 2015; Rook, 2013; von Hertzen et al., 2015). Rook (2013) argue that multiple physiological consequences of exposure to the natural environment (e.g., sunlight, physical exercise) supplement the immuneregulatory effects of microbial biodiversity (i.e., low CRP levels, low inflammation, low cytokine response to stress) and the psychological rewards of interaction with nature (e.g., relaxation, restoration, exercise, social capital).

Hanski, I., von Hertzen, L., Fyhrquist, N., Koskinen, K., Torppa, K., Laatikainen, T., ... Haahtela, T. (2012). Environmental biodiversity, human microbiota, and allergy are interrelated. Proceedings of the National Academy of Sciences of the United States of America, 109(21), 8334–8339. doi:10.1073/pnas.1205624109

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These notions have been brought forth by the hygiene hypothesis (i.e., Old Friends mechanism, biodiversity hypothesis) that explains the increasing prevalence of chronic inflammatory diseases (autoimmunity, allergy and inflammatory bowel diseases) in urban communities in high-income countries by a predisposition to poor regulation of inflammation gradually developed through reduced exposure to immunoregulation-inducing macro and microorganisms, and microbiota that accompanied mammalian evolution (Haahtela et al., 2013; Rook, Lowry, & Raison, 2013; von Hertzen et al., 2015). Rook (2013) suggests that the rapid occurrence of psychological effects could explain the fact that most studies have been oriented towards the psychological explanations, while there is still limited empirical evidence as to the contribution of immunoreglatory processes in the positive experience of exposure to nature (i.e., immunoregulatory mechanisms require prolonged exposure, especially during childhood when much of immune system training occurs).

There is evidence to suggest however that exposure to biodiverse urban green space (with a variety of microorganisms) is likely to be important in both reducing systemic inflammation and boost immune defence (Lee et al., 2012; Park et al., 2010). For examples, studies on immersion into forest environments have shown positive effects on natural killer cells, as well as intracellular anticancer proteins in lymphocytes (Li, 2010). Some support has been gathered for the hypothesis that such effects might be due to the effect of essential oils from trees as well as the stress reduction effects of green environments (Li, 2010) and that the effects lasted for up to 7 days after trips (Li et al., 2011). Above all, there is a stringent need for empirical evidence of the relationship between biodiversity and immunoregulation, as well as improved control of AIDs' evolution.

Strengths and weaknesses

+ Empirical support to the notion that exposure to biodiverse urban green space is important in both reducing systemic inflammation and boost immune defence (Lee et al., 2012; Jin Park, 2010).

- Limited empirical evidence as to the contribution of immunoreglatory processes in the positive experience of exposure to nature (Rook, 2013; von Hertzen et al., 2015).

Extended methodology

Recommended variables for inflammatory processes and immunoregulation:

- Prevalence/incidence of inflammatory disorders.
- Prevalence/incidence of cardiovascular disease.
- Prevalence/incidence of asthma.
- Prevalence/incidence of depression.
- Stress resilience.
- CRP (C-Reactive protein) levels (blood test).
- Atopic sensitization (i.e., allergic disposition) (see Hanski et al., 2012).

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HEALTH AND WELLBEING INDICATORS - FEATURE

CONNECTING NATURE

Prevalence, incidence, morbidity, and mortality of respiratory diseases

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Description

RD is a type of disease that affects the lungs and other parts of the respiratory system. Respiratory diseases include asthma, chronic obstructive pulmonary disease (COPD), pulmonary fibrosis, pneumonia, and lung cancer (National Cancer Institute - Dictionary of Cancer Terms, n.d.).

Prevalence is a measure of the burden of disease in a population in a given location and at a particular time, as represented in a count of the number of people affected (Ward, 2013). Prevalence is a function of both the incidence and duration of disease. In turn, duration is affected by the availability and effectiveness of curative treatments and by survival times of afflicted individuals (National Institutes of Health. Autoimmune diseases coordinating committee—Autoimmune diseases research plan, n.d.).

Level of expertise

. Methodology and data analysis requires high expertise in psycho-social research

. Quantitative data collection requires no expertise

Data collection

Required data

. Essential: NBS characteristics for each city/site.

Data input type

Quantitative

Data collection frequency

Before and after NBS implementation (longitudinal).

Participatory process

No opportunities identified

Connection with SDGs

Goal 3
Goal 11

References

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Incidence represents how quickly new cases occur relative to population size and the passage of time. Incidence is calculated as the ratio of the number of new cases of a disease occurring within a population during a given time to the total number of people in the population (National Institutes of Health. Autoimmune diseases coordinating committee—Autoimmune diseases research plan, n.d.). While the prevalence represents the existing cases of a disease, the incidence reflects the number of new cases of disease within a certain period and can be expressed as a risk or an incidence rate (Noordzij, Dekker, Zoccali, & Jager, 2010).

Morbidity refers to the state of being diseased and the severity and impact of disease. Like prevalence, measures of morbidity represent the burden that a disease places on a population. In contrast to prevalence, morbidity estimates use more complex approaches that are potentially more informative than a simple count of cases (National Institutes of Health. Autoimmune diseases coordinating committee—Autoimmune diseases research plan, n.d.).

Mortality measures deaths caused by a specific disease, deaths resulting from treatment for a specific disease, or deaths in which a specific disease is a contributing factor, but not the primary cause. Mortality is the number of deaths due to a disease during a specific time divided by the number of persons in that population at the beginning of the time period. Hence, mortality is a rate in the sense that it represents how quickly deaths occur relative to population size and the passage of time. It can be interpreted as reflecting the risk of death from a particular cause faced by persons within the population being studied (National Institutes of Health. Autoimmune diseases coordinating committee—Autoimmune diseases research plan, n.d.).

Methodology

Quantitative Procedure:

Epidemiological data (Health Data Administration/Cities).

Incidence of RD relevant for measurement, along prevalence, as it indicates the number of new cases of disease within a certain period (for example, since the implementation of the NBS), and can be expressed as a risk or an incidence rate.

Forum of International Respiratory Societies: Respiratory diseases in the world Realities of Today – Opportunities for Tomorrow (2013). Retrieved from https://www.ersnet.org/pdf/publications/firs-world-report.pdf

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Extended description

Breathing unhealthy air is a cause or contributor to most respiratory conditions. The most common sources of unhealthy air are tobacco smoke, indoor air pollution from burning solid fuels, unhealthy air in the workplace, air pollution from traffic and industrial sources, air containing microbes, and air with toxic particles or fumes (Forum of International Respiratory Societies: Respiratory diseases in the world Realities of Today – Opportunities for Tomorrow, 2013). Increased concentrations of greenhouse gases, especially carbon dioxide, in the earth’s atmosphere have already substantially warmed the planet, causing more severe and prolonged heat waves, temperature variability,

increased length and severity of the pollen season, air pollution, forest fires, droughts, and heavy precipitation events and floods, all of which put respiratory health at risk. The main diseases of concern are asthma, rhinosinusitis, chronic obstructive pulmonary disease (COPD) and respiratory tract infections, but the extent to which these are spread will vary according to the proportion of susceptible individuals in a given population. Individuals with pre-existing cardiopulmonary diseases are at higher risk of suffering from climate changes (D'Amato, Cecchi, D’Amato, & Annesi-Maesano, 2014).

Furthermore, many respiratory illnesses are related to immunologic dysfunction and this has been associated to unbalanced respiratory and gut microbiomes, due to a lack of appropriate exposure to biodiverse environments both at a time when a healthy immune system is formed as well as in adulthood (Haahtela et al., 2013; Hanski et al., 2012; Kuo, 2015). A study on children and adults in Finish and Russian Karelia found that allergic symptoms and diseases were systematically more common in Finnish children and adults than in their Russian counterparts (Haahtela, Laatikainen, Alenius, Auvinen, Fyhrquist, Hanski, von Hertzen, Jousilahti, Kosunen, Markelova, Mäkelä, Pantelejev, Uhanov, Zilber, & Vartiainen, 2015).

Sensitization to birch pollen was significantly larger in Finnish children, and while adults born in the 40’s in the two regions had similarly low rates of respiratory illnesses, those born in the 70’s differed significantly, supporting the notion that the epidemic of allergy and asthma is a result of reduced exposure to natural environments with rich microbiota, a changed diet and a sedentary lifestyle (Haahtela et al., 2015).

Villeneuve et al. (2012) advanced research findings that suggest that areas that have more green space have a slightly lower mortality rate (stronger association for respiratory disease mortality), yet authors emphasize the need for more research aimed at identifying whether there is a selection bias related to people who have been exercising in their youth move to areas with green space as well as the specific characteristics of green space that have the strongest influence on mortality, and at evaluating the potential confounding role of other lifestyle-related mortality risk factors.

The ways in which green space affects respiratory symptoms are yet to be fully understood, and seem to depend on the characteristics of the bio-geographical region (Markevych et al., 2017; Tischer et al., 2017), which indicates that other factors (e.g., dryness, heat, etc.) need to be taken into account.

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Results of designs aimed at exploring the link between respiratory disease and greenspace are inconsistent across studies, which makes it difficult to draw useful conclusions with regards to the amount, type and structure of green space that would be conducive to respiratory health. A systematic review of the greenspaces' effect on allergies and atopic sensitization, using studies that covered 11 cohorts, showed that findings are not consistent across studies, with four cohorts registering protective effects from greenspace, two cohorts showing an increase in sensitization related to greenspace, and five cohorts
displaying no significant effect of greenspace on atopic sensitization (Lambert, Bowatte, Tham, Lodge, Prendergast, Heinrich, Abramson, Dharmage, & Erbas, 2018). Lambert et al. (2018) suggest that this is due to variations in exposure measurements, study populations and location, the specific allergens tested, and inclusion of confounders. Authors also conclude that not only the contributions of greenspace to specific allergens need to be understood, but also how the amount, type of greenspace and specific allergens contribute to prevalence, incidence and risk of particular respiratory disease should be considered in future studies (Lambert et al., 2018).

Strengths and weaknesses

+ Some research that supports the notion of a solid association between greenspace and exposure to nature, and respiratory disease prevalence and mortality (e.g., Villeneuve et al., 2012).

- Inconsistencies across studies make it difficult to draw useful conclusions with regards to the amount, type and structure of green space that would be conducive to respiratory health; e.g., ecological cross-sectional study found no evidence at the scale of the American city for the general claim that access to green space yields health benefits; not only that there was no association between greenness and mortality from heart disease, diabetes, lung cancer, or automobile accidents, but mortality from all causes was significantly higher in greener cities (Richardson, Mitchell, Hartig, de Vries, Astell-Burt, & Frumkin, 2012).

Extended methodology

Pre-existing cardio-pulmonary diseases relevant to investigate, as they were found to heighten the risk of suffering from climate changes (D'Amato et al., 2014).

Recommended variables for RD:

Prevalence/incidence/morbidity/mortality of RD (asthma; acute bronchitis/cough; emphysema; lung cancer; pulmonary hypertension; autoimmune diseases that damage the lungs, such as scleroderma and rheumatoid arthritis).

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HEALTH AND WELLBEING INDICATORS - FEATURE

CONNECTING NATURE

Incidence of obesity /obesity rates (adults and children)

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(2) West University of Timisoara, Romania

Description

ADULTS

Obesity is defined as a measure of Body Mass Index (BMI) - a ratio of weight to height that is calculated by the following formula: BMI = weight (kg) ÷ height (m)^2. For adults, BMIs in the range of 18.5 to 24.9 are considered to be healthy – and associated with the lowest risk of mortality and morbidity. Overweight is defined as a BMI of 25.0 to 29.9; obesity is defined as a BMI of at least 30, with 3 sub-categories (Class I, Class II, and Class III) that are associated with increasing risk of cardiovascular disease, type 2 diabetes, and all-cause mortality (Bhrem and D'Alession, 2014).

CHILDREN

There is no consensus on a cut-off point for excess fatness of overweight or obesity in children and adolescents. European researchers classified overweight as at or above 85 percentile and obesity as at or above 95 percentile of BMI (Sahoo, Sahoo, Choudhury, Sofi, Kumar,& Bhadoria, 2015).

Level of expertise

. Methodology and data analysis requires high expertise in psycho-social research

. Quantitative data collection requires no expertise

Data collection

Required data

. Essential: NBS characteristics for each city/site.

Data input type

Quantitative

Data collection frequency

Before and after NBS implementation (longitudinal).

Participatory process

No opportunities identified

Connection with SDGs

Goal 3
Goal 11

References

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Incidence represents how quickly new cases occur relative to population size and the passage of time. Incidence is calculated as the ratio of the number of new cases of a disease occurring within a population during a given time to the total number of people in the population (National Institutes of Health. Autoimmune diseases coordinating committee—Autoimmune diseases research plan, n.d.). While the prevalence represents the existing cases of a disease, the incidence reflects the number of new cases of disease within a certain period and can be expressed as a risk or an incidence rate (Noordzij, Dekker, Zoccali, & Jager, 2010).

Methodology

Quantitative Procedure:
Epidemiological data (Health Data Administration/Cities)

Recommended measurements for obesity:

- Measurements of BMI - adults.
- Waist circumference - children.
- Measurement of subjective perception of the community environment (e.g., perceived accessibility to exercise facilities, satisfaction with safety, satisfaction with natural environment, satisfaction with living environment, satisfaction with public transportation) was proven to be of significance and it is recommended that is taken into account (see He Yoon and Kwon, 2014).

Extended description

With an abundance of convenient, palatable, energy dense foods and increasingly fewer demands for physical activity in usual lifestyles, the contemporary environment enables the energy balance to be tipped in favour of weight gain (obesogenic environment) (Bhrem & D'Alession, 2014). In adults, obesity is associated with increasing risk of cardiovascular disease, type 2 diabetes, and all-cause mortality. Most of the associated mortality and morbidity is mediated through major chronic diseases related to obesity, such as cardiovascular disease, diabetes, and cancer (Bhrem & D'Alession, 2014). Overweight children face a greater risk of a host of problems, including type 2 diabetes, high blood pressure, high blood lipids, asthma, sleep apnea, chronic hypoxemia (too little oxygen in the blood), early maturation, and orthopaedic problems (Samuels, 2004).

Lachowycz, K., & Jones, A. (2011). Greenspace and obesity: A systematic review of the evidence. Obesity Reviews: An Official Journal of the International Association for the Study of Obesity, 12, e183-e189. doi: 10.1111/j.1467-789X.2010.00827.x

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Yoon, N. H., & Kwon, S. (2014). The effects of community environmental factors on obesity among Korean adults: a multilevel analysis. Epidemiology and Health, 36, e2014036. doi:10.4178/epih/e2014036

CONNECTING NATURE

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They also suffer psychosocial problems, including low self-esteem, poor body image, and symptoms of depression (Samuels, 2004). Studies conducted so far have focused on the relationship between access to green space and obesity or obesityrelated health conditions, as well as to what extent this relationship is influenced by levels of physical activity, socio-economic status and age. A systematic review of evidence found that the majority of research undertaken have found a positive association between green space and obesity-related health indicators, but that the relationship varied across age, socioeconomic status and the type of greenspace measure, and findings are inconsistent and mixed across studies (Lachowicz & Jones, 2011). Beyond objective opportunities to access green space for physical activity and the availability and affordability of healthy food, actual use of green spaces might be a much better predictor of obesity outcomes (Lachowicz & Jones, 2011).

Yoon and Kwon (2014) performed multilevel analysis to investigate community environmental effects on obesity and obesity risks. Relying on data collected with Community Health Surveys over a period of 2 years, the authors reported that objectively measured physical environmental variables did not significantly influence obesity, but subjective perception of the community environment (e.g., perceived accessibility to exercise facilities, satisfaction with safety, satisfaction with natural environment, satisfaction with living environment, satisfaction with public transportation) significantly influenced obesity. While obesity rates were higher among residents living in communities with high satisfaction with the natural environment, rates were lower among those living in communities reporting high satisfaction with use of public transportation. This means that providing access to green spaces might not be sufficient in reducing obesity, if green spaces and facilities for active mobility, exercise and leisure are not perceived as high quality and satisfactory.

Calls for future research in studies focus on understanding intermediary mechanisms (e.g., psychosocial factors), as well as the amount and quality of green space necessary for significant reductions in obesity across all age groups (Lachowicz & Jones, 2011; Lachowicz & Jones, 2014).

Strengths and weaknesses

+ Some evidence as to an association between exposure to nature (e.g., physical exercise, healthy food intake) and obesity-related health indicators.

- Inconsistent and mixed results across studies, pointing at other variables that may be more relevant as predictors for obesity-related health indicators (e.g., actual use of green spaces, Lachowicz & Jones, 2011).

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Extended methodology

Body mass index (BMI) is the most commonly used simple measure of adiposity, but it has limitations: it measures presumed excess weight given height, rather than actual body fat, and does not give any indication as to the distribution of fat in the body, and in adults, central adiposity is more closely associated with health risks than general adiposity. A wide range of alternative simple tools to measure adiposity or obesity is available, such as waist circumference, neck circumference, skinfold thickness, waist-to-hip ratio, waist-to-height ratio, body adiposity index, Rohrer's ponderal index, Benn's index and fat mass index (Simmonds, Burch, Llewellyn, Griffiths, Yang, Owen, Duffy, & Woolacott, 2015; Simmonds, Llewellyn, Owen, & Woolacott, 2015).

While BMI seems appropriate for differentiating adults, it may not be as useful in children because of their changing body shape as they progress through normal growth. In addition, BMI fails to distinguish between fat and fat-free mass (muscle and bone) and may exaggerate obesity in large muscular children. Furthermore, maturation pattern differs between genders and different ethnic groups. While health consequences of obesity are related to excess fatness, the ideal method of classification should be based on direct measurement of fatness. Although methods such as densitometry can be used in research practice, they are not feasible for clinical settings. For large population-based studies and clinical situations, bioelectrical impedance analysis (BIA) is widely used. Waist circumference seems to be more accurate for children because it targets central obesity, which is a risk factor for type II diabetes and coronary heart disease (Sahoo et al., 2015).

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HEALTH AND WELLBEING INDICATORS - FEATURE

CONNECTING NATURE

Heat reduced mortality

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Description

Heat-related Deaths Indicator shows the annual rate for deaths classified by medical professionals as "heat-related" in a given country, based on death certificate records. Every death is recorded on a death certificate, where a medical professional identifies the main cause of death (also known as the underlying cause), along with other conditions that contributed to the death. These causes are classified using a set of standard codes. Dividing the annual number of deaths by the country's population in that year, then multiplying by one million, will result in the death rates (per million people) that this indicator shows (Climate Change Indicators: Heat-Related Deaths, n.d.).

Mortality measures deaths caused by a specific disease, deaths resulting from treatment for a specific disease, or deaths in which a specific disease is a contributing factor, but not the primary cause. Mortality is the number of deaths due to a disease during a specific time divided by the number of persons in that population at the beginning of the time period. Hence, mortality is a rate in the sense that it represents how quickly deaths occur relative to population size and the passage of time.

Level of expertise

. Methodology and data analysis requires high expertise in psycho-social research

. Quantitative data collection requires no expertise

Data collection

Required data

. Essential: NBS characteristics for each city/site

Data input type

Quantitative

Data collection frequency

Before and after NBS implementation (longitudinal).

Participatory process

No opportunities identified

Connection with SDGs

Goal 3
Goal 11

References

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It can be interpreted as reflecting the risk of death from a particular cause faced by persons within the population being studied (National Institutes of Health. Autoimmune diseases coordinating committee—Autoimmune diseases research plan, n.d.).

Methodology

Quantitative Procedure:

Epidemiological data (Health Data Administration/Cities).

Recommended variables:

- Discomfort Index, DI (i.e., Temperature– humidity index, THI) - combination of temperature and humidity that is a measure of the degree of discomfort experienced by an individual in warm weather (Temperature– humidity index - Meteorological Measurement, n.d.).
- Heat-related Deaths Indicator.

Extended description

A built-up environment has significant influence on urban air temperature, which has been found to be considerably warmer than its surrounding rural or peri-urban areas. This phenomenon is called the urban heat island (UHI) effect, where urban structures absorb solar heat (radiation) during the daytime and release it back to the environment at nighttime (Oke, 1981 as cited in Lehmann, 2014, p. 5).

Introducing greenery in cities is seen as the most cost effective strategy for mitigating the urban heat island effect, because greenery helps to cool the environment through the process of evapotranspiration where large amounts of solar radiation can be converted into latent heat (Lehmann, 2014).

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Berry, H., Bowen, K., & Kjellstrom, T. (2010). Climate change and mental health: A causal pathways framework. International Journal of Public Health, 55, 123-32. doi: 10.1007/s00038-009-0112-0

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Bowler, Buyung-Ali, Knight and Pullin (2010) reviewed the cooling effect of urban greening and found moderate to strong evidence for reduced temperature. The metaanalysis demonstrated that, on average, a park is 0.94 °C cooler as compared to surrounding built environments. Increased heat is a strong predictor of a range of diseases (including several which have to date not been addressed in studies on natural environments and health, such as infant mortality and renal disorders) and mortality (Basagaña, Sartini, Barrera-Gómez, Dadvand, Cunillera, Ostro, Sunyer, & Mercedes Medina-Ramón, 2011; Benmarhnia, Deguen, Kaufman, & Smargiassi, 2015). It also has an impact on mental health (Berry, Bowen, & Kjellstrom, 2010). The relation between heat and lung cancer mortality is not sufficiently investigated (van den Bosch and Ode Sang, 2017). An increase in mortality with heat has been reported for some specific causes, namely cardiovascular disease, respiratory disease, mental, and nervous systems disorders, diabetes, and kidney and urinary system diseases (Basagaña et al., 2011).

In the heat-related mortality literature, it is typical to distinguish two types of heat exposures: first, increases in ambient temperatures which can be defined as periods of high temperatures over single days, associated with mortality, and second, consecutive days of high heat also known as heat wave days, where population mortality is greater than on non-heat wave days (Benmarhnia et al., 2015). Basagaña et al. (2011) used a long mortality series (24 years) in a large geographic area of Spain to assess the effect of extremely hot days on mortality using a fine classification of the cause of death, including external causes and causes of infant mortality. The study included all persons who died in Catalonia during the warm season (defined as May 15–October 15, which included the halfmonths with an average maximum temperature greater than 20°C) of the 24-year period from 1983 to 2006.

Exposures to temperature and to humidity (records) were assigned to each deceased person based on the values registered in the nearest weather station within the climatic zone of the town of death. Epstein and Moran (2006) advanced arguments for use of DI - the Discomfort Index – for the measurement of heat stress.

Strengths and weaknesses

+ Robust evidence as to UHI being a strong predictor of death rates, especially for certain health conditions, like cardiovascular disease, respiratory disease, renal disorders, etc.

- Limited empirical evidence on heat's role in lung cancer complications, etc.

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HEALTH AND WELLBEING INDICATORS - FEATURE

CONNECTING NATURE

Perceived chronic loneliness

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Description

Loneliness, or social isolation, can be defined as disengagement from social ties, institutional connections, or community participation (Seeman, 1996).

Methodology

Quantitative Procedure:
Scale/Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)

Selective Tool:
Three-Item Loneliness Scale (Hughes et al., 2004).

Level of expertise

. Methodology and data analysis requires high expertise in psycho-social research

. Quantitative data collection requires no expertise

Data collection

Required data

. Essential: NBS characteristics for each city/site, more specifically nature of activities one can get involved into while engaging with nature, opportunities for social interaction and for physical exercise, etc.

. Desirable: Data on symbolic/affective meanings assigned to NBS (case studies, participatory data collection methods) – see also indicator Place Attachment.

Data input type

Quantitative

Data collection frequency

After NBS implementation or aligned with timing of targeted (especially long-term) objectives

Participatory process

No opportunities identified

Connection with SDGs

Goal 3
Goal 11

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

Extended description

Loneliness is a growing problem in industrialized countries, where around one in three people is affected, and one in 12 severely (Cacioppo & Cacioppo, 2018). It has become a public health problem, since in addition to the serious consequences for the psychological well-being of individuals who suffer it, longitudinal studies show that loneliness implies an increased risk of morbidity and premature mortality, when compared with individuals who are more socially integrated or do not feel isolated (Cacioppo & Cacioppo, 2018; Shankar et al., 2017). Specifically, loneliness increases the risk of premature death by 26% (Cacioppo & Cacioppo, 2018), and the strength of social isolation as a predictor of mortality is similar to other welldocumented risk factors, such as obesity or smoking (Pantell et al., 2013).

The so-called "common sense treatments" (i.e., social skills training) have not been effective in tackling loneliness, while behavioural interventions and community programs show greater evidence of positive impact (Cacioppo & Cacioppo , 2018). Many recent interventions aim to improve well-being through connection and contact with green spaces, since the majority of studies published in this regard show a positive relationship between some aspect of green space, and health and wellbeing (Wendelboe-Nelson et al., 2019). Even the combination of virtual social interaction with the relaxation effect of experiencing nature through virtual reality has been shown to contribute to reductions in feelings of loneliness, as well as in the risks in associated illnesses (White et al., 2018).

Green spaces increase social cohesion through fostering positive social interactions and social engagement (Jennings & Bamkole, 2019). Natural features also enhance feelings of place attachment and identity, promoting a sense of community that contributes to a decrease in feelings of loneliness (Prezza et al., 2001). A lower presence of green spaces in people's living environment was found to be related to greater feelings of loneliness and perceived shortage of social support (Maas et al., 2009). The association between green spaces, perceived social support and loneliness was found to be the strongest in highly urbanized areas.

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Strengths and weaknesses

+ The indicator allows evaluating one of the most pressing problems for health and well-being in modern societies.

+ Especially important indicator to assess levels of physical and mental health in the elderly.

- The relationship between the indicator, exposure to green spaces and levels of health and wellbeing are mediated by other variables such as social contact in those places.

Extended methodology

Three-Item Loneliness Scale (Hughes et al., 2004).

It includes three items with a three-point Likert response scale (Hardly ever; Some of the time; Often). The Three-Item Loneliness Scale greatly expands the possibilities for loneliness research in the older population.

The next questions are about how you feel about different aspects of your life. For each one, tell me how often you feel that way:

1. First, how often do you feel that you lack companionship?
2. How often do you feel left out?
3. How often do you feel isolated from others?

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HEALTH AND WELLBEING INDICATORS - FEATURE

CONNECTING NATURE

Improvement of behavioural development and symptoms of attention-deficit/hyperactivity disorder (ADHD)

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(2) West University of Timisoara, Romania

Description

ADHD is a disorder that makes it difficult for a person to pay attention and control impulsive behaviors. He or she may also be restless and almost constantly active. ADHD is not just a childhood disorder. Although the symptoms of ADHD begin in childhood, ADHD can continue through adolescence and adulthood. Even though hyperactivity tends to improve as a child becomes a teen, problems with inattention, disorganization, and poor impulse control often continue through the teen years and into adulthood (Attention-Deficit/Hyperactivity Disorder (ADHD): The Basics, n.d.).

Diagnostic tools: Diagnostic and Statistical Manual of Mental Disorders (DMS-V), International Classification of Diseases (ICD, 10th revision)

Level of expertise

. Methodology and data analysis requires high expertise in psycho-social research

. Quantitative data collection requires no expertise

Data collection

Required data

. Essential: NBS characteristics for each city/site, more specifically nature of activities one can get involved into while engaging with nature, opportunities for play and physical exercise, etc.

Data input type

Quantitative

Data collection frequency

After NBS implementation and aligned with timing of "Improvement of behavioural development and symptoms of attention deficit/hyperactivity disorder (ADHD)" study (i.e., relevant to study design, observation of children's play, etc.).

Participatory process

No opportunities identified

Connection with SDGs

Goal 3
Goal 11

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

Methodology

Quantitative Procedure:
Scale/Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration).

Selective Tool:
Strengths and Difficulties Questionnaires (SDQ, Goodman, 1997).

Extended description

Attention Deficit/Hyperactivity Disorder (ADHD) is the most commonly diagnosed behavioural disorder in children (Taylor and Kuo, 2011). A series of studies have documented reductions of symptoms of ADHD in children when they perform activities in green outdoor environments, independent of age, gender, income groups, community types or geographic regions (Kuo & Taylor, 2004). A walk of barely 20 minutes in a park holds more significant effects than a downtown or neighbourhood walk (Taylor & Kuo, 2011). Furthermore, children with ADHD who play regularly in green play settings were found to have milder symptoms than children who play in built outdoor and indoor settings (Taylor & Kuo, 2011). Authors report that only relatively open green spaces have this effect (Taylor & Kuo, 2011).

A large study of children between the ages of 7 and 10 in Barcelona found empirical support for the beneficial impact of contact with green spaces and blue spaces (beaches) on indicators of behavioural development and symptoms of attention deficit/hyperactivity disorder (ADHD) in schoolchildren. More playtime spent in green spaces and higher frequency of beach visits/attendance was found to be associated to better behavioural development, emotional adjustment, and better peer relationships, whereas less surrounding greenness was associated to higher ADHD scores (Amoly, Dadvand, Forns, López- Vicente, Basagaña, Julvez, Alvarez-Pedrerol, Nieuwenhuijsen, & Sunyer, 2014).

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CONNECTING NATURE

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Finally, a longitudinal study conducted in New Zealand, using data from a sample of almost 50.000 children born in 1998 assessed associations between ADHD prevalence and proximity to green spaces across the lifespan, as well as rural living, while controlling for other variables relevant in the onset of ADHD (Donovan, Michael, Gatziolis, Mannetje, & Douwes, 2019).

The study found that children who had always lived in a rural area and those that were exposed to greenness after 2 years of age were less likely to develop ADHD. Also, prenatal and proximity to greenness in the first two years of life had no association to prevalence of ADHD (Donovan et al., 2019).

Strengths and weaknesses

+ Previous empirical evidence as to relationship between improved symptomatology of ADHD and exposure to nature and urban green space.

- Research focused only on hyperactive/ADHD children; no data on hyperactive adults and exposure to greenness.

Extended methodology

Strengths and Difficulties Questionnaires (SDQ, Goodman, 1997)

It is a behavioral screening questionnaire used to generate separate scores for conduct problems, emotional symptoms, and hyperactivity (Goodman, 1997).

The SDQ asks about 25 attributes, 10 of which would generally be thought of as strengths, 14 of which would generally be thought of as difficulties, and one of which—" gets on better with adults than with other children"—is neutral.

The 25 SDQ items are divided between 5 scales of 5 items each, namely Hyperactivity Scale, Emotional Symptoms Scale, Conduct Problems Scale, Peer Problems Scale, Prosocial Scale (See Goodman, 1997, p. 582 – items scoring).

For each item (/.../), please mark the box for Not True, Somewhat True or Certainly True.
It would help us if you answered all items as best you can even if you are not absolutely certain or the item seems daft!

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Please give your answers on the basis of the child's behaviour over the last six months or this school year:

- Considerate of other people's feelings
- Restless, overactive. cannot stay still for long
- Often complains of headaches, stomach-aches or sickness
- Shares readily with other children (treats, toys, pencils, etc.)
- Often has temper tantrums or hot tempers
- Rather solitary, tends to play alone
- Generally obedient, usually does what adults request
- Many worries, often seems worried
- Helpful if someone is hurt, upset or feeling ill
- Constantly fidgeting or squirming
- Has at least one good friend
- Often fights with other children or bullies them
- Often unhappy, downhearted or tearful
- Generally liked by other children
- Easily distracted, concentration wanders
- Nervous or clingy in new situations, easily loses confidence
- Kind to younger children
- Often lies or cheats
- Picked on or bullied by other children
- Often volunteers to help others (parents, teachers, other children)
- Thinks things out before acting
- Steals from home, school or elsewhere
- Gets on better with adults than with other children
- Many fears, easily scared
- Sees tasks through to the end
- Good attention span

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HEALTH AND WELLBEING INDICATORS - FEATURE

CONNECTING NATURE

Exploratory behaviour in children

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Description

“Playscape” - play activities defined and classified into three categories (Frost, 1992 as cited in Fjørtoft and Sagaie, 2000, p. 86):

(1) Functional play comprised gross-motor activities and basic skills and were implemented in games like play tag, chase and catch, leapfrog, hide and seek, catch a tree, making angels in the snow, and other games involving basic movements.

(2) Construction play was the type of play that was afforded by landscape structures and loose parts, e.g., building shelters, dens and other constructions like a pirate ship, building with cones and sticks and other moveable things. In the winter season, snow was an excellent building material.

(3) Symbolic play included socio-dramatic play and was recorded as role play and fantasy play such as play house, pirates, play farm with cones and sticks, etc.

Level of expertise

. Methodology and data analysis requires high expertise in psycho-social research.

. Quantitative data collection requires no expertise.

. Qualitative data collection (case study and narrative study methodology, for example) requires high expertise in psycho-social research.

Data collection

Required data

. Essential: NBS characteristics for each city/site, more specifically nature of activities one can get involved into while engaging with nature, opportunities for play and physical exercise, etc.

Data input type

Qualitative (and quantitative)

Data collection frequency

After NBS implementation and aligned with timing of "Exploratory behaviour in children" study (i.e., relevant to study design, observation of children’s play, etc.)

Participatory process

No opportunities identified

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 730222

Methodology

Quantitative Procedure:
Scale/Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration).

Selective Tool:
Case study methodology –case study analysis, ethnographic case study (e.g., Stanley, 2011), drawings collection and analysis, surveys, brainstorming sessions, “Walkabout” audio-recorded interviews, Informal audio-recorded observations and photographs (e.g., Luchs & Fikus, 2013; Samborski, 2010).

Extended description

Regular contact with nature has many benefits for healthy child development. These range from the development of motor, cognitive, social and emotional skills; the regulation of attention and behavior; health-related benefits such as the development of a healthy immune system and a healthy vision, among others; and the development of knowledge, interest, appreciation and attachment to nature.

Play is a fundamental activity in children´s healthy development as well as mental and emotional health (Gill, 2014). Free play has significant positive effects on cognitive and social- emotional development, independence and creativity (Allee-Herndon, Taylor, & Roberts, 2019). A classical study has studied a diversity of urban environments and the role of different types of landscapes on play (Moore, 1986 as cited in Chawla, 2015, p. 436). The study found that natural elements emerged as children’s most frequent favourite places. Both the parks and rough ground functioned as places where children could be alone or with friends and gain environmental knowledge and awareness. Moore proposed that the number and type of skill-related behaviours supported by a given setting could be considered a reasonable measure of its childhood environmental quality (Chawla, 2015).

Connection with SDGs

Goal 3
Goal 11

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As naturalized playgrounds have become more popular, the following elements have been described as essential to their design (White & Stoecklin, 1998):

- Water.
- Indigenous vegetation, including trees, bushes, flowers and long grasses that children can explore and interact with.
- Animals, creatures in ponds, butterflies, bugs.
- Sand, and best if it can be mixed with water.
- Diversity of colour, textures and materials.
- Ways to experience the changing seasons, wind, light, sounds and weather.
- Natural places to sit in, on, under, lean against, climb and provide shelter and shade.
- Different levels and nooks and crannies, places that offer socialization, privacy and views.
- Structures, equipment and materials that can be changed, actually, or in their imaginations, including plentiful loose parts.

Many recent studies have shown that natural areas provide for more imaginative, constructive, sensory, and socially cooperative play than asphalt, flat expanses of lawn, or built play equipment (Fjørtoft, 2004; Fjørtoft & Sagaie, 2000; Samborski, 2010; Stanley, 2011; Cloward Drown & Christensen, 2014). Wells and Evans (2003) concluded that the benefits to children were greater when they experienced a greater amount of exposure to nature. In playground observations, Luchs and Fikus (2013) documented that children engaged in longer play episodes and a greater variety of different types of play in a natural versus traditional play area.

Strengths and weaknesses

+ Previous empirical evidence as to relationship between outdoor activity/exposure to nature and improved manifestations associated to exploratory behaviour in children (e.g., creativity, etc.).

- Complex methodologies demanding qualified researchers for both collecting qualitative data, and for its analysis.

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INDICATOR REVIEWS

SOCIAL COHESION

This collection of indicators on justice and social cohesion focuses on the interactions between members of the communities where Nature-based solutions are applied, as well as with the natural space that surrounds them. Measurements on social relationships, trust in the community or level of empowerment are useful to understand whether the promoted NBS have benefits to boost both individuals and communities. In addition, this cluster includes a proposal to evaluate the human-nature interaction through its link with the green space, pro-environmental attitudes or behavior.

Connecting Nature

INDICATOR REVIEWS

CORE

- Bonding social capital
- Bridging social capital
- Trust in community
- Solidarity between neighbours
- Tolerance and respect
- Perceived safety
- Actual safety
- Place attachment
- Empowerment
- Positive environmental attitudes motivated by contact with NBS
- Environmental identity

FEATURE

- Linking social capital
- Environmental education opportunities
- Pro-environmental behaviour
- Connectedness to nature

SOCIAL COHESION INDICATORS - CORE

CONNECTING NATURE

Bonding social capital

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Description

Trusting and co-operative relations between members of a network who see themselves as being similar, in terms of their shared social identity (socio-demographics) (Claridge, 2018; Szreter and Woolcock, 2004).

Methodology

Quantitative Procedure:
Scale/Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)

Selective Tool:
Scale consisting of 2 items measuring the presence of BoSC type of connections, and respondent's perception of quality of interactions within BoSC type of connections (Anucha et al., 2006 – item 1 adapted to purposes of current study; item 2 formulated for the purposes of current study)

Level of expertise

. Methodology and data analysis require high expertise in psycho-social research

. Quantitative data collection requires no expertise

. Basic training needed if participatory data collection is opted for

Data collection

Required data

Essential: NBS characteristics for each city/site, more specifically objectives (short-, medium-, and long-term) and challenges

Data input type

Quantitative and qualitative, if participatory data collection is opted for

Data collection frequency

Before NBS implementation and/or aligned with timing of targeted (especially long-term) objectives

Participatory process

Participatory methods (e.g., collaborative participatory data collection) may be applied to garner community-relevant information on BoSC's role in NBS implementation and expansion.

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Extended description

Social capital is largely conceived in terms of the nature, extent, and outcomes of networks and associated norms of reciprocity, thus generally seen as a contributor to individual and group (community, nation) growth, well-being, and progress (Szreter & Woolcock, 2004). Social capital enables individuals to gain access to resources (ideas, information, money, services, and favours) and to have accurate expectations regarding the behaviour of others by virtue of their participation in relationships that are themselves the product of networks of association (Claridge, 2018; Szreter & Woolcock, 2004). Data on bonding social capital (BoSC) can provide an indication of connections within a group or community characterised by high levels of similarity in demographic characteristics, attitudes, and available information and resources (Claridge, 2018). These connections foster social support by allowing people to access favors, information, and emotional support (Claridge, 2018). BoSC fulfils an important social function by providing the norms and trust that facilitate the kind of collaborative action required by initiatives like NBS/Nature-based Infrastructure. Conversely, Nature-based solutions have been hailed as beneficial to social cohesion and social capital (Ibes, 2015; Low, Taplin & Scheld, 2005; Volker, Flap & Lindenburg, 2007; Oldenburg, 1989). Oldenburg (1989) analyses the unique role of outdoor spaces as "third places" with significant value in the well-being of urban existence in that they supply community members with publicly accessible spaces for gathering, socializing, and recreating (as quoted in Ibes, 2015).

Strengths and weaknesses

+ Reliable indicator of resources that encourage reciprocity and collaboration within community/group/organization

- Tightly structured and mostly exclusive - networks with excessive levels of bonding tend to breed bias and racism, creating out-groups and exclusion (Claridge, 2018; Szreter & Woolcock, 2004)
- Putnam (2000) described it as a source of support to people "getting by" (as quoted in Claridge, 2018) – more impactful as a source of support to people who suffer from socio-economic hardship or poor health, than as a resource for initiatives that challenge the status-quo (e.g., NBS)
- Several studies have found that bonding social capital has either no effect or a negative effect on economic outcomes (Claridge, 2018)

+/- General agreement as to the importance of a balance of bonding and bridging social capital, in that neither is negative per se but can be negative depending on the balance and context. The precise nature of the social identity boundaries, and the political salience of bonding and bridging groups are highly context specific (Claridge, 2018; Szreter & Woolcock, 2004).

Connection with SDGs

Goal 1
Goal 2
Goal 3

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Extended methodology

1. Thinking about people you interact with ... (e.g., in your community garden, in your local park), are most of them of ...the same family or kin group

(coded as [1]yes or [0]no), ...the same religion (coded as [1]yes or [0]no),

...the same gender (coded as [1]yes or [0]no), ...the same age (coded as [1]yes or [0]no),

...the same ethnic or linguistic group/race/caste/tribe (coded as [1]yes or [0]no),

...the same occupation (coded as [1]yes or [0]no),

...the same educational background or level (coded as [1]yes or [0]no),

...and/or mostly the same income (coded as [1]yes or [0]no)?

2. Thinking about these same people, how would you rate the quality of your interactions with them?

1 ...2....3...4...5...6...7
extremely dissatisfied (1)... extremely satisfied (7)

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SOCIAL COHESION INDICATORS - CORE

CONNECTING NATURE

Bridging social capital

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Description

Social relationships of exchange, often of associations between people with shared interests or goals but contrasting social identity (socio-demographics); BrSC is essentially the result of networking outside normal social groupings (Claridge, 2018; Szreter & Woolcock, 2004).

Methodology

Quantitative Procedure:
Scale/Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)

Selective Tool:
Scale consisting of 2 items measuring the presence of BrSC type of connections, and respondent's perception of quality of interactions within BrSC type of connections (Anucha et al., 2006 – item 1 adapted to purposes of current study; item 2 formulated for the purposes of current study)

Level of expertise

. Methodology and data analysis require high expertise in psycho-social research

. Quantitative data collection requires no expertise

. Basic training needed if participatory data collection is opted for

Data collection

Required data

Essential: NBS characteristics for each city/site, more specifically objectives (short-, medium-, and long-term) and challenges

Data input type

Quantitative and qualitative, if participatory data collection is opted for

Data collection frequency

Before NBS implementation and/or aligned with timing of targeted (especially long-term) objectives

Participatory process

Participatory methods (e.g., collaborative participatory data collection) may be applied to garner community-relevant information on BrSC's role in NBS implementation and expansion.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

Extended description

Social capital is largely conceived in terms of the nature, extent, and outcomes of networks and associated norms of reciprocity, thus generally seen as a contributor to individual and group (community, nation) growth, well-being, and progress (Szreter & Woolcock, 2004). Social capital enables individuals to gain access to resources (ideas, information, money, services, and favours) and to have accurate expectations regarding the behaviour of others by virtue of their participation in relationships that are themselves the product of networks of association (Claridge, 2018; Szreter & Woolcock, 2004). Data on bridging social capital (BrSC) can provide an indication of associations between groups, communities, or organisations that link people across a cleavage that typically divides society (like race, class, or religion) (Claridge, 2018). These connections of respect and mutuality function as a social lubricant leading to an increased ability to gather information, ability to gain access to power or better placement within the network, or ability to better recognize new opportunities (Claridge, 2018).

Nature-based solutions (NBS) have been linked to the notion of environmental justice across studies that explore the role of supporting urban processes involving equal access to neighborhood green space in fostering social cohesion (e.g., bridging social capital) towards the cultural integration of typically-excluded social groups, like elderly, immigrants, persons with disabilities, etc. (i.e., recognition-based justice) (Ibes, 2015; Kweon, Sullivan & Wiley, 1998; Raymond et al., 2017; Raymond, Gottwald, Kuoppa & Kyttä, 2016; van Den Berg et al., 2017). BrSc's beneficial impact on collective initiatives like NBS can be far-reaching, as it allows different groups to share and exchange information, ideas and innovation and builds consensus among the groups representing otherwise diverse interests.

Connection with SDGs

Goal 1	Goal 8	Goal 12
Goal 2	Goal 9	Goal 13
Goal 3	Goal 10	Goal 16
Goal 5	Goal 11	Goal 17

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Strengths and weaknesses

+ Reliable indicator of resources that encourage reciprocity and collaboration between groups/communities/organisations

+ Mostly inclusive, fosters tolerance and acceptances of different people, values, and beliefs through contact with diverse others (Claridge, 2018; Szreter & Woolcock, 2004)

+ Putnam saw it as a resource that helps one "get ahead" (as quoted in Claridge, 2018), facilitates swifter recognition of new opportunities, and promotes social change, innovation and consensus among groups/communities/organisations

+ Can improve economic development, growth, and employment (Claridge, 2018)

- May enable collusion, price fixing, or corruption (Claridge, 2018; Szreter & Woolcock, 2004)

+/- general agreement as to the importance of a balance of bonding (see SC1) and bridging social capital, in that neither is negative per se but can be negative depending on the balance and context. The precise nature of the social identity boundaries, and the political salience of bonding and bridging groups are highly context specific (Claridge, 2018; Szreter & Woolcock, 2004).

Extended methodology

1. Thinking about people you interact with ... (e.g., in your community garden, in your local park), are most of them of

...mixed occupations (coded as [1] yes or [0] no),

...mixed religion (coded as [1]yes or [0]no),

...mixed ethnic or linguistic group/race/caste/tribe (coded as [1]yes or [0]no),

...mixed educational backgrounds or levels (coded as [1] yes or [0] no),

...and/or mixed income levels (coded as [1] yes or [0] no)?

2. Thinking about these same people, how would you rate the quality of your interactions with them?

1 ...2....3...4...5...6...7
extremely dissatisfied (1)... extremely satisfied (7)

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SOCIAL COHESION INDICATORS - CORE

CONNECTING NATURE

Trust in community

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Description

Perception that members of one's community are trustworthy and trust each other, as well as perception of how trust within community has changed over time.

Methodology

Quantitative Procedure:
Scale/Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)

Qualitative Procedure

Selective Tool 1: case study methodology – structured interviews, focus-groups, case study analysis

Selective Tool 2: participatory data collections methods, such as collaborative participatory data collection, bodies as tools for data collection, photo elicitation

Level of expertise

. Methodology and data analysis require high expertise in psycho-social research

. Quantitative data collection requires no expertise

Qualitative data collection through case study methodology requires high expertise in psycho-social research (basic training needed if participatory data collection is opted for)

Data collection

Required data

. Essential: NBS characteristics for each city/site, more specifically objectives (short-, medium-, and long-term) and challenges

. Desirable: Data on significant events in the recent history of the community with implications for the evolution of a sense of shared trust among its members

Data input type

Quantitative and qualitative, if participatory data collection is opted for

Data collection frequency

Before NBS implementation and/or aligned with timing of targeted (especially long-term) objectives

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Extended description

Trust, solidarity, tolerance, and respect are generally understood as manifestations of a cohesive society, one that works towards the well-being of all the members, i.e., towards the common good. Although the benefits of communitarian social capital (BoSC, BrSC, LSC) depend upon more basic structural factors of which inequality, level of education of the population and its ethnic-racial composition are considered as the most important, trust, solidarity, tolerance, and respect are core elements in the process of creating or building social capital which enables people to expect good from others (reciprocity) and to act on behalf of others in order to create a better future for all (Cloete, 2014). Moreover, whilst good governance has a significant impact on social cohesion by increasing trust, tolerance, and acceptance of diversity, it is in fact each individual who actually create trust and guarantee reciprocity through concurrent values and by abiding to norms that guide the process of participation in networks. It seems that people with values like honesty, trustworthiness, integrity, who care for their fellow humans, are likely to create social capital that could lead to the formation of public good (Cloete, 2014). Therefore, trust, solidarity, tolerance, and respect are considered fundamental resources in the inception, implementation, and potential success of any collective initiatives like NBS. Moreover, social cohesion has been proven to represent an important resource for long-term environmental sustainability in that socially cohesive communities tend to be more supportive of environmentally sustainable attitudes and behaviors compared with those communities where social cohesiveness is weaker (Uzzell, Pol & Badenas, 2002). The cognitive components of social cohesion, like trust, tolerance or respect, attachment, reflect the quality of social interactions which take place within neighborhoods or cities (Stafford et al., 2003), and can be particularly relevant as both precursors and mediators of community response to environmental planning decision and change (Mihaylov & Perkins, 2014).

Participatory process

Participatory methods (e.g., collaborative participatory data collection) may be applied to collect community- relevant information on the evolution of a sense of shared trust among its members; they present the opportunity to perform a gap analysis, if needed, in order to address (diagnosed) breaches of trust that could negatively impact NBS implementation and expansion.

Connection with SDGs

Goal 1
Goal 2
Goal 3
Goal 4
Goal 5
Goal 6
Goal 7
Goal 8
Goal 10
Goal 11
Goal 12
Goal 13
Goal 16

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Strengths and weaknesses

+ Reliable indicator of solid premises for collaboration and reciprocity among members of a community

+ Evolution of perception of trust can be traced back into the history of a community, and events that either decreased or boosted trust can be integrated as "lessons learnt" in the process of design and implementation of NBS + provides consistent information about the values that lay the foundation of both explicit and implicit norms within a community

- Highly context-dependent, its actual benefits for a local NBS can be foreseen through a good understanding of the values that shore up perceived trust, and of the recent history of the community (i.e., through qualitative methods like case studies, focus groups, and/or participatory data collection)

Extended methodology

Trust and Solidarity" scale of the Integrated Questionnaire for the Measurement of Social Capital (SC-IQ) (Grootaert et al., 2004)

4 items measuring perception of trust from "Trust and Solidarity" scale

1. Generally speaking, would you say that most people can be trusted, or that you can't be too careful in your dealings with other people?

1 Most people can be trusted 2 You can't be too careful

2. In general, do you agree or disagree with the following statements?
A. Most people who live in this city/neighborhood can be trusted.
B. In this city/neighborhood, one has to be alert or someone is likely to take advantage of you.
C. Most people in this
city/neighborhood are willing to help if you need it.
D. In this city/neighborhood, people generally do not trust each other in matters of lending and borrowing money.

1. Agree strongly 2. Agree somewhat 3. Neither agree nor disagree 4. Disagree somewhat 5. Disagree strongly

3. Now I want to ask you how much you trust different types of people. On a scale of 1 to 5, where 1 means a very small extent and 5 means a very great extent, how much do you trust the people in that category?
A. People from your ethnic or linguistic group/race/caste/tribe B. People from other ethnic or linguistic groups/race/caste/tribe C. Shopkeepers D. Local government officials E. Central government officials F. Police G. Teachers H. Nurses and doctors I. Strangers

1. To a very small extent 2. To a small extent 3. Neither small nor great extent 4. To a great extent 5. To a very great extent

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4. Do you think that over the last five years*, the level of trust in this city/neighborhood has gotten better, worse, or stayed about the same?

1 Gotten better 2 Gotten worse 3 Stayed about the same

[* ENUMERATOR: TIME PERIOD CAN BE CLARIFIED BY SITUATING IT BEFORE/AFTER MAJOR EVENT]

Neighbourhood Social Cohesion (Stafford et al., 2003) – Trust Scale

Trust is measured by the use of a series of opposing statements at either end of a row of seven boxes; respondents are asked to place a tick in the one box which best represents their agreement with the following statements:

1. People in this area would do something if a house was being broken into

2. In this area people would stop children if they saw them vandalising things

3. People would be afraid to walk alone after dark

4. People in this area will take advantage of you

5. If you were in trouble, there are lots of people in this area who would help you

6. Most people in this area can be trusted.

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SOCIAL COHESION INDICATORS - CORE

CONNECTING NATURE

Solidarity between neighbours

ADINA DUMITRU (1), CATALINA YOUNG (2), IRINA MACSINGA(2)

(1) University of A Coruña, Spain
(2) West University of Timisoara, Romania

Description

A shared practice (or a cluster of such practices) reflecting a collective commitment to carry 'costs' (financial, social, emotional, or otherwise) to assist others (Prainsack & Buyx, 2012).

Methodology

Quantitative Procedure:
Scale/Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)

Qualitative Procedure

Selective Tool 1: case study methodology – structured interviews, focus-groups, case study analysis

Selective Tool 2: participatory data collections methods, such as collaborative participatory data collection, bodies as tools for data collection, photo elicitation

Level of expertise

. Methodology and data analysis require high expertise in psycho-social research

. Quantitative data collection requires no expertise

Qualitative data collection through case study methodology requires high expertise in psycho-social research (basic training needed if participatory data collection is opted for)

Data collection

Required data

. Essential: NBS characteristics for each city/site, more specifically objectives (short-, medium-, and long-term) and challenges

. Desirable: Data on significant events in the recent history of the community with implications for the evolution of solidarity practices and relevant structures

Data input type

Quantitative and qualitative, if participatory data collection is opted for

Data collection frequency

Before NBS implementation and/or aligned with timing of targeted (especially long-term) objectives

CONNECTING NATURE

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Extended description

Trust, solidarity, tolerance, and respect are generally understood as manifestations of a cohesive society, one that works towards the well-being of all the members, i.e., towards the common good. Although the benefits of communitarian social capital (BoSC, BrSC, LSC) depend upon more basic structural factors of which inequality, level of education of the population and its ethnic-racial composition are considered as the most important, trust, solidarity, tolerance, and respect are core elements in the process of creating or building social capital which enables people to expect good from others (reciprocity) and to act on behalf of others in order to create a better future for all (Cloete, 2014). Moreover, whilst good governance has a significant impact on social cohesion by increasing trust, tolerance, and acceptance of diversity, it is in fact each individual who actually create trust and guarantee reciprocity through concurrent values and by abiding to norms that guide the process of participation in networks. It seems that people with values like honesty, trustworthiness, integrity, who care for their fellow humans, are likely to create social capital that could lead to the formation of public good (Cloete, 2014). Therefore, trust, solidarity, tolerance, and respect are considered fundamental resources in the inception, implementation, and potential success of any collective initiatives like NBS. Moreover, social cohesion has been proven to represent an important resource for long-term environmental sustainability in that socially cohesive communities tend to be more supportive of environmentally sustainable attitudes and behaviors compared with those communities where social cohesiveness is weaker (Uzzell, Pol & Badenes, 2002). The cognitive components of social cohesion, like trust, tolerance or respect, attachment, reflect the quality of social interactions which take place within neighborhoods or cities (Stafford et al., 2003), and can be particularly relevant as both precursors and mediators of community response to environmental planning decision and change (Mihaylov & Perkins, 2014).
Solidarity is a particularly elusive concept, like most important concepts in our lives, such as health, love, or happiness (Prainsack & Buyx, 2012). Social solidarity as a practice requires contributions in terms of time, effort and emotional investments, or money that groups or individuals make to assist others.
Prainsack and Buyx (2012) underline the notion that motivations, feelings such as empathy, etc., are not sufficient to satisfy the operationalization of solidarity as practice, unless they manifest themselves in acts. Individuals come to engage in solidarity practices through recognition of similarity with one (or more) other people in a relevant aspect (interpersonal level), forms of solidarity institutionalization defined by social norms of ‘good conduct’ (group practices), and/or highly institutionalized structures (contractual and legal manifestations) (Prainsack and Buyx, 2012). Authors make plain that not every practice of solidarity at interpersonal and/or group level solidifies into contractual and legal manifestations, and the former can exist without highly institutionalized structures.

Participatory process

Participatory methods (e.g., collaborative participatory data collection) may be applied to collect community-relevant information on past and present enactments of solidarity (layers, structures); they present the opportunity to grasp both existing resources and potential pitfalls of relevance to emergent NBS initiatives within a certain community and culture of social solidarity.

Connection with SDGs

Goal 1, Goal 2, Goal 3, Goal 4, Goal 5, Goal 6, Goal 7, Goal 8, Goal 10, Goal 11, Goal 12, Goal 13, Goal 16

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In contrast, interpersonal and group practices may change (i.e., break away) following the institutionalization into contractual and legal manifestations of solidarity (i.e., the welfare society arrangements). Accordingly, collecting data on the typical manifestations of solidarity within a certain community and society (state, nation – the wider culture) (i.e., through qualitative research approaches) can best inform NBS initiatives on both existing resources and pitfalls when it comes to this complex layer of enacted values.

Strengths and weaknesses

+ Reliable indicator of solid premises for partnership around and towards the common good (i.e., awareness of sameness/similarity with fellow community members)

+ Evolution of solidarity practices can be traced back into the history of a community, and events that either endangered or inspired solidarity can be integrated as "lessons learnt" in the process of design and implementation of NBS

+ Provides consistent information about the values that lay the foundation of both explicit and implicit norms within a community

- Highly abstract a concept that requires attention to operationalization so as to distinguish it from empathy, friendship, charity, dignity, reciprocity, altruism, and trust

- Highly context-dependent, its actual benefits for a local NBS can be foreseen through a good understanding of the existing structures for enactment of a core value like solidarity within a certain community, and of its recent history (i.e., through qualitative methods like case studies, focus groups, and/or participatory data collection)

Extended methodology

Items measuring perception of solidarity from "Trust and Solidarity" scale of the Integrated Questionnaire for the Measurement of Social Capital (SC-IQ) (Grootaert et al., 2004)

In every community, some people get along with others and trust each other, while other people do not. Now, I would like to talk to you about trust and solidarity in your community.

5. How well do people in your city/neighborhood help each other out these days? Use a five point scale, where 1 means always helping and 5 means never helping.
1 Always helping 2 Helping most of the time 3 Helping sometimes 4 Rarely helping 5 Never helping

6. If a community project does not directly benefit you, but has benefits for many others in the city/neighborhood, would you contribute time or money to the project?
A. Time B. Money

1 Will not contribute time 1 Will not contribute money 2 Will contribute time 2 Will contribute money.

Quantitatively measured as perception of own willingness to manifest solidarity (i.e., elusive, idealized, abstract), and perception of solidarity manifested by fellow community members (a closer fit to the understanding of the concept as a practice). Consequently, qualitative methods are valuable to capturing idiosyncratic manifestations of solidarity within a certain community that could inform NBS implementation and successful development.

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SOCIAL COHESION INDICATORS - CORE

CONNECTING NATURE

Tolerance and respect

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(2) West University of Timisoara, Romania

Description

Attitudes that manifest as acceptance of the very things one disagrees with, disapproves of or dislikes, and of the differences between others and ourselves we would rather fight, ignore or overcome (van Doorn, 2012, 2014). These attitudes are paramount to overcoming or avoiding conflict, and often reached only after controversy or conflict (van Doorn, 2012, 2014).

Methodology

Quantitative Procedure:
Scale/Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)

Qualitative Procedure

Selective Tool 1: case study methodology – structured interviews, focus-groups, case study analysis

Selective Tool 2: participatory data collections methods, such as collaborative participatory data collection, bodies as tools for data collection, photo elicitation

Level of expertise

. Methodology and data analysis require high expertise in psycho-social research

. Quantitative data collection requires no expertise

Qualitative data collection through case study methodology requires high expertise in psycho-social research (basic training needed if participatory data collection is opted for)

Data collection

Required data

. Essential: NBS characteristics for each city/site, more specifically objectives (short-, medium-, and long-term) and challenges

. Desirable: Data on significant events in the recent history of the community with implications for the evolution of tolerance and respect, as well as for the presence of deep-seated prejudice

Data input type

Quantitative and qualitative, if participatory data collection is opted for

Data collection frequency

Before NBS implementation and/or aligned with timing of targeted (especially long-term) objectives

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

Extended description

Trust, solidarity, tolerance, and respect are generally understood as manifestations of a cohesive society, one that works towards the well-being of all the members, i.e., towards the common good. Although the benefits of communitarian social capital (BoSC, BrSC, LSC) depend upon more basic structural factors of which inequality, level of education of the population and its ethnic-racial composition are considered as the most important, trust, solidarity, tolerance, and respect are core elements in the process of creating or building social capital which enables people to expect good from others (reciprocity) and to act on behalf of others in order to create a better future for all (Cloete, 2014). Moreover, whilst good governance has a significant impact on social cohesion by increasing trust, tolerance, and acceptance of diversity, it is in fact each individual who actually create trust and guarantee reciprocity through concurrent values and by abiding to norms that guide the process of participation in networks. It seems that people with values like honesty, trustworthiness, integrity, who care for their fellow humans, are likely to create social capital that could lead to the formation of public good (Cloete, 2014). Therefore, trust, solidarity, tolerance, and respect are considered fundamental resources in the inception, implementation, and potential success of any collective initiatives like NBS. Moreover, social cohesion has been proven to represent an important resource for long-term environmental sustainability in that socially cohesive communities tend to be more supportive of environmentally sustainable attitudes and behaviors compared with those communities where social cohesiveness is weaker (Uzzell, Pol & Badenes, 2002). The cognitive components of social cohesion, like trust, tolerance or respect, reflect the quality of social interactions which take place within neighborhoods or cities (Stafford et al., 2003), and can be particularly relevant as both precursors and mediators of community response to environmental planning decision and change (Mihaylov & Perkins, 2014). Significantly, tolerance and respect is linked to social capital in that they reflect urban community's capacity for inclusion of diverse members or struggle thereof with a strong sense of identity which limits the access of minority members to decisional processes and shared resources (Cook & Swyngedouw, 2012, Stafford et al., 2003).

Participatory process

Participatory methods (e.g., collaborative participatory data collection) may be applied to collect community- relevant information on past and present experiences with tolerance and/or prejudice; they present the opportunity to grasp both existing resources and potential pitfalls of relevance to emergent NBS initiatives within a certain community/culture.

Connection with SDGs

Goal 1	Goal 6	Goal 11
Goal 2	Goal 7	Goal 12
Goal 3	Goal 8	Goal 13
Goal 4	Goal 10	Goal 16
Goal 5		

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Strengths and weaknesses

+ Reliable indicator of capacity to overcome differences (i.e., tolerance and respect are important resources in conflict management)

+ Evolution of these attitudes can be traced back into the history of a community, and events that challenged tolerance or brought forth deep-seated prejudices can be integrated as "lessons learnt" in the process of design and implementation of NBS

+ Provides consistent information about the values that lay the foundation of both explicit and implicit norms within a community

- Highly context (culture)-dependent, its actual benefits for a local NBS can be foreseen through a good understanding of the evolution of tolerance and respect within a certain community, and of its recent history (i.e., through qualitative methods like case studies, focus groups, and/or participatory data collection)

- Highly vulnerable to social desirability bias

Extended methodology

Neighbourhood Social Cohesion (Stafford et al., 2003) – 'Tolerance or Respect' Scale

A 7-point Likert scale to measure respondents' agreement with each of these statement was developed for the purposes of this study

1 - full agreement, 2- moderate agreement, 3 - slight agreement, 4 - neutral, 5 - slight disagreement, 6 - moderate disagreement, 7 - full disagreement

1.Everybody in this area should have equal rights and an equal say

2.People in this area treat each other with respect

3.People in this area are tolerant of others who are not like them

4.People in this area respect one another's privacy

5.In this area there are some people who belong and some who don't (R)

6.In this area there is pressure to behave like everyone else (R)

Quantitatively measured as perception of own willingness to manifest solidarity (i.e., elusive, idealized, abstract), and perception of solidarity manifested by fellow community members (a closer fit to the understanding of the concept as a practice). Consequently, qualitative methods are valuable to capturing idiosyncratic manifestations of solidarity within a certain community that could inform NBS implementation and successful development.

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SOCIAL COHESION INDICATORS - CORE

CONNECTING NATURE

Perceived safety

ADINA DUMITRU (1), CATALINA YOUNG (2), IRINA MACSINGA(2)

(1) University of A Coruña, Spain
(2) West University of Timisoara, Romania

Description

Self-reported perceptions of neighborhood/community crime and safety

Methodology

Quantitative Procedure:
Scale/Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)

Selective Tool 1:
Conflict and Violence Scale from "Social Cohesion and Inclusion" module of the Integrated Questionnaire for the Measurement of Social Capital (SC-IQ) (Grootaert et al., 2004) adapted to purposed of NBS research

Selective Tool 2:
Criminal Victimization and Perceptions of Community Safety Survey (Smith et al., 1999) adapted to the purposes of NBS research

Level of expertise

. Methodology and data analysis require high expertise in psycho-social research

. Quantitative data collection requires no expertise

. Qualitative data collection through case study methodology and PPGIS requires high expertise in psycho-social research (basic training needed if participatory data collection is opted for)

Data collection

Required data

Essential: NBS characteristics for each city/site, more specifically objectives (short-, medium-, and long-term) and challenges

Data input type

Quantitative and qualitative, if case study methodology and/or participatory data collection are opted for

Data collection frequency

Before NBS implementation and/or aligned with timing of targeted (especially long-term) objectives

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

Extended description

Neighborhood safety is generally understood as an environmental demand (environmental press) in that perceived or actual low safety of a neighborhood environment could exceed person's physical or psychological capacity to manage the demands of the environment (Jin-Choi & Matz-Costa, 2018). Such adversity is particularly challenging for vulnerable groups like women, children, or elders. As a dimension of social capital, relations with neighbors and social support from interactions with neighbors are strongly related to the subjective sense of community, and mediate the relationship between neighborhood factors and residents' well-being. Research on neighborhood effects has explored relationships between burdensome physical conditions (e.g., living in deteriorating neighborhoods, public drug use, public drinking, loitering, street harassment, poor lighting, homeless sleeping in public, abandoned cars, trash, overgrown trees) and perceptions of psycho-social conditions (e.g., trust, support, sense of well-being) (Kruger, 2008; Loukaitou-Sidaris, 2006). Along these lines, neighborhood safety has been highlighted as a significant indicator for both the social capital of a community, and the health and well-being of its members, thereby a major factor in the implementation, and potential success of any collective initiatives like NBS. Indeed, McCabe (2014) brings forth evidence on how community gardens as community-based multi-prolonged initiatives effectively stabilize distressed neighborhoods, and positively associate with reduced violence, greater perception of residents' safety, lowered stress levels, improved relations with police, and greater empowerment as residents take pride and ownership in the development of their neighborhoods.
Furthermore, Bogar and Beyer (2015) conducted a systematic study of existing research on relationships among urban green space, violence, and crime in the United States, and found overwhelmingly positive associations between urban green space and neighborhood safety that withstand methodological idiosyncrasies and a limited understanding of causal pathways. Notably, Sreetheran and van den Bosch (2014) systematically reviewed the combination of characteristics that evoke fear of crime in urban green spaces and delineated their complex interaction by putting forward a social-ecological framework to promote a thorough understanding of the cumulative effect of the complex interaction between:

Participatory process

Participatory methods (e.g., collaborative participatory data collection, GIS with top-down goals of understanding neighborhood dynamics, location-based PPGIS) may be applied to collect community-relevant information about factors that play a role in members' perception of safety; data can further inform NBS implementation and expansion.

Connection with SDGs

Goal 3 Goal 11
Goal 6 Goal 16

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CONNECTING NATURE

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Environmental factors (such as vegetation character, density, and maintenance), individual aspects (e.g., age, gender, education level, minority status, ethnic background) and social attributes (like social cohesion, trust, frequency of visit) on people's fear towards crime or perceived personal safety in urban green spaces.
In accordance with the research investigated by the authors, gender is a significant and strong predictor of fear of crime in urban green spaces in that females have significantly higher fear levels than their male counterparts. Of all social attributes explored, social incivilities (e.g., the presence of youth gangs, beggars, homeless persons) were found to have a significant impact on fear of crime in urban green spaces. As the most investigated environmental attribute, vegetation density and maintenance was reported as a major cue evoking fear of crime in urban green spaces (Sreetheran & van den Bosch, 2014).

Strengths and weaknesses

+ Reliable indicator of challenges to neighborhood/community resources for a shared sense of trust, and for an individual sense of well-being

+ Perception of safety with respect to green spaces (parks, trees etc.) can inform NBS on best approaches so as to meet community's capacity to manage the demands of environment

+ Consistently adds to the information on a community's shared notion of trust and solidarity

- Measurement scales usually limit the investigation to neighborhood crime, conflict, and violence, whereas physical conditions related to housing (e.g., garbage, insects, and inadequate heat) and neighborhood (e.g., noise, crime, abandoned buildings, dark streets and sidewalks, and low accessibility to shops) hazards play an important role into a shared sense of community safety as well

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Extended methodology

- SC-IQ (Grootaert et al., 2004)

8 items representing Conflict and Violence Scale from "Social Cohesion and Inclusion" module (neighbourhood level)

1. In your opinion, is your neighborhood generally peaceful or marked by violence?
1 Very peaceful 2 Moderately peaceful 3 Neither peaceful nor violent 4 Moderately violent 5 Very violent
2. Compared to … years ago*, has the level of violence in your neighborhood increased, decreased, or stayed the same? [* ENUMERATOR: TIME PERIOD CAN BE CLARIFIED BY SITUATING IT BEFORE/AFTER …e.g., the park was built]
1 Increased a lot 2 Increased a little 3 Stayed about the same 4 Decreased a little 5 Decreased a lot
3. In general, how safe from crime and violence do you feel when you are alone at home?
1 Very safe 2 Moderately safe 3 Neither safe nor unsafe 4 Moderately unsafe 5 Very unsafe
4. How safe do you feel when walking down your street alone after dark?
1 Very safe 2 Moderately safe 3 Neither safe nor unsafe 4 Moderately unsafe 5 Very unsafe
5. In the past 12 months, have you or anyone in your household been the victim of a violent crime, such as assault or mugging?
1 Yes 2 No → go to question 7.
6. How many times?
7. In the past 12 months, has your house been burglarized or vandalized?
1 Yes 2 No
8. How many times?

- Criminal Victimization and Perceptions of Community Safety Survey(Smith et al., 1999)

7 items (neighbourhood and city level), to be adapted so as to best fit in with objectives of final survey

1. How fearful are you about crime in your neighborhood?
1.Very fearful 2. Somewhat fearful 3. Not very fearful – Skip to 3 4 .Not at all fearful – Skip to 3 5. Don't know – Skip to 3
2. Over the last 12 months, have your fears increased, decreased, or stayed the same?
1. Increased 2. Decreased 3. Stayed the same 4. Don't know
3. How fearful are you about crime in your city?
1 Very fearful 2. Somewhat fearful 3. Not very fearful – Skip to 5 4 .Not at all fearful – Skip to 5 5. Don't know – Skip to 5
4. Over the last 12 months, have your fears increased, decreased, or stayed the same?
1. Increased 2. Decreased 3. Stayed the same 4. Don't know
5. The following questions are more neighborhood specific. Do any of the following conditions or activities exist in your neighborhood?
(Read each category then enter the appropriate code for each category – 1, yes; 2, no; 3, don't know)

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...Abandoned cars and/or buildings
...Rundown/neglected buildings
...Poor lighting
...Overgrown shrubs/trees
...Trash
...Empty lots
...Illegal public drinking/public drug use
...Public drug sales
...Vandalism and Graffiti
...Prostitution
...Panhandling/begging
...Loitering/"hanging out"
...Truancy/youth skipping school
...Transients/homeless sleeping on benches, streets

NOTE: Do any of the categories in 5 contain an entry of 1 (yes)?

Yes - continue with questions 6 and 7   No

6. Do any of the conditions you just mentioned make you feel less safe in your neighborhood?

1.Yes 2. No 3. I don't know

7. Which of the conditions just mentioned affects your feeling of safety the most?

...Abandoned cars and/or buildings
...Rundown/neglected buildings
...Poor lighting
...Overgrown shrubs/trees
...Trash
...Empty lots
...Illegal public drinking/public drug use
...Public drug sales
...Vandalism and Graffiti
...Prostitution
...Panhandling/begging
...Loitering/"hanging out"
...Truancy/youth skipping school
...Transients/homeless sleeping on benches, streets
...Don't know

Qualitative Procedure:

Selective Tool:
Case study methodology – structured interviews, case study analysis

Selective Tool:
Participatory data collections methods, such as collaborative participatory data collection, bodies as tools for data collection, photo elicitation

Public participation geographic information system (PPGIS) methods/approaches

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SOCIAL COHESION INDICATORS - CORE

CONNECTING NATURE

Actual safety

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Description

Actual presence of environmental (e.g., unattended dogs) and/or human (e.g., reckless drivers) factors that have an impact on a neighborhood/community's objective parameters of safety (e.g., crime types, frequency of crimes committed, number of hospitalizations related to neighborhood safety hazards, etc.)

Methodology

Quantitative Procedure:
Objective measures through administrative data (police) of various types of crimes (e.g., aggravated assaults with and without guns, robberies with and without guns, narcotics sales and possession, burglaries, thefts, vandalism, disorderly conduct, public drunkenness, illegal dumping ...)

Public participation geographic information system (PPGIS) methods/approaches

Level of expertise

. Methodology and data analysis require high expertise in psycho-social research

. Quantitative data collection requires no expertise

. PPGIS requires high expertise in psycho-social research (basic training needed if participatory data collection is opted for)

Data collection

Required data

Essential: NBS characteristics for each city/site, more specifically objectives (short-, medium-, and long-term) and challenges

Data input type

Quantitative

Data collection frequency

Before NBS implementation and/or aligned with timing of targeted (especially long-term) objectives

Participatory process

Participatory methods (e.g., collaborative participatory data collection, GIS with top-down goals of understanding neighborhood dynamics, location-based PPGIS) may be applied to collect community-relevant information about crimes and safety hazards; data can further inform NBS implementation and expansion.

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Extended description

Neighborhood safety is generally understood as an environmental demand (environmental press) in that perceived or actual low safety of a neighborhood environment could exceed person's physical or psychological capacity to manage the demands of the environment (Jin-Choi & Matz-Costa, 2018). Such adversity is particularly challenging for vulnerable groups like women, children, or elders. As a dimension of social capital, relations with neighbors and social support from interactions with neighbors are strongly related to the subjective sense of community, and mediate the relationship between neighborhood factors and residents' well-being. Research on neighborhood effects has explored relationships between burdensome physical conditions (e.g., living in deteriorating neighborhoods, public drug use, public drinking, loitering, street harassment, poor lighting, homeless sleeping in public, abandoned cars, trash, overgrown trees) and perceptions of psycho-social conditions (e.g., trust, support, sense of well-being) (Kruger, 2008; Loukaitou-Sidaris, 2006). Along these lines, neighborhood safety has been highlighted as a significant indicator for both the social capital of a community, and the health and well-being of its members, thereby a major factor in the implementation, and potential success of any collective initiatives like NBS. A body of environmental studies have addressed the relationship between urban green space, violence and crime, yet literature remains divided as to the direction of this relationship and the factors that influence it (Bogar & Beyer, 2015; Frumkin et al., 2017; Kuo & Sullivan, 2011a; Younan, Tuvblad, Lianfa Li, Jun Wu, Lurmann, Franklin, Berhane, McConnell, Wu, Baker, & Jiu-Chiuan, 2017).

McCabe (2014) brings forth evidence on how community gardens as community-based multi-prolonged initiatives effectively stabilize distressed neighborhoods, and positively associate with reduced violence, greater perception of residents' safety, lowered stress levels, improved relations with police, and greater empowerment as residents take pride and ownership in the development of their neighborhoods. This research is in line with the many others have reported data that supports the contention that urban vegetation is negatively associated with crime rate and violence (Bogar & Beyer, 2015; Branas, Cheney, MacDonald, Tam, Jackson, & Ten Have, 2011; Garvin, Cannuscio, & Branas, 2012; Kuo & Sullivan, 2011a; Kuo & Sullivan, 2011b; Younan et al., 2017). On the other hand, some studies have suggested that low, dense vegetation (e.g., extending between residential and industrial properties) is positively associated with actual or perceived crime risk because it affords criminals a place to hide (Troy, Grove, & Neil-Dunne, 2012; Weber, Boley, Palardy, & Gaither, 2017).

Kuo and Sullivan (2001b) proposed that in poor inner-city neighbourhoods, vegetation can inhibit crime through the following two mechanisms: by increasing actual and implied surveillance (i.e., vegetation might introduce more eyes on the street by increasing residents' use of neighborhood outdoor spaces, and by deterring criminals through environmental cues suggesting that surveillance is likely even when no observers are present) and by mitigating some of the psychological precursors to violence (by mitigating residents' mental fatigue).

Connection with SDGs

Goal 3
Goal 6
Goal 11
Goal 16

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Kuo and Sullivan (2001b) proposed that in poor inner-city neighbourhoods, vegetation can inhibit crime through the following two mechanisms: by increasing actual and implied surveillance (i.e., vegetation might introduce more eyes on the street by increasing residents' use of neighborhood outdoor spaces, and by deterring criminals through environmental cues suggesting that surveillance is likely even when no observers are present) and by mitigating some of the psychological precursors to violence (by mitigating residents' mental fatigue).
Bogar and Beyer (2015) carried out an extensive literature review with the purpose of informing population and health intervention based on existing evidence of relationship between urban green space, crime, and violence, only to document the presence of numerous study variations (e.g., study design, unit of analysis, study location, study analysis, measurement, outcomes, statistical analysis methods) that impact interpretation and comparison, and report that no overarching conclusions can be drawn, yet existing studies support the idea that urban green space holds great potential to decrease community crime and violence.
Future research exploring relationships among urban green space, violence, and crime must remain cognizant of the potential for resident perceptions of urban green spaces as places that harbor crime and violence (Bogar & Beyer, 2015).

Strengths and weaknesses

+ Objective indicator of challenges to neighborhood/community resources for a shared sense of trust, and for an individual sense of well-being
+ Safety hazards related to green spaces (parks, trees etc.) can inform NBS on best approaches so as to meet community's capacity to manage the demands of environment
+ Consistently adds to the information on a community's shared notion of trust and solidarity
+ Previously used for measurement of crime/violence by several studies reported in literature
+ Empirical evidence as to negative relationship between urban greenery and crime rate
-Measurements of actual safety usually limit the investigation to neighborhood crime, conflict, and violence, yet physical conditions related to housing (e.g., garbage, insects, and inadequate heat) and neighborhood (e.g., noise, crime, abandoned buildings, dark streets and sidewalks, heavy traffic, and low accessibility to shops) hazards are relevant to actual/real safety as well
- Lack of methodological consistency in the area of research (measurement, analysis, etc.) that severely limits potential to generalize analysis based on data collected

Extended methodology

Crime rate per area (i.e., in and around NBS) for time frame (i.e., before and after NBS implementation).
A crime rate describes the number of crimes reported to law enforcement agencies per 100,000 total population, and is calculated by dividing the number of reported crimes by the total population; the result is multiplied by 100,000 ("Computational Formulas", n.d.).

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SOCIAL COHESION INDICATORS - CORE

CONNECTING NATURE

Place attachment

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Description

Jorgensen and Stedman (2001):
. Sense of Place (SOP) is an individual's favorable or unfavorable attitude toward spatially demarcated object. SOP can be inferred from responses of a cognitive, affective or conative nature.
. Place identity can be regarded as an individual's cognitions, beliefs, perceptions or thoughts that the self is invested in a particular spatial setting.
. Place attachment can be defined in terms of an individual's affective or emotional connection to a spatial setting.
. Place dependence can be considered as the perceived behavioral advantage of a spatial setting relative to other settings.

Methodology

Quantitative Procedure:
Scale/Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)

Level of expertise

. Methodology and data analysis require high expertise in psycho-social research

. Quantitative data collection requires no expertise

Qualitative data collection through case study methodology requires high expertise in psycho-social research (basic training needed if participatory data collection is opted for)

Data collection

Required data

. Essential: NBS characteristics for each city/site, more specifically objectives (short-, medium-, and long-term) and challenges

. Desirable: Data on symbolic/affective meanings assigned to NBS (case studies, participatory data collection methods)

Data input type

Quantitative and qualitative, if participatory data collection is opted for

Data collection frequency

After NBS implementation or aligned with timing of targeted (especially long-term) objectives

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Extended description

Environmental psychology's place theory is still challenged by a lot of criticism aimed at confusion related to terminologies and concepts used in describing place attachment, and at its lack of developmental theory (Counted, 2016). Place attachment is sometimes used interchangeably with "sense of place" - a personal identification with a location or landscape on an emotional level as an individual or as a member of a community (Wolf, Krueger, & Flora, 2014). A number of studies have confirmed the expectation grounded in social identity and self-categorization theories that the greater the identification with the place, the greater the desire to express positive attitudes in relation to environmental transformations that could, in turn, give a more positive character to that place (Bernardo & Palma-Oliveira, 2012, 2016). Psychometric measures for assessing place attachment behaviors have been developed on the foundation conferred by a general agreement among theorists on the definition of place attachment as an "affective bond or link between people and specific places" (Hidalgo & Hernandez, 2001, as quoted in Counted, 2016). Measurements of emotional/symbolic attachments to places provide a means for people to articulate natural resource values (Williams & Vaske, 2003) that contribute to NBS initiatives, actual implementation, and expected success. Jorgensen and Stedman (2001) advanced an attitude-based conception of sense of place (SOP) conceived as a complex psychosocial structure that organizes self-referent cognitions (place identity), emotions (place attachment) and behavioral commitments (place dependence). This multidimensional construct makes for theoretical support in instances where self-evaluations contrast significantly for certain attitude objects. For example, a person may feel favorable toward their lakeshore property, but consider it peripheral to their identity and a poor place to perform certain behaviors (Jorgensen & Stedman, 2001).

Research aimed at exploring the relationship between green space (density, maintenance, proximity) and place attachment has yielded mixed results. On one hand, there are studies (e.g., Kim & Kaplan, 2004, Mohapatra & Mohamed, 2013, Xu, Matarrita-Cascante, Lee, & Luloff, 2019) which contend that natural features of the physical environment and open spaces (e.g., neighborhood parks) play a particularly important role in place attachment and the sense of community.

Participatory process

Participatory methods (e.g., collaborative participatory data collection) may be applied to collect community-relevant information on symbolic and emotional bonds with NBS/green spaces.

Connection with SDGs

Goal 3	Goal 11	Goal 14
Goal 4	Goal 13	Goal 15

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Conversely, there is research data (Kimpton, Wickes, & Corcoran, 2014) that does not support the suggestion that physical features like green space (e.g., living next to green spaces, living in a green community) influence how attached residents feel towards their community. Instead, Kimpton et al. (2014) report that community socio-structural characteristics such as social ties, ethno-racial diversity, affluence or economic disadvantage are strong predictors of place attachment.
Brown, Raymond and Corcoran (2015) advance data and suggestions for future research founded on public participation GIS (PPGIS) and related crowd-sourcing mapping methods. The authors also highlight the need for an operationalization, measurement and calibration of the concept of place attachment that would render it suited to predict certain events or outcomes like place-protective or place-enhancement behaviors if the concept is to have any utility for land usage or decision support in the future.

Strengths and weaknesses

+ Reliable indicator of psychosocial resources that boost individual self-esteem, a sense of belonging to one's community, and communication about environmental values and policies (Williams & Vaske, 2003)

+ Can inspire and encourage individuals to actively protect green places/NBS, and engage in pro-environmental behavior (Wolf et al., 2014)

+ Oriented towards inclusiveness, high potential to further trust within community, and to inculcate a community sense of pride

- Abuse of terminologies, and confusion related to concepts related to people-place relations, which leads to methodological gaps and challenges (Counted, 2016)

Extended methodology

Place Identity Scale (Williams & Vaske, 2003)

It comprises 6 items that measure place dependence and place identity as dimensions of place attachment

Items are presented in a 5-point "strongly disagree" (1) to "strongly agree" (5) format with a neutral point of 3.

1. I feel "X" is a part of me.

2. "X" is very special to me.

3. I identify strongly with "X".

4. I am very attached to "X".

5. Visiting "X" says a lot about who I am.

6. "X" means a lot to me.

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Sense of Place (SOP) inventory (Jorgensen & Stedman, 2001)

12 items developed to measure the three dimensions of an attitude- based place attachment experience, namely: place identity, place attachment, and place dependence

Place Identity Items:
1. Everything about my [...] is a reflection of me. 2. My [...] says very little about who I am.
3 I feel that I can really be myself at my [...]
4 My [...] reflects the type of person I am.

Place Attachment Items:
1 I feel relaxed when I'm at my [...] 2 I feel happiest when I'm at my [...]
3 My [...] is my favorite place to be.
4 I really miss my [...] when I'm away from it for too long.

Place Dependence Items:
1. My [...] is the best place for doing the things that I enjoy most.
2. For doing the things that I enjoy most, no other place can compare to my [...]
3. My [...] is not a good place to do the things I most like to
do.
4. As far as I am concerned, there are better places to be than at my [...]

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SOCIAL COHESION INDICATORS - CORE

CONNECTING NATURE

Empowerment

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Description

Psychological empowerment is a process by which individuals gain mastery and control over their lives, and a critical understanding of their environment; it operates through intrapersonal, interactional, and behavioral components (Zimmerman et al., 1992; Zimmerman, 1995)

Methodology

Quantitative Procedure:
Scale/Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)

Selective tool: 3 items at measuring respondents' perception of their ability to make decisions that affect everyday activities and may change the course of their life from the "Empowerment and Political Action" module of Social Capital-Integrated Questionnaire (SC-IQ) (Grootaert et al., 2004)

Level of expertise

. Methodology and data analysis require high expertise in psycho-social research
. Quantitative data collection requires no expertise
. Qualitative data collection (case study and narrative study methodology, for example) requires high expertise in psycho- social research (basic training needed if participatory data collection is opted for)

Data collection

Required data

. Essential: NBS characteristics for each city/site, more specifically objectives (short-, medium-, and long-term) and challenges
. Desirable: Data on empowerment processes and outcomes specifically related a certain NBS initiative in a community/city, and accounting for country/community- distinctive cultural, economic, legal, and political factors that play a role in empowerment dynamics (narrative studies, participatory data collection methods, participatory action research)

Data input type

Quantitative and qualitative,if narrative studies, participatory data collection methods, and/or participatory action research are opted for

Data collection frequency

Aligned with NBS implementation and timing of targeted objectives

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

Extended description

- The intrapersonal component (self-perception) refers to how people think about their capacity to influence social and political systems important to them (i.e., domain- specific perceived control, domain-specific self-efficacy, motivation to exert control, perceived competence)

- The interactional component (information, knowledge, decision process) refers to the transactions between persons and environments that enable one to successfully master social or political systems (i.e., knowledge about the resources needed to achieve goals, understanding causal agents, a critical awareness of one's environment, and the development of decision-making and problem- solving skills necessary to actively engage one's environment)

- The behavioral component (participation) refers to the specific actions one takes to exercise influence on the social and political environment through participation in community organizations and activities (i.e., participation in community organizations such as neighborhood associations, political groups, and participation in community-related activities, like contacting public officials or organizing a neighborhood issue).

Although generally recognized as a concept that bespeaks having, or taking, control over resources and decision-making processes that can affect one's quality of life (Carr, 2016), empowerment remains fairly ambiguous and debatable due to poor definitional clarity, followed by difficulties in measurement (Cross, Woodall, & Warwick-Booth, 2017). One of the most enduring problem arising from definitional diversity and differential understandings is the widespread use of a reductionist approach to its measurement (i.e., centered around individual/psychological empowerment) despite across-the-board acknowledgment that it can occur at different levels (individual, group, community or society) (Cross et al., 2017). Pratley (2016) emphasizes the five conceptual dimensions of empowerment commonly found throughout the literature (i.e., psychological, social, economic, legal, political), and states that the 'major challenges include complexity in measuring progress in several dimensions, and the situational, context dependent nature of the empowerment process' (p. 119).

Participatory process

Participatory methods (e.g., narrative studies, participatory data collection methods, and/or participatory action research) may be applied to collect community-relevant information on empowerment processes and outcomes specifically related to a certain NBS/green space initiative in a community/city, and accounting for country/community-distinctive cultural, economic, legal, and political factors that play a role in empowerment dynamics

Connection with SDGs

Goal 9
Goal 10
Goal 11
Goal 13
Goal 16

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The fact that empowerment is a moving target (i.e., distinction between empowering processes and empowering outcomes, and appreciation of the intricate interplay of their dynamics), and that its assessment is value-driven (i.e., culturally and ideologically molded) have added to measurement of empowerment often falling short of the range of expectations (Jupp, Ali, & Barahona, 2010).

In his delineation of a nomological network of empowerment at the individual level of analysis (i.e., psychological empowerment, PE), Zimmerman (1990) argues that ‘PE may be an open-ended construct that is not easily reduced to a universal set of operational rules and definitions’ (p. 583), and concedes that measures developed for one study may not be appropriate for another. One key component of empowerment targeted by NBS research is the participatory processes engaged in by individuals as they work to improve their quality of life (Cumbers, Shaw, Crossan & McMaster, 2018; Feldman & Westphal, 2000; Fernandez & Burch, 2003; Jennings & Bamkole, 2019; Westphal, 2003). Consequently, the theoretical work on empowerment from a psychological/individual perspective (Zimmerman, 1990a, 1990b, 1995; Zimmerman, Israel, Schulz, & Checkoway, 1992) has been valued for its insights into the active participation of individuals and groups in altering and shaping the socio- environmental context (Speer, Jackson, & Peterson, 2001).

Feldman and Westphal (2000) affirm the value of citizens’ participation in environmental decision making and stress the importance of careful consideration of the process of participation through all the stages of an urban greening project in order to harness the individual and collective empowering potential of participatory practices. Drawing on case study, the authors illustrate how an open space revitalization project in a public housing development in Chicago contributed to empowerment by ultimately producing a useful and satisfying space, attracting other professional knowledge, and garnering economic resources.

Westphal (2003) brings forth more insight into the imperative of careful consideration of unique factors at play in the process of participatory planning and design on a case by case basis. The author designed a qualitative research founded on empowerment theory (Zimmerman, 1995) and collected data on indicators of empowerment like efficacy, mastery, control, new resources, participation, increased skills, proactive behavior, critical awareness, sense of competence, shared leadership, etc., from 4 sites involved in landscaping projects, approximately 2 years after their implementation.

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Two of the sites had been initially thought to greatly benefit from the greening project, while other two had not been foreseen as socially benefitting from it. The comparative analysis illustrates how "empowerment outcomes from urban and community forestry projects are possible but far from a given" (p. 144), and how what might initially look as a success can end in
utter failure, bringing empirical evidence to the notion that empowerment is "a possible, but not automatic" social benefit of urban and community NBS, and outlining recommendations for before, during, and after the project to guide the effective involvement of individuals and communities in urban forestry.
Cumbers et al. (2018) carried out a qualitative research between February and July 2014 in 16 gardens across Glasgow and built on Massye's (1991) notion of an active sense of place to find empirical support for the role of community gardening in advancing community empowerment by facilitating "the recovery of individual agency, construction of new forms of knowledge and participation, and renewal of reflexive and proactive communities that provide broader lessons for building more progressive forms of work in cities" (p. 133).
Notably, Calvet-Mir and March (2019) analyse the meanings and politics of urban gardening in post-economic crisis Barcelona, and report data that support the assertion that urban gardens have proven successful as a source of collective empowerment promoting emancipatory and alternatives views about the right of citizen to the city and challenging speculative urban development.

Strengths and weaknesses

+ Reliable indicator of resources (psychosocial, etc.) that ground individual/group self-efficacy, self-esteem, and confidence, as well as sustain participation, pro-activeness and tenacity in the pursuit of goals that ultimately lead to socio-environmental change

+ Oriented towards inclusiveness, high potential to further sense of belonging and trust within community, and to inculcate a community sense of pride

- Complex concept and ambiguous definitions, followed by considerable limitations in psychometric quality of measurement

- Individual (psychological) empowerment by itself does little to influence change in the political and social context in which people live (Woodall, Warwick-Booth, & Cross, 2012); research design and measurement has to depart from an understanding of the culture in which studies are carried out, and account for the economic, political, legal, and social dimensions (at least at the level of community members' understanding of their sociopolitical environment) in order to lend credence to data collected by quantitative measures of PE

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Extended methodology

"Empowerment and Political Action" module of Social Capital-Integrated Questionnaire (SC-IQ) (Grootaert et al., 2004)

1. How much control do you feel you have in making decisions that affect your everyday activities? Do you have ...

1.1 No control
1.2 Control over very few decisions
1.3 Control over some decisions
1.4 Control over most decisions
1.5 Control over all decisions

2. Do you feel that you have the power to make important decisions that change the course of your life? Rate yourself on a 1 to 5 scale, where 1 means being totally unable to change your life, and 5 means having full control over your life.

1.1 Totally unable to change life
1.2 Mostly unable to change life
1.3 Neither able nor unable
1.4 Mostly able to change life
1.5 Totally able to change life

3. Overall, how much impact do you think you have in making your street/ your neighborhood/ your city a better place to live?

1.1 A big impact
1.2 A small impact
1.3 No impact

Qualitative procedure

Selective tool 1: case study methodology – semistructured interviews, case study analysis, participant and non- participant observation (Calvet-Mir & March, 2019; Cumbers et al., 2018; Fernandez & Burch, 2003; Nikolaïdou, Klöti, Tappert, & Drilling, 2016)

Selective tool 2: participatory data collections methods, such as Community-based Participatory Research (Bateman et al„ 2017), Stakeholder Analysis participatory or non- participatory methods (e.g., focus groups, Social Network Analysis, Q methodology, Knowledge Mapping, Interest-Influence Matrices, Actor-Linkage Matrices) (Reed, 2008; Reed, Graves, Dandy, Posthumus, Hubacek, Morris, Prell, Quinn & Stringer, 2009); collaborative participatory data collection - narrative study (communal narratives and personal stories) (Rappaport, 1995), photoelicitation and semistructured interview techniques (Westphal, 2003); participatory action research (PAR) to follow empowering processes in a community (Zimmerman, 1995); historical analysis of the process of creating just or unjust environmental conditions (Schönach, 2014); ethnographic accounts of justice (Checker, 2011, as quoted in Raymond et al., 2017); public participatory GIS to assess experiential qualities (Laatikainen et al., 2015; Raymond et al., 2016)

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SOCIAL COHESION INDICATORS - CORE

CONNECTING NATURE

Positive environmental attitudes motivated by contact with NBS

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Description

"Psychological tendency that is expressed by evaluating perceptions of or beliefs regarding the natural environment, including factors affecting its quality, with some degree of favor [...]" (Milfont, 2007 as quoted in Milfont, 2009).

Methodology

Quantitative Procedure:
Scale/Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)

Selective tool: Environmental Attitudes Inventory (EAI – Milfont & Duckitt, 2010) assesses broad evaluating perceptions of or beliefs regarding the natural environment, including factors affecting its quality; EAI 24, the brief 24 items version of the instrument is included here; authors recommend use of a shortened Social Desirability Scale with the brief EAI.

Level of expertise

. Methodology and data analysis require high expertise in psycho-social research

. Quantitative data collection requires no expertise

Qualitative data collection through case study methodology requires high expertise in psycho-social research (basic training needed if participatory data collection is opted for)

Data collection

Required data

. Essential: NBS characteristics for each city/site, more specifically objectives (short-, medium-, and long-term) and challenges

. Desirable: Data on environmental education programs which mediated contact with NBS, longitudinal evaluations of impact of programs (environmental literacy)

Data input type

Quantitative and qualitative, if participatory data collection is opted for

Data collection frequency

After NBS implementation or aligned with timing of targeted (especially long-term) objectives

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Extended description

Positive environmental attitudes (EA) make for a significant part of the environmental education (EE) process/environmental literacy (EL) continuum. EE programs are expected to engage individuals in exploration of environmental issues, critical thinking, problem solving, and decision making to improve the environment (Kudryavtsev, Krasny and Stedman, 2012; Kudryavtsev, Stedman, & Krasny, 2012). Accordingly, attitudes of concern for the environment and motivation to improve or maintain environmental quality (U.S. EPA, n.d.) have been invested as an indicator of a finely tuned and efficient intervention through such transformative programs. Moreover, a number of studies have provided empirical support to the idea that exposure to nature is positively associated with constructive attitudes towards the environment (Baur, Tynon, Ries, & Rosenberger, 2014; Byrka, Hartig, & Kaiser, 2010; Tarrant & Green, 1999; Whitburn, Linklater, & Milfont, 2019; Williams, Jones, Gibbons, & Clubbe, 2015). In a quasi-experimental study with 423 urban residents in 20 neighborhoods in Wellington City, New Zealand, Whitburn et al. (2019) identified environmental attitudes as mediator of the relationship between exposure to nature/engagement with nature and pro-environmental behaviors. Baur et al. (2014) employed a general population survey of urban residents of four cities in Oregon (734 completed surveys returned), USA and found that increased visitation to urban parks, forest reserves or other urban and urban-proximate green spaces is strongly associated with greater public understanding and support for urban natural resource management. Along similar lines, Williams et al. (2015) interviewed 1054 visitors at five UK botanic gardens and found that environmental attitudes are more positive among respondents leaving a botanic garden, than among those about to enter one. In a systematic review of the existing literature on the benefits of children's engagement with nature, Gill (2015) finds support for the assertion that time spent in nature promotes positive environmental attitudes and values. The studies reviewed present solid evidence that "spending time in natural environments as child is associated with adult pro- environment attitudes and feelings of being connected with the natural world and is also associated with a stronger sense of place" (p. 18). Additionally, Soga et al. (2016) surveyed 397 Tokyo elementary schoolchildren and found that children's affective attitudes and willingness to conserve biodiversity were positively associated not only with the frequency of direct experiences of nature, but also with the frequency of vicarious manifestations of experience with nature (like reading books/watching TV about wildlife and nature, or talking with parents/friends about wildlife and nature).

Connection with SDGs

Goal 8	Goal 10	Goal 13
Goal 9	Goal 11	Goal 16

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Schultz, Shriver, Tabanico, & Khazian (2004) defined EA as "the collection of beliefs, affect, and behavioral intentions a person holds regarding environmentally related activities or issues". The intricate nature of the construct as latent (i.e., cannot be observed directly) and multidimensional (i.e., values rooted in a concern for the self - egoistic, for other people – altruistic, or for the biosphere) has been a fertile ground for numerous studies attempting at consolidating the relevance of predicted connection between general environmental concern and ecological behavior (Bamberg, 2003; Bamberg & Rees, 2015; Milfont & Duckitt, 2006; Milfont, Duckitt, & Cameron, 2006; Milfont & Duckitt, 2010). Milfont and Duckitt (2006, 2010) have approached the challenge by departing from the traditional three-component model of attitude structure (i.e., cognitive, affective, and behavioral) to integrate the function of evaluative tendencies (i.e., values) which can both be inferred from and have an influence on beliefs, affects, and behaviors regarding human-environment relations. Subsequently, authors developed a multidimensional inventory to assess EA cross-culturally. Environmental Attitudes Inventory (EAI) is a collection of twelve specific scales that capture the main facets measured by previous research (Milfont & Duckitt, 2010). The twelve scales have shown high internal consistency, homogeneity, high test- retest reliability, and have also proven to be largely free from social desirability (Milfont, 2009; Milfont & Duckitt, 2010). Furthermore, their psychometric qualities have been supported in cross-cultural studies (Milfont, Duckitt, & Wagner, 2010). These attributes render authors' conceptual model empirically robust, thus relevant to our research objectives.

Strengths and weaknesses

+ Indicator of resources (awareness, values, etc.) that create preconditions for environmentally responsible behaviors
+ Indicator of successful impact of environmental education initiatives (longitudinal studies)

- Low relevance as predictors of actual behaviors; general agreement to treat them as general decisional preconditions for considering the potential environmental impact of decisions (Bamberg & Rees, 2015)
- Impact vs. intent – approach and risk for methodological bias: intent-oriented measures tend to neglect behavior patterns with a strong objective environmental impact (e.g., reducing CO_2 emissions) by omitting relevant structural/contextual factors (e.g., income, type of car, size of house) in favor of psychological variables like values or attitudes (Bamberg & Rees, 2015)

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Extended methodology

Environmental Attitudes Inventory (EAI – Milfont & Duckitt, 2010)

Construct definition of EAI scales (Milfont & Duckitt, 2010):

Scale 1. Enjoyment of nature: Belief that enjoying time in nature is pleasant and preferred to spending time in urban areas, versus belief that enjoying time in nature is dull, boring and not enjoyable, and not preferred over spending time in urban areas.

Scale 2. Support for interventionist conservation policies: Support for conservation policies regulating industry and the use of raw materials, and subsidising and supporting alternative ecofriendly energy sources and practices, versus opposition to such measures and policies.

Scale 3. Environmental movement activism: Personal readiness to actively support or get involved in organized action for environmental protection, versus disinterest in or refusal to support or get involved in organized action for environmental protection.

Scale 4. Conservation motivated by anthropocentric concern: Support for conservation policies and protection of the environment motivated by anthropocentric concern for human welfare and gratification, versus support for such policies motivated by concern for nature and the environment as having value in themselves.

Scale 5. Confidence in science and technology: Belief that human ingenuity, especially science and technology, can and will solve all environmental current problems and avert or repair future damage or harm to the environment, versus belief that human ingenuity, especially science and technology, cannot solve all environmental problems.

Scale 6. Environmental fragility: Belief that the environment is fragile and easily damaged by human activity, and that serious damage from human activity is occurring and could soon have catastrophic consequences for both nature and humans, versus belief that nature and the environment are robust and not easily damaged in any irreparable manner, and that no damage from human activity that is serious or irreparable is occurring or is likely.

Scale 7. Altering nature: Belief that humans should and do have the right to change or alter nature and remake the environment as they wish to satisfy human goals and objectives, versus belief that nature and the natural environment should be preserved in its original and pristine state and should not be altered in any way by human activity or intervention.

Scale 8. Personal conservation behaviour: Taking care to conserve resources and protect the environment in personal everyday behaviour, versus lack of interest in or desire to take care of resources and conserve in one's everyday behaviour.

Scale 9. Human dominance over nature: Belief that nature exists primarily for human use, versus belief that humans and nature have the same rights

Scale 10. Human utilization of nature: Belief that economic growth and development should have priority rather than environmental protection, versus belief that environmental protection should have priority rather than economic growth and development.

Scale 11. Ecocentric concern: A nostalgic concern and sense of emotional loss over environmental damage and loss, versus absence of any concern or regret over environmental damage.

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Scale 12. Support for population growth policies: Support for policies regulating the population growth and concern about overpopulation, versus lack of any support for such policies and concern.

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24 items

Please indicate the extent to which each of the following statements describes your beliefs by using the appropriate number from the scale below.

1 - strongly disagree ...2...3...4 - neither agree nor agree...5...6...7 - strongly agree

1. I really like going on trips into the countryside, for example to forests or fields. [SCALE 01 - Enjoyment of nature]
2. I think spending time in nature is boring. (R) [SCALE 01 - Enjoyment of nature]
3. Governments should control the rate at which raw materials are used to ensure that they last as long as possible. [SCALE 02 - Support for interventionist conservation policies]
4. I am opposed to governments controlling and regulating the way raw materials are used in order to try and make them last longer. (R) [SCALE 02 - Support for interventionist conservation policies]
5. I would like to join and actively participate in an environmentalist group. [SCALE 03 - Environmental movement activism]
6. would NOT get involved in an environmentalist organization. (R) [SCALE 03 - Environmental movement activism]
7. One of the most important reasons to keep lakes and rivers clean+H17 is so that people have a place to enjoy water sports. [SCALE 04- Conservation motivated by anthropocentric concern]
8. We need to keep rivers and lakes clean in order to protect the environment, and NOT as places for people to enjoy water sports. (R) [SCALE 04- Conservation motivated by anthropocentric concern]
9. Modern science will NOT be able to solve our environmental problems. (R) [SCALE 05 - Confidence in science and technology]
10. Modern science will solve our environmental problems. [SCALE 05 - Confidence in science and technology]
11. Humans are severely abusing the environment. [SCALE 06 - Environmental threat]
12. I do not believe that the environment has been severely abused by humans. (R) [SCALE 06 - Environmental threat]
13. I'd prefer a garden that is wild and natural to a well groomed and ordered one. (R) [SCALE 07 - Altering nature]
14. I'd much prefer a garden that is well groomed and ordered to a wild and natural one. [SCALE 07 - Altering nature]
15. I am NOT the kind of person who makes efforts to conserve natural resources. (R) [SCALE 08 - Personal conservation behavior]
16. Whenever possible, I try to save natural resources. [SCALE 08 - Personal conservation behavior]
17. Human beings were created or evolved to dominate the rest of nature. [SCALE 09 - Human dominance over nature]
18. I DO NOT believe humans were created or evolved to dominate the rest of nature.(R) [SCALE 09 - Human dominance over nature]
19. Protecting peoples' jobs is more important than protecting the environment. [SCALE 10 - Human utilization of nature]
20. Protecting the environment is more important than protecting peoples' jobs. (R) [SCALE 10 - Human utilization of nature]
21. It makes me sad to see forests cleared for agriculture. [SCALE 11 - Ecocentric concern]
22. It does NOT make me sad to see natural environments destroyed. (R) [SCALE 11 - Ecocentric concern]
23. Families should be encouraged to limit themselves to two children or less. [SCALE 12 - Support for population growth policies]
24. A married couple should have as many children as they wish, as long as they can adequately provide for them. (R) [SCALE 12 - Support for population growth policies]

Qualitative procedure

Selective tool 1: case study methodology – interviews, unobtrusive observation

Selective tool 2: priming and response competition measures (Van Vugt & Samuelson, 1999)

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SOCIAL COHESION INDICATORS - CORE

CONNECTING NATURE

Environmental identity

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Description

Environmental identity is one part of the way in which people form their self-concept; a sense of connection to some parts of the nonhuman natural environment, based on history, emotional attachment, and/or similarity, that affects the way in which we perceive and act towards the world; a belief that the environment is important to us and an important part of who we are. (Clayton, 2003, pp. 45-46)

Methodology

Quantitative Procedure:
Scale/Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)

Selective tool: Environmental Identity Scale (Clayton, 2003) made up of 24 items that measures the relationship between self and nature, inspired by identity theory. The structure of the scale was based in part on discussions of the factors that determine a collective social identity, and include the salience of the identity, the identification of oneself as a group member, agreement with an ideology associated with the group, and the positive emotions associated with the collective (Clayton, 2003, p. 52).

Level of expertise

. Methodology and data analysis require high expertise in psycho-social research

. Quantitative data collection requires no expertise

Data collection

Required data

. Essential: NBS characteristics for each city/site, more specifically objectives (short-, medium-, and long-term) and challenges

. Desirable: Data on pro-environmental behaviour relevant to NBS

Data input type

Quantitative

Data collection frequency

After NBS implementation or aligned with timing of targeted (especially long-term) objectives

Connection with SDGs

Goal 8	Goal 10	Goal 13
Goal 9	Goal 11	Goal 16

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

Extended description

Another concept that describes human-nature relationship and presents the promise of explaining/predicting pro-environmental behavior relevant to NBS is that of environmental identity (EID), understood as a dimension of social identity that resides in our ties to the natural world, like connections to pets, trees, mountain formations, or particular geographic locations which have commonly been studied under the construct of "place identity" (Clayton, 2003). In the overall analysis, environmental identity has been theoretically and methodologically invested with the potency to prompt and sustain ecological behavior both as a product of complex interactions between our self-concept and the natural world (i.e., self-relevant beliefs infused by contact with natural environment), and as a driving force behind personal, social, and political choices and actions (i.e., environmentally sustainable behavior) (Clayton, 2003; Balundė, Jovarauskaitė, & Poškus, 2019; Freed, 2015; Olivos & Aragonés, 2011). For instance., Dresner, Handelman, Steven Braun, and Rollwagen-Bollens (2014) surveyed and interviewed 172 adults participating in 18 urban volunteer events in area parks across Portland, Oregon between February and June 2012. Based on the annual frequency of participation in such events, the stewards were differentiated as first-time volunteers, mid-level volunteers (3-10 events/year), and frequent volunteers (>10 events/year). Environmental identity was reported as one of the main three factors that explained the variation in survey response across the board, alongside pro-environmental behavior and civic engagement. Environmental identity, pro-environmental behavior, and civic engagement were positively correlated with the frequency of volunteer participation in park area events, with frequent volunteers scoring the highest degree of attention to environmental issues, environmental identity, and self-reported pro-environmental behaviors (Dresner et al., 2014).

Clayton (2003) devised a psychometric instrument for the measurement of EI (i.e., Environmental Identity Scale - EIS), and advanced research data in support of "the idea that environmental identity is a meaningful and measurable construct, with consequences for attitudes and behavior, and that by thinking about environmental identity we learn something beyond what we learn by talking about attitudes and values" (pp. 52-58). Balundė et al. (2019) carried out a meta-analysis to investigate the relationship between EI and other two constructs devised to represent the human-nature relations, namely "connectedness with nature" (Schultz, 2002) and "environmental self-identity" (van der Werff, Steg, & Keizer, 2013).

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Their results confirmed a strong correlation between measures of connectedness with nature and environmental identity (see also Olivos, Aragonés, & Amérigo, 2011) as well as environmental self-identity, indicative of the fact that, although theoretically discernible, they may be psychometrically undistinguishable, thus redundant (Balundė et al., 2019). Accordingly, we have included EIS (Clayton, 2003) as measurement of participants' relationship with nature, environment, and NBS, in view of its psychometric properties having been examined and confirmed cross-culturally (i.e., Spain) (Olivos & Aragonés, 2011).

In line with research on environmental education and the evolution of environmental attitudes (see SC 10 and SC 11.1), Bremer (2014) argues that childhood experiences with nature are highly influential in shaping an environmental identity. Her qualitative analysis of interviews and surveys of six students and their parents indicate that caregivers have a significant role in environmental identity development. The authors concludes that the greatest influence upon environmental identity formation is accomplished when parents "are deeply involved in their child's life, engage in a positive relationship with the child, and guide their child's attention toward the environment while also allowing their child to make discoveries and develop independent moral reasoning" (Bremer, 2014, p. 64). Along similar lines, Prévot, Clayton, and Mathevet (2018) advocate for access and opportunities for children and young people to experience nature freely and bring forth data collected on 919 French students that support the contention that there is a strong positive correlation between childhood experiences with nature (i.e., rurality) and environmental identity. The authors show that this relation is mediated by adult behavior (i.e., visiting natural areas) which "promotes higher scores of environmental identity in a virtuous cycle: previous experiences predict both identity and current behavior, and identity and current behavior reinforce each other." (Prévot et al., 2014, p. 271-272).

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Strengths and weaknesses

+ Indicator of resources (beliefs, motivation, affect, etc.) that create preconditions for environmentally responsible choices, decisions, or behaviors

+ Better predictor of behavior than environmental attitudes (EA) (Clayton, 2003; Olivos & Aragonés, 2011), but not a solidly proven predictor of pro-environmental behavior – e.g., Freed (2015) sheds light on how environmental structures (i.e., recycling bins outside classrooms and around campus) can influence behaviors without changing a person's environmental

- Variability across cultures of constructs applied to the EI operationalization - as part of social identity, "understanding of oneself in a natural environment cannot be fully separated from the social meanings given to nature and to environmental issues, which will vary according to culture, world view, and religion" (Clayton, 2003, p. 53); EIS is based on North American understandings of the ways in which we value and interact with nature, and thus far cross-cultural validated only on Spanish population (Olivos & Aragonés, 2011)

Extended methodology

Environmental Identity Scale (Clayton, 2003)

Please indicate the extent to which each of the following statements describes you by using the appropriate number from the scale below.

1 - not at all true of me ...2...3...4 - neither true nor untrue...5...6...7 - completely true of me

1. I spend a lot of time in natural settings (woods, mountains, desert, lakes, ocean).

2. Engaging in environmental behaviors is important to me.

3. I think of myself as a part of nature, not separate from it.

4. If I had enough time or money, I would certainly devote some of it to working for environmental causes.

5. When I am upset or stressed, I can feel better by spending some time outdoors "communing with nature".

6. Living near wildlife is important to me; I would not want to live in a city all the time.

7. I have a lot in common with environmentalists as a group.

8. I believe that some of today's social problems could be cured by returning to a more rural lifestyle in which people live in harmony with the land.

9. I feel that I have a lot in common with other species.

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10. I like to garden.

11. Being a part of the ecosystem is an important part of who I am.

12. I feel that I have roots to a particular geographical location that had a significant impact on my development.

13. Behaving responsibly toward the earth -- living a sustainable lifestyle -- is part of my moral code.

14. Learning about the natural world should be an important part of every child's upbringing.

15. In general, being part of the natural world is an important part of my self-image.

16. I would rather live in a small room or house with a nice view than a bigger room or house with a view of other buildings.

17. I really enjoy camping and hiking outdoors.

18. Sometimes I feel like parts of nature -- certain trees, or storms, or mountains-- have a personality of their own.

19. I would feel that an important part of my life was missing if I was not able to get out and enjoy nature from time to time.

20. I take pride in the fact that I could survive outdoors on my own for a few days.

21. I have never seen a work of art that is as beautiful as a work of nature, like a sunset or a mountain range.

22. My own interests usually seem to coincide with the position advocated by environmentalists.

23. I feel that I receive spiritual sustenance from experiences with nature.

24. I keep mementos from the outdoors in my room, like shells or rocks or feathers.

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SOCIAL COHESION INDICATORS - FEATURE

CONNECTING NATURE

Bridging social capital

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(2) West University of Timisoara, Romania

Description

Social relations with those in authority that can be used to access resources or power (Claridge, 2018; Szreter & Woolcock, 2004).

Methodology

Quantitative Procedure:
Scale/Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)

Selective Tool:
Scale consisting of 2 items measuring the presence of LSC type of connections, and respondent's perception of quality of interactions within LSC type of connections (Anucha et al., 2006 – item 1 adapted to purposes of current study; item 2 formulated for the purposes of current study)

Level of expertise

. Methodology and data analysis require high expertise in psycho-social research

. Quantitative data collection requires no expertise

. Basic training needed if participatory data collection is opted for

Data collection

Required data

Essential: NBS characteristics for each city/site, more specifically objectives (short-, medium-, and long-term) and challenges

Data input type

Quantitative and qualitative, if participatory data collection is opted for

Data collection frequency

Before NBS implementation and/or aligned with timing of targeted (especially long-term) objectives

Participatory process

Participatory methods (e.g., collaborative participatory data collection) may be applied to garner community- relevant information on LSC's role in NBS implementation and expansion.

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Extended description

Social capital is largely conceived in terms of the nature, extent, and outcomes of networks and associated norms of reciprocity, thus generally seen as a contributor to individual and group (community, nation) growth, well- being, and progress (Szreter & Woolcock, 2004). Social capital enables individuals to gain access to resources (ideas, information, money, services, and favours) and to have accurate expectations regarding the behaviour of others by virtue of their participation in relationships that are themselves the product of networks of association (Claridge, 2018; Szreter & Woolcock, 2004). Data on linking social capital (LSC) inform on norms of respect and networks of trusting relationships between people who are interacting across explicit, formal or institutionalized power or authority gradients in society (Claridge, 2018). These relationships are described as 'vertical' and the key feature is differences in social position or power (Claridge, 2018). An example could be relationships between a community- based organisation and government or other funders (Claridge, 2018). Relationships that connect people across explicit 'vertical' power differentials, particularly as it pertains to accessing public and private services that can only be delivered through on-going face-to-face interaction, such as classroom teaching, general practice medicine, and agricultural extension, are central to shaping welfare and well-being (especially in poor communities) (Claridge, 2018). Consequently, LSC has many benefits on collective initiatives like NBS by connecting government officials and specialists (doctors, teachers, etc.) with people in the community, and by opening up economic opportunities to those belonging to less powerful or excluded groups. Nature-based Infrastructure has been linked to the notion of environmental justice across studies that explore the role of supporting urban processes involving equal access to neighborhood green space in fostering social cohesion (e.g., bridging social capital) towards the cultural integration of typically-excluded social groups, like elderly, immigrants, persons with disabilities, etc. (i.e., recognition-based justice) (Ibes, 2015; Kweon, Sullivan & Wiley, 1998; Raymond et al., 2017; Raymond, Gottwald, Kuoppa & Kyttä, 2016; van Der Berg et al., 2017).

Connection with SDGs

Goal 1	Goal 7	Goal 13
Goal 2	Goal 8	Goal 14
Goal 3	Goal 9	Goal 15
Goal 4	Goal 10	Goal 16
Goal 5	Goal 11	Goal 17
Goal 6	Goal 12	

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Strengths and weaknesses

+ Reliable indicator of resources that encourage reciprocity and collaboration among people or institutions at different levels of societal power hierarchy

+ Indicator central to welfare and wellbeing (Claridge, 2018)

+ Networks and ties with individuals, groups or corporate actors represented in public agencies, schools, business interests, legal institutions and religious/political groups are of paramount importance to economic progress, or to the implementation of initiatives that promote social change and innovation (Claridge, 2018; Szreter & Woolcock, 2004)

+ Oriented towards inclusiveness, high potential to further trust within community, to ground tolerance and respect, and to inculcate a community sense of safety (Claridge, 2018)

- Can be put to unhappy purposes—e.g., nepotism, corruption, and suppression (Szreter & Woolcock, 2004) +/- It is important to have an appropriate balance of all types of social capital. Research has found that without linking types of social capital, bonding social capital alone may not be sufficient for community development to occur (Claridge, 2018; Szreter & Woolcock, 2004).

Extended methodology

1. Thinking about people you interact with ... (e.g., meetings to define the open-space strategy, interactions in participatory sessions), are some of them of

...higher social status (coded as [1] yes or [0] no), ...higher public/political power (coded as [1] yes or [0] no)

...higher financial capability (coded as [1] yes or [0] no)?

2. Thinking about these same people, how would you rate the quality of your collaborative interactions with them?

1 ...2....3...4...5...6...7
extremely dissatisfied (1)... extremely satisfied (7)

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SOCIAL COHESION INDICATORS - FEATURE

CONNECTING NATURE

Bridging social capital

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Description

Environmental education opportunities generally designate educational programs sponsored by elementary and secondary schools, colleges and universities, youth camps, municipal recreation departments, local or international not-for-profit organizations, and private entrepreneurs.

Methodology

Quantitative Procedure:
Scale/Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)

Quantitative Procedure:
Qualitative methodologies can be used to explore the outcomes of EE opportunities experienced by community members in longitudinal research

Level of expertise

. Methodology and data analysis require high expertise in psycho-social research

. Quantitative data collection requires no expertise

. Qualitative data collection (case study, for example) requires high expertise in psycho-social research (basic training needed if participatory data collection is opted for)

Data collection

Required data

. Essential: NBS characteristics for each city/site, more specifically objectives (short-, medium-, and long-term) and challenges

. Desirable: evaluations of EE programs, especially of those designed to promote NBS

Data input type

Quantitative and qualitative, if participatory data collection is opted for

Data collection frequency

Aligned with NBS implementation and timing of targeted objectives

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

Extended description

Environmental education (EE) is a learning process that increases people's knowledge and awareness about the environment and associated challenges, develops the necessary skills and expertise to address the challenges, and fosters attitudes, motivations, and commitments to make informed decisions and take responsible action (UNESCO, Tbilisi Declaration, 1978). EE is aimed at producing a citizenry that is knowledgeable concerning the biophysical environment and its associated problems, aware of how to help solve these problems, and motivated to work toward their solution (Stapp, Havlick, Bennett, Bryan, Fulton, & MacGregor, 1969), i.e., an environmentally literate citizenry.

The term EE refers to education about the environment, including population growth, pollution, resource use and misuse, urban and rural planning, and modern technology with its demands upon natural resources. The goals and objectives of EE were agreed upon at UNESCO's Tbilisi Intergovernmental Conference (UNESCO, 1978), came to define the aforementioned notion of environmental literacy (i.e., components), and include awareness, knowledge, affect, skills, and participation. EE departs from learning opportunities that help people better understand and connect with the environment close to home, i.e., the environment in their own neighborhoods and communities (Carter and Simmons, 2010). Cole (2007) draws attention to local and cultural appropriateness in designing these learning opportunities, in that the ideas taught need to originate from and resonate with locally and culturally appropriate knowledge, values, and ways of living. Although not all EE programs have the potential to generate social capital among participants (e.g., classroom instruction), there are forms of EE that can foster social connectivity, trust, and associational and volunteer involvement (e.g., programs that incorporate collective opportunities for volunteer and associational involvement around stewardship, like community gardening and tree planting, or those that incorporate opportunities for intergenerational learning and collective decision-making, like place-based learning, school-community partnership for sustainability, environmental action, action competence, community-based natural resource management EE, social-ecological systems resilience) (Krasny, Kalbacker, Stedman, & Russ, 2015). For this reason, environmental education opportunities presented to a community are envisioned as a significant indicator of its resources for associational involvement in NBS, and of contexts for building trust.

Participatory process

Participatory methods (e.g., phenomenological analysis) may be applied to collect community-relevant information on EE programs (and their outcomes) specifically related to a certain NBS/green space initiative in a community/city, and accounting for country/community/place-distinctive culture.

Connection with SDGs

Goal 9
Goal 10
Goal 11
Goal 13
Goal 16

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CONNECTING NATURE

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Hailing the importance of green spaces beyond health benefits, Wolsink (2012a, 2012b) reports data of an explorative study conducted in all secondary schools in Amsterdam that indicates that proximity to green spaces is associated with the number of environmental education excursions. Specifically, the study suggests that increasing urban green spaces has a positive impact on environmental education activities, including the number of visits to green places. The author strongly affirms the environmental justice imperative of recognizing environmental education "as a viable stake in the urban development of green spaces" (Wolsink, 2012 a, p. 179).

Using a quasi-experimental research design, Kudryavtsev, Krasny and Stedman (2012) found empirical support for the hypothesis that interventions such as environmental education can nurture sense of place (Kudryavtsev, Stedman, & Krasny, 2012) in high school students. As sense of place has been found to cultivate place-specific pro- environmental behaviors (see Indicator SC 6), data gathered by Kudryavtsev et al. (2012) on youth participants in urban environmental education summer programs in the Bronx support the expectation that urban environmental education programs that cultivate the significance of urban green space "may inspire community-based initiatives to create more urban farms, roof gardens, community gardens and greenways, or to further restore aquatic ecosystems and urban forests" (p. 11).

Derr (2017) emphasizes the sustainable benefits of participatory environment education by finding empirical support for built environment education (BEE), an empowering model of education aimed at facilitating a stronger role of young people in decision making and shaping their environments. Elaborating on two cases in the City of Boulder, Colorado where children and youth were involved in the redesign of a natural public space, the author argues that BEE which includes participatory processes that facilitate group action and action competence furnishes "a holistic educational framework in which young people can explore nature, integrate multiple capabilities, and think about care of the social, cultural, and natural environment" (Derr, 2017, p. 14).

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Strengths and weaknesses

+ Indicator of resources (capacity-building, psychosocial, etc.) that forge participation, pro-activeness and tenacity in the pursuit of environmentally responsible goals

+ Oriented towards inclusiveness, high potential to further sense of belonging and trust within community, and to inculcate a community sense of pride, and efficacy

- Limited information on outcomes (environmental literacy, EL) - data on EE opportunities reflects enough potential for capacity-building, but the actual quality of EE curricula (e.g., local/cultural appropriateness), as well as the outcome (i.e., environmental literacy) can only be explored through studies aimed at evaluating EE programs (see Cole, 2007; Farmer et al., 2007; Kopnina, 2013; McBeth & Volk, 2010; Merenlender et al., 2016; Tidball & Krasny, 2010; Varela-Losada, et al., 2016)

Extended methodology

Quantitative procedure

Selective tool 1
Add-on items to any survey/questionnaire to collect accounts of EE programs attended in the past year, if any, as well as topic/theme covered; open-ended question(s) can be included to collect information about perceived usefulness, and/or how the knowledge/skills garnered have been put to use, if the case.

Selective tool 2
Adapted items from “Instructor/Student/Parent Environmental Survey” (see Cruz Lasso de la Vega, 2004, p. 25 and Appendix)

Qualitative procedure

Selective tool 1
Case study methodology – structured interviews, case study analysis, phenomenological analysis

Selective tool 2
Participatory data collections methods, such as collaborative participatory data collection, bodies as tools for data collection, photo elicitation

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SOCIAL COHESION INDICATORS - FEATURE

CONNECTING NATURE

Pro-environmental behaviour

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Description

Pro-environmental behavior is such behavior which is generally (or according to knowledge of environmental science) judged in the context of the considered society as a protective way of environmental behavior or a tribute to the healthy environment (Krajhanzl, 2010, p. 252).

Methodology

Quantitative Procedure:
Scale/Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)

Quantitative Procedure:
Qualitativemethodologiescanbeusedin
mixed-methods research designs to explore the dimensions of PEB, as defined by community members (i.e., participant- driven approach, Larson et al., 2015)

Level of expertise

. Methodology and data analysis require high expertise in psycho-social research

. Quantitative data collection requires no expertise

. Qualitative data collection (case study, for example) requires high expertise in psycho-social research (basic training needed if participatory data collection is opted for)

Data collection

Required data

. Essential: NBS characteristics for each city/site, more specifically objectives (short-, medium-, and long-term) and challenges

. Desirable: evaluations of "local land stewardship activities" (Larson et al., 2015), i.e., conservation-oriented actions that improve the ecological features of the neighborhood/city (e.g., tree planting) – actions specific to each NBS

Data input type

Quantitative and qualitative, if participatory data collection is opted for

Data collection frequency

Aligned with NBS implementation and timing of targeted objectives

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Extended description

Pro-environmental behavior (PEB) represents another dimension of interest in the evaluation of NBS' impact and foreseeable sustainability. Narrowly defined as "behavior which has a significant impact on the environment" (Krajhanzl, 2010, p. 252), PEB has been central to both theoretical and empirical endeavors aimed at shedding light on the factors that foster accountability in relation with nature. Evidently, the behavior addressed in PEB can be encountered in various unintentional forms (e.g., purchase of soya products).

Larson, Stedman, Cooper, and Decker (2015, p. 113) summarized the theoretical evidence for PEB's multidimensionality:

- Some behaviors are inherently more difficult to carry out than others, and participation levels are influenced by a wide array of social and structural factors.
- Participation in PEB is influenced by both hedonic, gain, and normative goals and intent. These drastically different motives not only result in different rates of behavioral expression; they may also affect the ways in which people perceive actions and their environmental impacts.
- PEB varies substantially when it comes to type of impacts (e.g., direct vs. indirect), and scope of influence or specificity (e.g., local to global)

Moreover, environmental theory employs a variety of terms to capture different nuances of the pro-environmental manifestation, like "ecological behavior" (Kaiser, 1998), "sustainable behavior" (Tapia-Fonllem, Coral-Verdugo, Fraijo-Sing, & Duron-Ramos, 2013), "environment-protective behavior", "environment-preserving behavior", "environmentally responsible behavior" (Krajhanzl, 2010). For instance, Tapia-Fonllem et al. (2013) emphasize that "although sustainable behavior is, in practical terms, synonymous with pro-environmental behavior, the latter has been used to emphasize efforts to protect the natural environment, while the former specifies actions aimed at protecting both the natural and the human (social) environments" (p. 712).

Pro-environmental behavior has been investigated in relation with numerous other variables pertinent to NBS research, such as environmental stewardship (Dresner, Handelman, Steven Braun, & Rollwagen-Bollens, 2014; Whitburn, Milfont, & Linklater, 2018), place attachment (Ramkissoon, Weiler, & Smith, 2012; Takahashi & Selfa, 2015), connectedness to nature (Whitburn et al, 2018), environmental identity (Brick, Sherman, & Kim, 2017; Brick & Lai, 2018), or education (Kudryavtsev, Krasny, & Stedman, 2012; Meyer, 2015).

Participatory process

Participatory methods can be used in mixed-methods research designs to explore the dimensions of PEB, as defined by community members (i.e., participant-driven approach, Larson et al., 2015)

Connection with SDGs

Goal 2	Goal 10	Goal 13
Goal 3	Goal 11	Goal 15
Goal 6	Goal 12	Goal 16
Goal 7		

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Whitburn et al. (2018) explored the relationship between pro-environmental behaviors and personal relationship with nature in a quasi-experimental research with 423 participants from 20 neighborhoods varying with respect to their vegetation. The authors measured past PEB as participants' active involvement in a tree-planting action and reported results that indicate a strong association between connectedness to nature and engagement in PEB. Moreover, participants' involvement in tree-planting and the level of neighborhood greenness explained 46% of the variance in PEB, where connectedness to nature, environmental attitudes, and use of nature for psychological restoration acted as mediators.
Dresner et al. (2014) surveyed and interviewed 172 adults participating in 18 urban volunteer events in area parks across Portland, Oregon between February and June 2012. Based on the annual frequency of participation in such events, the stewards were differentiated as first-time volunteers, mid-level volunteers (3-10 events/year), and frequent volunteers (>10 events/year). Pro-environmental behavior, environmental identity, and civic engagement were positively correlated with the frequency of volunteer participation in park area events, with frequent volunteers scoring the highest degree of attention to environmental issues, environmental identity, and self-reported pro-environmental behaviors (Dresner et al., 2014).
Brick et al. (2017) built on the significance of identity signalling (i.e., the visibility of our behaviour to others) and its role in shaping our social identity to propose that "the most important identity for expressing and signalling pro- environmental behavior is identifying with environmentalists" (p. 227) and showed that environmentalist identity predicts pro-environmental behavior more strongly for self-reported high-visibility behaviors than even political orientation. Brick and Lay (2018) replicated this finding and reported that explicit identity strongly and uniquely predicted pro- environmental behaviors and policy preferences.

Strengths and weaknesses

+ Indicator of participation, pro-activeness and tenacity in the pursuit of environmentally responsible goals
- Self-reported measures are susceptible to the effects of social desirability on respondents' answers
- Complex, multidimensional construct, highly dependent on social and cultural variables making it difficult to effectively measure the full range of potential pro-environmental behaviors in a single study (Larson et al., 2015)
- Generalizable PEB measurement scales based on behaviors that transcend place/location may not capture the reality of implemented actions playing a role in local environmental quality (Larson et al., 2015); Local land stewardship activities (i.e., efforts to physically enhance local environments) may represent a particularly relevant component of PEB when "place" matters (Larson et al., 2015, p. 114).

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Extended methodology

Quantitative procedure

Pro-environmental Behavior (Brick and Lay, 2018)

6 items adapted from the Recurring Environmental Behavior Scale (Brick et al., 2017) measuring the self-reported frequency of PEB assessed on a 5-point Likert scale - 1 (never), 3 (sometimes), 5(always)

1. When you visit the grocery store, how often do you use reusable bags?
2. How often do you conserve water when showering, cleaning clothes, washing dishes, watering plants, or during other activities?
3. How often do you discuss environmental topics, either in person or with online posts (Facebook, Twitter, etc.)?
4. When you buy clothing, how often is it from environmentally friendly brands?
5. How often do you engage in political action or activism related to protecting the environment?
6. How often do you educate yourself about the environment?

Recurring Environmental Behavior Scale (Brick et al., 2017)

21 items measuring the self- reported frequency of PEB assessed on a 5-point Likert scale - 1 (never), 3 (sometimes), 5(always)

1. When you visit the grocery store, how often do you use reusable bags?
2. How often do you walk, bicycle, carpool, or take public transportation instead of driving a vehicle by yourself?
3. How often do you drive slower than 60mph on the highway? 4. How often do you go on personal (non-business) air travel? 5. How often do you compost your household food garbage? 6. How often do you eat meat?
7. How often do you eat dairy products such as milk, cheese, eggs, or yogurt?
8. How often do you eat organic food?
9. How often do you eat local food (produced within 100 miles)?
10. How often do you eat from a home vegetable garden (during the growing season)?
11. How often do you turn your personal electronics off or in low-power mode when not in use?
12. When you buy light bulbs, how often do you buy high efficiency compact fluorescent (CFL) or LED bulbs?
13. How often do you act to conserve water, when showering, cleaning clothes, dishes, watering plants, or other uses?
14. How often do you use aerosol products?
15. When you are in PUBLIC, how often do you sort trash into the recycling?
16. When you are in PRIVATE, how often do you sort trash into the recycling?
17. How often do you discuss environmental topics, either in person or with online posts (Facebook, Twitter, etc.)?
18. When you buy clothing, how often is it from environmentally friendly brands?

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19. How often do you carry a reusable water bottle?
20. How often do you engage in political action or activism related to protecting the environment?

General Ecological Behaviour Scale (Kaiser, Wolfing, & Fuhrer, 1999)

Established as a Rasch- scale that assesses behavior by considering the tendency to behave ecologically and the difficulties in carrying out the behaviors, which depend on influences beyond people's actual behavior control; consists of 38 items representing different types of ecological behavior and some nonenvironmental, prosocial behaviors as well; a yes/no response format for these items is used. *Negatively formulated items.

Prosocial behaviour items:
1. Sometimes I give change to panhandlers.
2. From time to time I contribute money to charity.
3. If an elderly or disabled person enters a crowded bus or subway, I offer him or her my seat.
4. If I were an employer I would consider hiring a person previously convicted of a crime.
5. In fast food restaurants, I usually leave the tray on the table.*
6. If a friend or relative had to stay in hospital for a week or two for minor surgery _e.g., appendix, broken leg., I would visit him or her.
7. Sometimes I ride public transportation without paying a fare.*
8. I would feel uncomfortable if Turks lived in the apartment next door.*

Ecological behaviour items:
1. I put dead batteries in the garbage.*
2. After meals, I dispose of leftovers in the toilet.*
3. I bring unused medicine back to the pharmacy.
4. I collect and recycle used paper.
5. I bring empty bottles to a recycling bin.
6. I prefer to shower rather than to take a bath.
7. In the winter, I keep the heat on so that I do not have to wear a sweater.*
8. I wait until I have a full load before doing my laundry.
9. In the winter, I leave the windows open for long periods of time to let in fresh air.*
10. I wash dirty clothes without prewashing.
11. I use fabric softener with my laundry.*
12. I use an oven-cleaning spray to clean my oven.*
13. If there are insects in my apartment I kill them with a chemical insecticide.*
14. I use a chemical air freshener in my bathroom.*
15. I use chemical toilet cleaners.*
16. I use a cleaner made especially for bathrooms rather than an all-purpose cleaner.*
17. I use phosphate-free laundry detergent.
18. Sometimes I buy beverages in cans.*
19. In supermarkets, I usually buy fruits and vegetables from the open bins.*

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20. If I am offered a plastic bag in a store I will always take it.*
21. For shopping, I prefer paper bags to plastic ones.
22. I usually buy milk in returnable bottles.
23. I often talk with friends about problems related to the environment.
24. I am a member of an environmental organization. 25. In the past, I have pointed out to someone his or her unecological behaviour.
26. I sometimes contribute financially to environmental organizations.
27. I do not know whether I may use leaded gas in my automobile.*
28. Usually I do not drive my automobile in the city.
29. I usually drive on freeways at speeds under 100 k.p.h. _62.5 m.p.h..
30. When possible in nearby areas waround 30 km, _18.75 miles.x, I use public transportation or ride a bike.

Qualitative procedure

Selective tool 1

Case study methodology – structured interviews, case study analysis, phenomenological analysis

Selective tool 2

participatory data collections methods, such as collaborative participatory data collection

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SOCIAL COHESION INDICATORS - FEATURE

CONNECTING NATURE

Connectedness to nature

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Description

An individual's affective, experiential connection to nature, consisting of three components: cognitive (awareness of being part of nature), affective (sensitivity towards the protection of nature) and behavioural (engagement in nature protection) (Mayer & Frantz, 2004; Sobko et al., 2018).

Methodology

Quantitative Procedure:
Scale/Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)

Selective Tool 1 (Adults): Connectedness to nature scale (Mayer & Frantz, 2004)

Selective Tool 2 (Children): Connectedness to nature index—parents of preschool children (CNI-PPC; Sobkoet al., 2018)

Level of expertise

. Methodology and data analysis requires high expertise in psycho-social research

. Quantitative data collection requires no expertise

Data collection

Required data

. Essential: NBS characteristics for each city/site, more specifically nature of activities one can get involved into while engaging with nature

. Desirable: Data on symbolic/affective meanings assigned to NBS (i.e., case studies)

Data input type

Quantitative

Data collection frequency

Before and after NBS implementation or aligned with timing of targeted (especially long-term) objectives

Participatory process

No opportunities identified

Connection with SDGs

Goal 3 Goal 11 Goal 13

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Extended description

At the heart of the boom in the scientific study that encompasses the human-nature-relationship, the concept of connectedness to nature (CN) is central to understanding how people identify with the natural environment, how it influences personal values and attitudes, as well as the behavioural implications for achieve environmental management goals (Restall & Conrad, 2015). These authors point out that scientific research has collected a multiplicity of terms to refer to the CN indicator, such as nature connectedness, nature relatedness, love and care for nature, connectivity with nature, emotional affinity toward nature, dispositional empathy with nature or inclusion of nature in the self. The initial conceptualization made by Schultz (2002) described that individuals can understand their place in nature and the impact of their actions on the natural environment. CN theory has progressed over the years, consolidating relationships with other similar variables, thanks to the development of valid and reliable measurement tools (Restall & Conrad, 2015).
The behavioural component of the CN theory is of great interest for the field of pro-environmental actions. Therefore, the relationship between CN and pro-environmental behaviour has been of huge significance in the scientific literature, as highlighted by Gosling and Williams (2010). There is a consensus that identification with nature, through an emotional association, implies expand the sense of self and positively value non-human species, leading to greater pro-environmental behaviour (Gosling & Williams, 2010). Analysing this relationship more specifically, Dong et al. (2020) found that CN favours positive effects in sustainable consumption behaviour, specifically in green purchasing and green recycling. The influence between CN and pro-environmental behaviour is not always direct, and may be mediated by other factors such as the anthropomorphic effect of considering the entity "mother nature" (Liu et al., 2019), empathy and personality traits (Di Fabio & Kenny, 2021), self-awareness and pro-environmental attitudes (Franz et al., 2005) or contact with nature (Richardson et al., 2020). Regarding the relationship between contact with nature and pro-environmental behavior or other health outcomes, it does not seem so important to live in a greener neighborhood (Martin et al., 2020), but rather to engage in simple nature activities, which favors CN (Richardson et al., 2020).
In addition to pro-environmental behaviour, the other major impact that research has focused on the CN indicator is well-being caused by a greater connection with nature. The research developed by Cervinka et al. (2011) through five studies founded a robust, positive and statistically significant relationship between CN and psychological wellbeing, meaningfulness and vitality.

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CONNECTING NATURE

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These results, have been contrasted throughout numerous studies, including meta-analyses that found positive associations between CN and hedonic well-being (Capaldi et al., 2014) as well as with eudaimonic wellbeing (Pritchard et al., 2020). Other studies have highlighted the role of other variables that may play a role as mediators or outcomes, such as mindfulness traits (non-evaluative awareness) (Schutte, Malouf, 2018), the restorative potential of green spaces (Leavell et al., 2019), environmental identity (Balunde et al., 2019), or better attentional capacity and ability to reflect on life problems (Franz et al., 2009). Richardson et al. (2021) further emphasized the importance of maintaining a connection with the natural world to increase human well-being, since time in contact with nature is not a great predictor of well-being, but the fact of having a psychological and emotional connection with nature or engaging with nature through simple activities (e.g., smelling flowers). In recent decades, the relationships between CN, pro-environmental behaviour and well-being have also been tested in children, achieving similar results (Barrera-Hernández et al., 2021). Children who have a perception of themselves as more connected to nature tend to have more sustainable behaviours and achieve a higher level of happiness (Barrera-Hernández et al., 2021). The CN construct is fostered in children if they receive environmental education programs (Liefländer et al., 2013). For more information on the impact of these programs, see the indicator "Environmental education opportunities". The main source of CN in people is exposure to green spaces, especially those with higher environmental quality (Wyles et al., 2019). Therefore, and based on nature-based education in children, it is crucial to foster environmental knowledge and connectedness to nature as complementary drivers of ecological and pro-environmental behaviour, being a highly promising approach to develop the ecological motivations of individuals (Otto & Pensini, 2017). Greater contact with nature in childhood is positively associated with greater contact in adulthood, enhancing connectedness to nature and pro-environmental behaviour (Rosa et al., 2018). However cultural variables in each country must be considered, especially during adolescence (Krettenauer et al., 2020), as well as parental/guardians' CN, since it has been found to be a great predictor of this same construct in children (Passmore et al. al., 2021)

In summary, evaluating the impact of this indicator is essential when carrying out nature-based solutions that promote exposure to green spaces and contact with nature. In line with the trend to improve mental wellbeing through nature-based social prescribing in urban settings (Leavell et al., 2019), connectedness to nature is a clear benefit for human mental health, as well as a promising factor in promoting pro-environmental behaviour.

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

Strengths and weaknesses

+ The indicator allows knowing the degree of cognitive, affective and behavioural linkage of individuals with nature

- Understanding the relationship of the indicator with well-being or pro-environmental behaviour involves assessing other intermediate mechanisms

Extended methodology

Connectedness to nature scale (Mayer& Frantz, 2004)

Please answer each of these questions in terms of the way you generally feel, using the following scale 1 to 5 (i.e., 1 = strongly disagree and 5 = strongly agree).

1. I often feel a sense of oneness with the natural world around me

2. I think of the natural world as a community to which I belong

3. I recognize and appreciate the intelligence of other living organisms

4. I often feel disconnected from nature

5. When I think of my life, I imagine myself to be part of a larger cyclical process of living

6. I often feel a kinship with animals and plants

7. I feel as though I belong to the Earth as equally as it belongs to me

8. I have a deep understanding of how my actions affect the natural world

9. I often feel part of the web of life

10. I feel that all inhabitants of Earth, human, and nonhuman, share a common 'life force'

11. Like a tree can be part of a forest, I feel embedded within the broader natural world

12. When I think of my place on Earth, I consider myself to be a top member of a hierarchy that exists in nature

13. I often feel like I am only a small part of the natural world around me, and that I am no more important than the grass on the ground or the birds in the trees

14. My personal welfare is independent of the welfare of the natural world

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

Connectedness to nature index—parents of preschool children (CNI-PPC; Sobkoet al., 2018)

Please read the following statements and indicate your degree of agreement on a scale of 1 to 5 (i.e., 1 = strongly disagree and 5 = strongly agree).

1. My child likes to hear different sounds in nature

2. My child likes to see wild flowers in nature

3. Being in the nature makes my child feel peaceful

4. My child likes to garden and plant

5. My child enjoys collect rocks and shells

6. My child enjoys touching animals and plants

7. My child feels sad when wild animals are hurt

8. My child is distressed when he/she sees animals being hurt

9. My child is heartbroken when animals pass away

10. My child believes that picking up trash on the ground can help the nature

11. My child treats plants, animals and insects with care

12. My child enjoys recycling paper and bottles

13. My child notices wildlife wherever he/she is

14. My child chooses to read about plants and animals

15. My child feels the difference between outdoor and indoor

16. My child hears birds and other sounds in the nature

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INDICATOR REVIEWS

ECONOMIC

The economic impacts of Nature-based solutions can be comprehensively assessed using the following selection of indicators. Each indicator suggests tools or processes to perform measurements before (baseline), during and after the implementation of the NBS. On the one hand, Core indicators are a fast and efficient way to collect evidence on economic development potential and green business opportunities. On the other hand, Feature indicators form a robust set of measures on economic impact and its relationships with other social aspects such as innovation, well-being, or social return on investment.

INDICATOR REVIEWS

CORE

- New Businesses 'attracted' or started and additional rates received
- Net additional jobs created/enabled by NBS
- Increase in tourism
- Net impact on public expenditure from NBS implementation
- Private finance attracted to the NBS site

FEATURE

- New customers to business in proximity to NBS
- Local economy GDP
- Innovation impact
- Income/disposable income per capita
- Upskilling & related earning increase
- Renewable energy produced
- Overall economic, social and health wellbeing
- Change in natural capital
- Reduced/avoided flood damage costs
- Social return on investment

ECONOMIC INDICATORS - CORE

CONNECTING NATURE

New Businesses 'attracted' or started and additional rates received

1) New businesses established in proximity to NBS

Original text by: Laura Wendling (1), Ville Rinta-Hiiro (1), Maria Dubovik (1), Arto Laikari (1), Johannes Jermakka (1), Zarrin Fatima (1), Malin zu-Castell Rüdenhausen (1), Peter Roebeling (2), Ricardo Martins (2), Rita Mendonça (2). Project: UNaLab (Grant Agreement no. 730052). 24.1 New businesses established in proximity to NBS. Indicator included in Dumitru, A. & Wendling, L. (2021). Evaluating the Impact of Nature-based Solutions: A Handbook for Practitioners. Appendix of Methods. Luxembourg: Publications Office of the European Union.

(1) VTT Technical Research Centre Ltd, P.O. Box 1000 FI-02044 VTT, Finland
(2) CESAM – Department of Environment and Planning, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal

Description

Number of new businesses established in the area surrounding implemented NBS (within 300 m linear distance of NBS of at least 0.5 ha in size).

Methodology

A report by Gore, Ozdemiroglu, Eadson, Gianferrara, and Phang (2013) states that gross domestic product (GDP) and gross value added (GVA) metrics alone cannot accurately estimate the contribution of green infrastructure/NBS to economic growth.

Level of expertise

Low to moderate

Data collection

Required data

A number of possibilities exist, including GDP, GVA, number of start-ups, etc. (See Measurement procedure and tool)

Data input type

Quantitative

Data collection frequency

Before and after NBS implementation

Scale

District to regional scale

Connection with SDGs

Goal 8

Goal 9

Participatory process

No opportunities identified

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

Extended description

Urban regeneration can lead to improvement in the economic, physical, and social conditions of an area that has witnessed negative changes (Tallon, 2013). As such, it can include aspects such as development of business, housing, and a positive change on the community level (Tyler, Warnock, Provins, & Lanz, 2013).
Nature-based solutions also provide a ground for 'Green businesses' to flourish (Organisation for Economic Co-operation and Development [OECD], 2013).

Strengths and weaknesses

+ The indicator is easy to define
- A lot of input data needs to be collected

Extended methodology

Some methods to measure success can include occupation of premises in local areas or taking up of vacated spaces, changes in taxation, increase in start-ups, increase in visitors, new and expanding producer and retail firms, direct employment in development, maintenance and services, indirect employment in supporting firms, attracting and retaining the workforce.
The major indicator is the number of established businesses located around the implemented NBS and also the rates paid for occupying that particular space (Gore et al., 2013). However, this will require gathering data over a period of years to understand the trend and business activities, both before and after the NBS implementation.
Data can be derived annually from municipalities, planning departments and interviews with local businesses.
Understanding and identifying the buffer zone surrounding NBS and assessing the number of new businesses in parallel is a critical component. It may be useful to define the proximity of land or property to NBS similarly to urban green space accessibility as in the indicator Accessibility of urban green spaces, i.e., land or properties within a 300 m distance from NBS. The type, quality and size of a given NBS, and the different recreational opportunities, attractiveness and aesthetic values associated with the NBS, will largely determine the extent (in distance or time) and magnitude of its impact on local business development.

References

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CONNECTING NATURE

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

ECONOMIC INDICATORS - CORE

CONNECTING NATURE

New Businesses 'attracted' or started and additional rates received

2) Value of rates paid by businesses in proximity to NBS

Original text by: Laura Wendling (1), Ville Rinta-Hiiro (1), Maria Dubovik (1), Arto Laikari (1), Johannes Jermakka (1), Zarrin Fatima (1), Malin zu-Castell Rüdenhausen (1), Peter Roebeling (2), Ricardo Martins (2), Rita Mendonça (2).
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(1) VTT Technical Research Centre Ltd, P.O. Box 1000 FI-02044 VTT, Finland
(2) CESAM – Department of Environment and Planning, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal

Description

Value of rates paid by businesses established in the area surrounding implemented NBS (within 300 m linear distance of NBS of at least 0.5 ha in size)

Methodology

To accurately determine the impact of NBS implementation on the value of rates paid by nearby businesses, it is necessary to gather data over a period of years to understand trends and business activities before and after NBS implementation.

Level of expertise

Low to moderate

Data collection

Required data

Input data from municipalities, planning departments, and interviews with local businesses as well as area and categorisation of green spaces

Data input type

Quantitative

Data collection frequency

Before and after NBS implementation

Scale

District to regional scale

Connection with SDGs

Goal 8

Goal 9

Participatory process

No opportunities identified

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

Extended description

The major indicator is the total value of rates paid by businesses within a defined area surrounding implemented NBS for occupying that particular space (Gore et al., 2013).

Strengths and weaknesses

+ The indicator is easy to define
- A substantial amount of input data needs to be collected

Extended methodology

Data can be derived annually from municipalities, planning departments and interviews with local businesses.
Understanding and identifying the buffer zone surrounding NBS and assessing the number of new businesses in parallel is a critical component. It may be useful to define the proximity of land or property to NBS similarly to urban green space accessibility as in the indicator Accessibility of urban green spaces, i.e., land or properties within a 300 m distance from NBS. The type and size of a given NBS, and the different recreational opportunities and aesthetic values associated with the NBS, will largely determine the extent (in distance or time) and magnitude of its impact on local business development.

References

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CONNECTING NATURE

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ECONOMIC INDICATORS - CORE

CONNECTING NATURE

Net additional jobs created/enabled by NBS

Original text by: Jose Fermoso (1), Silvia Gómez (1), María González (1), Esther San José (1), Raúl Sánchez (1). Project: URBAN GreenUP (Grant Agreement no. 730426). 23.3 Number of new jobs created. Indicator included in Dumitru, A. & Wendling, L. (2021). Evaluating the Impact of Nature-based Solutions: A Handbook for Practitioners. Appendix of Methods. Luxembourg: Publications Office of the European Union.

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Description

Green jobs should contribute to environmental benefits. They should be strive for minimisation of resources, create decent employment opportunities and build low-carbon sustainable societies. The International Labour Organization (ILO) has a methodology to estimate green jobs. According to ILO's various country-wide studies, primary green activities (i.e., organic agriculture, sustainable forestry), secondary activities (i.e., renewable energy, clean industry, sustainable construction) and tertiary activities (i.e., recycling, sustainable tourism, and sustainable transport) are defined as green jobs.

Methodology

Essentially a 'before-after' indicator which captures the part of the employment increase that is (a) direct consequence of NBS implementation (workers employed to implement the NBS project should not be directly counted).

Level of expertise

Technical / Basic

Data collection

Required data

City official data, city platforms, questionnaires, smallmedium enterprise accounts... (Related to de NBS investment zone)

Data input type

· (Nº jobs) (€/m2)
· (Nº jobs or nº users) (€/year)

Data collection frequency

None

Scale

City / neighbourhood

Connection with SDGs

Goal 1, Goal 8, Goal 12, Goal 4, Goal 10, Goal 5, Goal 11

Participatory process

None identified

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

Extended description

This KPI, related to economic aspects measurements, evaluates how NBS interventions can increase the attraction of businesses, or how to increase the value of the existing ones. This value, evaluated through the measurements of number of jobs created will reflect the economic opportunities and potential of NBS solutions.

Strengths and weaknesses

- Medium or long term assessment.
- It needs municipality data from different departments.
- This KPI will require citizens' collaboration, so recovering the data could be difficult.

Extended methodology

The positions needs to be filled (vacant posts are not counted) and increase the total number of jobs in the enterprise. If total employment in the enterprise does not increase, the value is zero – it is regarded as realignment, not increase. Safeguarded, etc., jobs are not included.
Gross: Not counting the origin of the jobholder as long as it directly contributes to the increase of total jobs in the organisation. The indicator should be used if the employment increase can plausibly be attributed to the support.
Full-time equivalent: Jobs can be full time, part time or seasonal. Seasonal and part time jobs are to be converted to FTE using ILO/statistical/other standards.
Durability: Jobs are expected to be permanent, i.e., last for a reasonably long period depending on industrialtechnological characteristics; seasonal jobs should be recurring. Figures of enterprises that went bankrupt are registered as a zero employment increase.
Timing: Data is collected before the project starts and after it finishes; the NBS holders are free to specify the exact timing (depending on the NBS time needed to get the profit). Using average employment, based on 6 months or a year, is preferred to employment figures on certain dates.

- Number of jobs created (Direct employment)

Direct value on employment by zone, before and after implementation, during the established period.
Number of jobs created= n * Z [(nº jobs) (€/m2)]
Where n is referring to the direct full time employment in during the time defined (directly related to the each particular NBS); Z- affected zone/area in reference to the NBS (should depend on NBS the definition of the area).

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ECONOMIC INDICATORS - CORE

CONNECTING NATURE

Increase in tourism

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(1) Trinity College Dublin, Ireland
(2) University of A Coruña, Spain
(3) University of East London, United Kingdom
(4) West University of Timisoara, Romania

Description

The increase (or decrease) in number of visitors per day that is seen as fully or partially connected to the NBS at a local or international level.

Methodology

Location up to region

Scientific solid evidence

Many EU countries rely on tourism as a major contributor to the economy. Area improvements brought about by NBS implementation may provide increased incentives for visitors to the area, thereby increasing the number and amount spent by tourists.

Level of expertise

Moderate

Data collection

Required data

Number of visitors to NBS area (generally broken down by local / international)

Data input type

Quantitative

Data collection frequency

Anywhere from daily to annually

Connection with SDGs

Goal 8 Goal 12 Goal 13

Participatory process

No opportunities identified

References

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ECONOMIC INDICATORS - CORE

CONNECTING NATURE

Net impact on public expenditure from NBS implementation

1) Initial costs of NBS Implementation

Original text by: Gerardo Caroppi (1,2), Carlo Gerundo (2), Francesco Pugliese (2), Maurizio Giugni (2), Marialuce Stanganelli (2), Farrokh Nadim (3), Amy Oen (3). Project: PHUSICOS (Grant Agreement no. 776681). 24.5 Initial costs of NBS implementat. Indicator included in Dumitru, A. & Wendling, L. (2021). Evaluating the Impact of Nature-based Solutions: A Handbook for Practitioners. Appendix of Methods. Luxembourg: Publications Office of the European Union.

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(2) University of Naples Federico II (UNINA), Department of Civil, Architectural and Environmental Engineering, Naples, Italy
(3) Norwegian Geotechnical Institute (NGI), Oslo, Norway

Description

Project's initial costs are those occurring during the design and construction phases.

Methodology

Different methods can be used to assess initial cost and the choice among them depends on the detail of the available data and of the evaluation itself.

Level of expertise

High

Data collection

Required data

Parametric costs; Similar projects

Data input type

Quantitative

Data collection frequency

At the beginning of the project

Scale

Euros (€)

Connection with SDGs

Goal 12

Participatory process

Given the high degree of expertise needed to calculate this indicator, technical stakeholder can contribute to the provision of data needed for the estimation model implementation.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

Extended description

Indicators of Cost-Benefit Analysis of the Intervention subcriterion will assess the financial feasibility of the project scenario.

Strengths and weaknesses

+ Top-down synthetic approach could ensure rapid estimation but low accuracy;
- Bottom-up analytical approach and parametric approach are very time-consuming.

Extended methodology

These methods can be classified in three different approaches:

1) Top-down synthetic approach: when few and generic information is available, the estimation can be carried out by analogy with existing projects or by experts opinions;

2) Bottom-up analytical approach: when more and detailed information is available, the estimation can be carried out using the work (cost) breakdown structure;

3) Parametric approach: the estimation is carried out by analogy with existing projects but high quality data are needed.

References

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

ECONOMIC INDICATORS - CORE

CONNECTING NATURE

Net impact on public expenditure from NBS implementation

2) Maintenance costs of NBS

Original text by: Elizabeth Gil-Roldán (1), Gerardo Caroppi (2,3), Carlo Gerundo (3), Francesco Pugliese (3), Maurizio Giugni (3), Marialuce Stanganelli (3), Farrokh Nadim (4), Amy Oen (4). Project: proGIreg (Grant Agreement no. 776528) and PHUSICOS (Grant Agreement no. 776681). 24.6 Maintenance costs of NBS. Indicator included in Dumitru, A. & Wendling, L. (2021). Evaluating the Impact of Nature-based Solutions: A Handbook for Practitioners. Appendix of Methods. Luxembourg: Publications Office of the European Union.

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(4) Norwegian Geotechnical Institute (NGI), Oslo, Norway

Description

The maintenance costs indicator sums the total costs of sustaining the NBS implemented.

Methodology

Data can be collected via an economic and labour questionnaire to be distributed to the entities in charge of long-term maintenance of the planned or implemented NBS. Estimation from project financial assessment.

Level of expertise

High. Generally, the financial officer of the administrating entity should be able to respond.

Data collection

Required data

Cost estimates or actual cost reporting from entitles administering the NBS and sub-contractors

Data input type

Quantitative

Data collection frequency

At least once after implementation. Potential to estimate maintenance costs during planning stage

Scale

NBS level (typically building plot-district scale)

Connection with SDGs

Goal 8

Goal 12

Participatory process

None identified

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

Extended description

Maintenance expenses are the costs incurred to keep an item in good condition or good working order. This total maintenance cost must include total annual labour costs, land leasing costs, machinery, energy costs, licensing, etc. Indicators of Cost-Benefit Analysis of an NBS Intervention enable assessment of the financial feasibility of a given project scenario.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

ECONOMIC INDICATORS - CORE

CONNECTING NATURE

Net impact on public expenditure from NBS implementation

3) Replacement costs of NBS

Original text by: Gerardo Caroppi (1,2), Carlo Gerundo (2), Francesco Pugliese (2), Maurizio Giugni (2), Marialuce Stanganelli (2), Farrokh Nadim (3), Amy Oen (3). Project: PHUSICOS (Grant Agreement no. 776681). 24.7 Replacement costs of NBS. Indicator included in Dumitru, A. & Wendling, L. (2021). Evaluating the Impact of Nature-based Solutions: A Handbook for Practitioners. Appendix of Methods. Luxembourg: Publications Office of the European Union.

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(2) University of Naples Federico II (UNINA), Department of Civil, Architectural and Environmental Engineering, Naples, Italy
(3) Norwegian Geotechnical Institute (NGI), Oslo, Norway

Description

Replacement costs or replacement values refer to the amount that an entity would have to pay to replace an asset at the present time, according to its current worth.

Methodology

Replacement cost refers to the price that it would cost to replace an existing asset with a similar asset at the current market price. The asset in question, in the project scenario, should be the NBS/Hybrid/Grey solution implemented.

Level of expertise

High

Data collection

Required data

Model

Data input type

Cash flows of the project

Data collection frequency

At least once after project definition

Scale

Euros (€)

Connection with SDGs

Goal 12

Participatory process

Given the high degree of expertise needed to calculate this indicator, technical stakeholder can contribute to the provision of data needed for the estimation of the cash flows

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

Extended description

Indicators of Cost-Benefit Analysis of the Intervention subcriterion will assess the financial feasibility of the project scenario.

Strengths and weaknesses

+ Replacement costs is straightforward to calculate (especially with a spreadsheet); If calculated using NPV, cash flows rather than net earnings will be used (which includes non-cash items such as depreciation).
- A discount rate must be selected; NPV assumes you can accurately assess and predict future cash flows.

Extended methodology

For a damaged asset, the replacement cost for that asset takes into consideration the pre-damaged condition of the asset. Replacement costs are common in insurance policies to cover assets that are damaged or destroyed in a disaster, such as an floods or earthquakes. The process of determining an appropriate cost estimate of replacing an infrastructure is complex, and it requires various pieces of data and knowledge of construction in order to make an informed assessment. When making a decision on the infrastructure to be replaced and the cost to be incurred, businesses use the net present value (NPV).
The NPV method is used to analyze the cash inflows and outflows in order to make a purchase decision. It uses a discount rate to estimate the minimum rate of return on the asset.

The formula for Net Present Value is:

$$NPV_{XYZ} = \frac{Z_1}{(1+r)} + \frac{Z_2}{(1+r)^2} - X_0$$

where:

$Z1$ = Cash flow in time 1
$Z2$ = Cash flow in time 2
r = Discount rate
$X0$ = Cash outflow in time 0 (i.e., initial cost)

References

Daves, P. (2004). Net present value (npv). In M. J. Stahl (Ed.), Encyclopedia of health care management (pp. 386-386). Thousand Oaks, CA: SAGE Publications, Inc. doi: 10.4135/9781412950602.n533

CONNECTING NATURE

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

ECONOMIC INDICATORS - CORE

CONNECTING NATURE

Net impact on public expenditure from NBS implementation

4) Avoided costs due to NBS implementation

Original text by: Gerardo Caroppi (1,2), Carlo Gerundo (2), Francesco Pugliese (2), Maurizio Giugni (2), Marialuce Stanganelli (2), Farrokh Nadim (3), Amy Oen (3). Project: PHUSICOS (Grant Agreement no. 776681). 24.8 Avoided costs due to NBS implementation. Indicator included in Dumitru, A. & Wendling, L. (2021). Evaluating the Impact of Nature-based Solutions: A Handbook for Practitioners. Appendix of Methods. Luxembourg: Publications Office of the European Union.

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Description

Avoided costs are essentially the costs of the damages, which a catastrophic event could provoke without the expected intervention.

Methodology

The avoided costs method estimates the cost that the community would incur in the absence of project scenario implementation.

Level of expertise

High

Data collection

Required data

Different type of data (spatial data, models, parametric costs, etc.), depending on the hazardous phenomenon taken into account

Data input type

Quantitative

Data collection frequency

It could be assessed when the project scenario is clear and defined

Scale

Euros (€)

Connection with SDGs

Goal 12

Participatory process

Given the high degree of expertise needed to calculate this indicator, technical stakeholder can contribute to the provision of data needed for the estimation of the expected damages.

CONNECTING NATURE

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Extended description

Indicators of Cost-Benefit Analysis of the Intervention subcriterion will assess the financial feasibility of the project scenario.

Strengths and weaknesses

+ It is a frequently used benefit estimation technique, both because it is a common sense approach and because the information needed to assess avoided costs is often readily achievable.
- It could be very time consuming since many different models should be implemented to assess the expected damages.

Extended methodology

Given that NBS could prevent multiple risks, the avoided costs is equal to the sum of costs associated with responding to each risk faced by NBS.

Thus, for each hazardous phenomenon regarding the study area, it is essential to assess the expected damages and the cost of actions taken in response to the phenomenon after it occurs.

References

U.S. Environmental Protection Agency (1993), A Guide for Costeffectiveness and Cost-benefit Analysis of State and Local Ground Water Protection Programs.

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ECONOMIC INDICATORS - CORE

CONNECTING NATURE

Private finance attracted to the NBS site

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Description

This indicator seeks to capture the level (in monetary terms) of non-public ("private") in nature-based solutions and/or the 'bioeconomy'. The indicator will provide information on the extent to which private investors (or philanthropists) value nature-based solutions or nature- based enterprises that have a positive, or at least a neutral impact on the environment. It will also provide information on the long-term sustainability of nature-based solutions.

Methodology

Data collection will need to be planned with the NBS project team in order to identify firstly any private finance that has been deployed in the planning, development and/or maintenance of the NBS itself.

Level of expertise

Moderate

Data collection

Required data

- Amount (in monetary terms) of investment in NBS

- Related bio-economy activities over a specified period - type of finance provided

- Source of finance provided

Data input type

Quantitative

Data collection frequency

Annually

Scale

NBS location to regional scale

Connection with SDGs

Goal 9 Goal 13

Reference

YouMatter (2020). Bioeconomy Definition: Benefits, Economic Growth And Sustainability. Retrieved from https://youmatter.world/en/definition/bioeconomy-definition/

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Extended description

Private investment and/or finance is defined as financial resources that are deployed by non-governmental agencies and sourced from monies that were not raised through taxes or other public fees / fines / assessments. Monies raised through the provision of goods/services relating to the NBS should not be included here.

Note that this will include monies that are deployed with an expectation of financial return and those that are 'concessionary' – philanthropic grants and 'impact investments' that do not required a financial return.

While nature-based solutions are defined elsewhere in this document, the definition of the 'bioeconomy' is less well- covered and is worth repeating here. The European Commission states that the "bioeconomy comprises those parts of the economy that use renewable biological resources from land and sea – such as crops, forests, fish, animals and micro-organisims – to produce food, materials and energy"

Strengths and weaknesses

+ The indicator is a meaningful and comparable at multiple levels of aggregation

- The causal relationship between the NBS and other bio-economy private finance activities may be difficult to establish

- The data will be widely dispersed and maybe difficult to collect

Extended methodology

Data collection will need to be planned with the NBS project team in order to identify firstly any private finance that has been deployed in the planning, development and/or maintenance of the NBS itself. If this has occurred, then it will be meaningful to report not only the absolute amount of private investment, but also the percentage of the total finance for the project arising from private sources.

In addition to the private finance for the NBS itself, the evaluation team will need to consult with the project team - and perhaps more widely - to determine what, if any, other bio-economy related activities may be linked to the NBS and the period over which this influence may be reasonably expected to occur. If no other criteria are deemed relevant, then the evaluation team should set a geographic boundary around the NBS being evaluated and choose a relatively short time period that would begin with the development of the NBS and extend to some agreed period (defined in years) following completion. Any bio- economy related activities occurring within the time/space boundaries agreed would be surveyed to assess: a) the extent to which the stakeholders involved in the activity attribute their actions to the existence of the NBS, and b) the value of private finance attracted by this activity.

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In both cases (the NBS itself and related bioeconomy activities), the data collected should be categorised by the type and source of private finance received. While there are numerous typologies for classifying finance type, the main one is between 'grant' finance –requiring no financial return – and 'commercial' finance, which requires / expects a financial return.

In the case of 'commercial' finance, this is generally sub- divided into loan vs. equity finance. 'Loan' finance is provided in return for a promise by the 'borrower' that the total amount of the loan ('principal') plus an agreed amount of interest will be paid back to the 'lender' over a specified period of time. 'Equity' finance is provided in return for an ownership percentage in the asset(s) being financed. Equity owners are generally entitled to a share of any income generated from the asset(s) and a percentage of the proceeds if the asset is sold.

In the past, private 'grant' finance was largely provided by philanthropists with no further expectations on those being funded other than the money would be used for the purposes agreed. Recently, however, the emergence of 'venture philanthropists', 'crowd-financing' (which may or may not be commercial) and 'impact investors' has given rise to new expectations around what is required from those in receipt of grant finance. Again, there are many ways to classify the different conditions under which private grant funds might be provided and the evaluation team should be guided by their own context. If no other classification scheme is selected, then it is suggested that private grant funding be classified as either 'formal impact reporting' or 'other'. 'Formal impact reporting' is present when the grant finance comes with a requirement that those in receipt of the funding must provide the granting body with reports on the 'impact' of their activity using a standard set of procedures (e.g., Social Return on Investment) or indicators (e.g., IRIS or SDGs). 'Other' is any grant finance that does not have formal impact reporting requirements associated with the receipt of funding.

The source of the finance may be classified in any number of ways that is relevant to the evaluation being undertaken. Again, if the evaluation team has no other preferred way of classifying the source of finance, then the sources might be typed as:

1) Firms;

2) Philanthropic organisations;

3) Individual / Community, or

4) Other.

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ECONOMIC INDICATORS - FEATURE

CONNECTING NATURE

New customers to business in proximity to NBS

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Description

This indicator provides information about the change in the number of customers of: 1) existing businesses in proximity to the NBS and/or 2) new businesses established either directly or indirectly due to the NBS.

Methodology

Measuring new customers directly will require asking businesses to report the number of total customers per period (month / year / quarter). It is likely that they will have this data on their financial systems, but it is not generally something that is reported to public bodies. This is because the number of customers a given business has in a period is often considered to be competitively sensitive information.

Level of expertise

Low (assuming the primary data is collected and reported by the relevant businesses themselves)

Data collection

Data input type

Quantitative

Data collection frequency

The primary data (footfall or customer purchases) is generally collected by businesses on a daily basis. Collection for the purpose of reporting NBS impact can be undertaken over longer periods and reported as period averages

Scale

Individual business to street/small area

Connection with SDGs

Goal 8

Participatory process

No opportunities identified

References

Butz Jr, H.E. and Goodstein, L.D., 1996. Measuring customer value: gaining the strategic advantage. Organizational dynamics, 24(3), pp.63-77.
Jones, M.A., Mothersbaugh, D.L. and Beatty, S.E., 2002. Why customers stay: measuring the underlying dimensions of services switching costs and managing their differential strategic outcomes. Journal of business research, 55(6), pp.441-450.

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Extended description

The change in the number of customers reported by businesses in the vicinity of the NBS or new businesses directly related to the NBS. Note that this is different from 'footfall' which only counts the presence of an individual in a given location – but who may or may not be a customer of any given business. Customers must – by definition – purchase something from the relevant business. However, it may be easier to collect information about 'footfall' in a given area and let businesses make their own calculations about the conversion of people in the vicinity to 'customers'.

Strengths and weaknesses

+ The indicator is easy to define and understand

+ The indicator is meaningful for businesses considering starting up or expanding in a given area

+ The indicator may assist local authorities determine / provide evidence for appropriate rate levels to set in the area

- The data is 'owned' by individual businesses and may be difficult to collect

- The causal relationship between the NBS and the purchasing decision by a customer may be difficult to establish (more so than for a similar / related indicator of 'footfall').

Extended methodology

If businesses within the 'buffer zone' of the NBS are willing or can be convinced to provide this information, it should be collected periodically from those businesses and the change in customers may be calculated / analysed and aggregated over time. It should be noted that a single individual may be counted multiple times if they buy from more than one business within the buffer zone, but this is not a problem as long as the indicator is NOT used for purposes other than reporting number of customers.

If it proves impossible to get businesses in the buffer zone to provide this information, then the next best indicator is 'footfall'. Footfall is a measure of the number of people visiting a store or an area in a given period (usually per day). Footfall is generally reported on an average basis – i.e., "on average 20,000 people per day visit the shopping centre". Footfall is measured using sensor / laser technology that can analyse when people are coming or going into/out of a shop / area and (more advanced) how long they linger. Footfall data may be converted to number of customers through the use of a 'conversion rate'. Conversion rate is defined the proportion of shop/area visitors who actually make a purchase. Conversion rates are indicators of average purchase behaviour and generated as an average over a period by individual businesses and can be used to approximate number of customers arising from 'footfall'.

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As for new customers, 'footfall' is something that may already be collected by the relevant businesses or in the area by an industry or public body. If collected by an industry / public body for a given area (generally done for high end / concentrated retail areas), then the data should be requested per period to establish change in 'footfall'. If not, then individual businesses will have to be asked to provide the data – along with conversion rates – in order to generate customer numbers.

If the data is unavailable from businesses or industry sources, and there is appetite (and resources available), then sensors may be deployed around the relevant area to measure footfall directly. This is a high cost option, but may be useful as input data for other indicators as well.

Understanding and identifying the buffer zone surrounding NBS and determining the relevant geographic area from which to report new customers is a critical component of this indicator. It may be useful to define the area surrounding the NBS similarly as defined in the indicator Distribution of public green space, e.g., land or properties with a 5 min walk from NBS (Madureira et al., 2011). Alternatively, proximity of land or property to NBS could be defined similarly to urban green space accessibility as in the indicator Accessibility of urban green spaces, i.e., land or businesses within a 300-500 m distance from NBS (Tamosiunas et al., 2014). Once the relevant buffer zone is agreed then new customers or 'footfall' should be gathered from the businesses in the designated area.

The type and size of a given NBS, and the different economic and/or recreational opportunities and aesthetic values associated with the NBS, will largely determine the extent (in distance, population size and/or time) and magnitude of its impact on the affected community.

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ECONOMIC INDICATORS - FEATURE

CONNECTING NATURE

Local economy GDP

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Description

This indicator provides information about the change in total consumption/production for a given area in proximity to the NBS. It is a general indicator of the direction of economic growth (increasing/stable/decreasing) and is easily aggregated and comparable at many levels.

GDP (Gross Domestic Product) is a measure of the 'output' of a specified economy.

Methodology

GDP (and GNP) are regularly calculated and reported by national statistics offices based on sales data collected from businesses, government expenditure and trade flows.

Level of expertise

Moderate

Data collection

Required data

GDP is generally collected and reported by national statistics offices. The challenge is to define the area affected by the NBS and to map this to administrative boundaries within which GDP is reported.

Data input type

Quantitative

Data collection frequency

Annually (actual data) and quarterly (estimated)

Scale

Regional - National

Connection with SDGs

Goal 8

Participatory process

No opportunities identified

References

Eurostat (2010) European System of National and Regional Accounts (2010), EU – may be accessed at https://ec.europa.eu/eurostat/documents/3859598/5925693/KS- 02-13-269-EN.PDF/44cd9d01-bc64-40e5-bd40-d17df0c69334

Eggermont, H., Balian, E., Azevedo, J.M.N., Beumer, V., Brodin, T., Claudet, J., Fady, B., Grube, M., Keune, H., Lamarque, P. and Reuter, K., 2015. Nature-based solutions: new influence for environmental management and research in Europe. GAIA- Ecological Perspectives for Science and Society, 24(4), pp.243- 248.

Stiglitz, J., Sen, A.K. and Fitoussi, J.P., 2009. The measurement of economic performance and social progress revisited: reflections and overview.

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Extended description

Data can be collected at any scale as the indicator is simply the total monetary value of all production/sales in a given location / within a given boundary. Eurostat relates GDP to Gross Value Added and defines GDP as: "an aggregate measure of production, GDP is equal to the sum of the gross value added of all resident institutional units engaged in production, plus any taxes on products and minus any subsidies on products. Gross value added is the difference between output and intermediate consumption."

It should be noted that GDP is often confused with GNP (Gross National Product), which is defined as GDP plus "net" income from other countries.

Strengths and weaknesses

+ The indicator is widely reported and generally understood

+ The indicator is a meaningful and comparable at multiple levels of aggregation

- The causal relationship between the NBS and the overall change in GDP may be difficult to establish

- The geographic scale at which the data is available may not be adequate for reporting NBS impact

Extended methodology

The specific components of GDP are:

GDP = C (private Consumption) + I (gross private Investment) + G (Government investment) + X (eXports) – M (iMports).

GNP adjusts measures of GDP based on remittances in/out of the country. For example, if Apple Inc. produces €100 million of computers in Ireland and sends €20 million in profits to shareholders in the US, then €20 million would be subtracted from Ireland's GDP (which includes the original €100 million). In addition, the US figure for GNP would be increased by €20 million.

GDP is generally reported as a total in a given period (usually a year) within a specific administrative boundary (e.g., state, region, country). Most statistical offices will be able to provide this data at lower levels of geographic scale, following locally defined administrative boundaries. However, it is more likely that Income per Household or per Person (See Indicator 12.2.17) will be reported at smaller geographical scales. It is also the case, that in some jurisdictions – and for some purposes – GNI (Gross National Income) is used instead of GDP/GNP as an indicator of economic performance.

CONNECTING NATURE

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Determining GDP for a given area in proximity to an NBS will involve establishing the appropriate 'buffer zone' around the NBS and determining the relevant source for GDP data at that scale.

Understanding and identifying the buffer zone surrounding NBS and determining the relevant geographic area from which to report GDP is a critical component of this indicator. It may be useful to define the area surrounding the NBS similarly as defined in the indicator Distribution of public green space, e.g., land or properties with a 5 min walk from NBS (Madureira et al., 2011). Alternatively, proximity of land or property to NBS could be defined similarly to urban green space accessibility as in the indicator Accessibility of urban green spaces, i.e., land or businesses within a 300-500 m distance from NBS (Tamosiunas et al., 2014).

From a data availability standpoint, however, it is likely to be more convenient to define the impact area in relation to existing administrative boundaries for which GDP is already reported. Note that administrative areas are often established based on population numbers (e.g., electoral districts, community healthcare zones, etc.). This means that the economic data is available for pre-defined geographic areas that may – or may not – align with the expected impact 'buffer zone' or be comparable to other impact indicators' geographic span of impact.

Therefore, it may be necessary to assess the proportion of a given administrative area's population / economy that is affected by the NBS in order to use existing data to represent overall impact. In Connecting Nature, we are trialling an approach that will establish thresholds of geographic coverage to determine what proportion of a given administrative area's measurements to include / what weight to assign. Our initial approach will be to set a maximum threshold of geographic coverage above which the entire administrative area's measurements will be included and a minimum threshold below which the area will not be included in the indicator measurement at all. In between these thresholds, it will be up to the relevant measurement body and NBS promoter to assess the relevant proportion of the population in the administrative area to include in the overall measurement.

The type and size of a given NBS, and the different economic and/or recreational opportunities and aesthetic values associated with the NBS, will largely determine the extent (in distance, population size and/or time) and magnitude of its impact on the affected community.

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ECONOMIC INDICATORS - FEATURE

CONNECTING NATURE

Innovation impact

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Description

This indicator provides information about the impact that the NBS has had on innovation by firms / organisations involved in developing and/or maintaining the NBS. The expectation is that the challenges and opportunities presented by climate change and urban development – along with the disparate perspectives and knowledge brought by stakeholders to the NBS project - will result in innovations that can generate economic value as well as be deployed elsewhere.

Methodology

The assessment team will first need to confer with NBS project management to determine which of the recommended measures to use.

Level of expertise

High

Data collection

Required data

No. of patents produced by NBS-related firms/organisations (output – quantitative)
No. of new products / services created by NBS-related firms/organisations (output - quantitative)
Annual revenue from new products / services created by NBS- related firms/organisations (output - quantitative)
No. of hours spent by NBS-related firms/organisations' employees / project members on research/ideation and/or innovation training (process – quantitative)
Range of knowledges / perspectives involved in design, development or ongoing governance of NBS (process – qualitative)

Data input type

Quantitative (4); Qualitative (1)

Data collection frequency

Post implementation and then periodically (suggest every 2-3 years) during the maintenance phase

Scale

Site/Project and may be aggregated across projects and over time.

Connection with SDGs

Goal 8

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Extended description

'Innovation' is generally defined as "the generation, acceptance and implementation of new ideas, processes, products or services (Thompson 1965:2)". There is no indicator that could capture every type or aspect of innovation that might possibly arise out of an NBS project, but the economic focus of this indicator suggests that new products and services are the appropriate aspects of innovation in this case.

Furthermore, we draw on literature that suggests specific types of inputs / processes that would be expected to result in new innovations, which may be measured as a proxy / leading indicators for the emergence of innovations at a later stage. This is consistent with the understanding that innovation is not just about discrete items, but also that it may be embedded in processes and that certain processes are core to innovation.

Across the literature, all definitions of innovation – no matter their disciplinary source – will include the word 'new'. Therefore it is important to provide the definition of 'new' so that evaluators can clearly explain how they have designated something as an innovation. The OECD defines new products as those that "differ significantly in their characteristics or intended uses from products previously produced ..." (OECD 2005). Furthermore, patent offices generally require that inventors demonstrate that their inventions are: 'novel' (not published / made available previously); 'inventive' (non-obvious solutions to a problem); and useful/practical (has identifiable benefits and is possible to produce). In assessing whether something is an innovation or not, evaluators should keep these criteria in mind.

It may also be helpful to consider the extent to which the problem being addressed by the innovation is well-understood. Satell (2017) suggests that there are 4 types of innovation – varying along two dimensions:

1) How well the problem is defined

2) How well the skills necessary to solve the problem are understood

References

Acar, O.A. and van den Ende, J. (2016) "Knowledge Distance, Cognitive-Search Processes, and Creativity: The Making of Winning Solutions in Science Contests", Psychological Science, vol. 27(5), pp. 692-699. https://doi.org/10.1177/0956797616634665

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Dziallas, M. and Blind, K. (2019) "Innovation indicators throughout the innovation process: An extensive literature analysis", Technovation, vol. 80-81, pp. 3-29

Jeppesen, L. B., & Lakhani, K. (2010) "Marginality and problem-solving effectiveness in broadcast search", Organization Science, vol. 21, pp. 1016–1033.

OECD (2005) "The Measurement of Scientific and Technological Activities: Guidelines for Collecting and Interpreting Innovation Data: Oslo Manual, Third Edition" prepared by the Working Party of National Experts on Scientific and Technology Indicators, OECD, Paris, para. 158

Satell G. (2017) "The 4 Types of Innovation and the Problems They Solve" Harvard Business Review Digital Articles, June 2017:1-6.

Taques, F. H., et al. (2020) "Indicators used to measure service innovation and manufacturing innovation", Journal of Innovation & Knowledge. https://doi.org/10.1016/j.jik.2019.12.001

Thompson, V.A. (1965), "Bureaucracy and innovation", Administrative Science Quarterly, vol. 10, pp. 1-20.

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Well-defined problems requiring well-defined skills will result in 'Sustaining Innovation" – or innovation that creates incremental improvements to existing areas of activity. "Basic Research" is innovation that addresses undefined problems and requires unknown types/levels of skills. In between these two extremes (of defined problem/skills domains) are: "Breakthrough innovations" which address well-defined problems but require unusual / unexpected knowledge & skills and "Disruptive Innovations" which occur when things we know how to do are combined in unexpected ways and result in solutions to problems we didn't know we had. Considering the type of innovation being counted will aid the assessment process and provide better evidence for why (or why not) an innovation was counted.

Satell's article highlights the fact that new ways of combining and fostering skills and knowledge are critical components of innovation processes and outcomes. Assessing the extent to which skills / knowledge are being combined / developed in new ways will provide a leading indicator of the likelihood of current/future innovation. Recent research confirms that 'knowledge distance' is an important element of creativity which can lead to innovation (Taques et al 2020; Acar and van den Ende 2016).

Looking more broadly at innovation indicators, Dziallas and Blind (2019) examined 226 articles relating to innovation indicators between 1980-2015 and found 82 different indicators for measuring innovation. They also found that there were more indicators looking at the 'process' of innovation than at the 'products' of innovation, and concluded that: "Despite the high number of well-known indicators and factors, concrete indicators to evaluate innovations are difficult to identify (p. 16)". Hence, the measurement procedures recommended here should be reviewed regularly against emerging literature and best practice.

Strengths and weaknesses

+ The indicator is strongly aligned with public policy to encourage and deliver innovation

+ The indicator provides leading information about the potential for future economic gain

+ The indicator is a meaningful and may be aggregated (depending upon measurement used)

- Depending upon the measurement used, it may require significant resources to collect and analyse

- Depending upon the measurement used, there may be challenges in comparing measures across projects

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Extended methodology

It may be that multiple indicators are selected – which would be consistent with recommended practice in industry, but extremely time consuming. The five measurement options are:

- No. of patents;
- No. of new products / services;
- Annual revenue arising for sales of new products / services;
- No. of hours spent by relevant individuals in research, ideation and/or innovation training;
- Range of knowledge / perspectives involved in design, development or ongoing governance of NBS.

Choosing between these will generally be driven by relevance for the NBS and NBS-related activities; resources and data availability; and interest from relevant stakeholders.

Data on patents filed is publicly available in most jurisdictions and so may be the least expense / time-consuming to collect. The challenge will be to attribute patents to the NBS project and this will require determining the firms/organisations that have worked with the NBS and the period over which any patents filed could reasonably have been influenced by their involvement with the NBS.

Data on new products and services will need to be collected through interviewing the relevant firms/organisations just after the implementation of the NBS and throughout the operations (maintenance) period to ask for the number (No.) of new products and services and the Annual Revenue (in relevant currency) from sales of these. The evaluation team should use the guidance provided in the definition above – and any other sources at their disposal – to provide the definition of new products and services to firms / organisations in order to ensure comparability across respondents.

Data on hours spent on research, ideation or innovation training should be collected from firms/organisations involved in the NBS during the planning and development phases on an as-agreed basis and would generally be reported upon the completion of the development phase and (if-desired) on an annual basis throughout the maintenance phase.

Reporting the range of knowledge / perspectives brought together by the project will be more of a qualitative assessment by the project team and may be difficult to compare across projects. Nevertheless, it could be of significant interest to assess the relationship between this measure and a number of other measures across the spectrum of NBS indicators. It is likely that – should this indicator be chosen – the evaluation team will need to discuss how best to assess this. The decision to use this indicator will need to be done as close as possible to the beginning of the project as it would be very difficult to credibly assess this on a post-project basis.

For those wishing to explore more quantitative ways of measuring knowledge distance, Acar & van den Ende (2020) used a survey instrument developed by Jeppesen & Lakhani (2010) to measure knowledge distance in relation to a given problem – which in this case could be the NBS itself. Respondents rated the extent to which the problem they are addressing was within their field of expertise on a scale from 1 to 7 (1 = inside my field of expertise , 4 = at the boundary of my field of expertise , 7 = outside my field of expertise). While the resulting measure is a number, it cannot be said that it is an 'objective' measure.

Another way of quantifying the range of perspectives involved would be to determine the number of individuals involved in the design, development and/or governance of the NBS from different stakeholder groups. Sectors could be defined in any number of ways including the 5 groups in the Quintuple Helix: Academic; Industry; Government; Media; Nature (Carayannis et al 2012); 3 sectors of civil society: State; Market; Civil Society (including non- profit organisations and households); or other typologies of stakeholders as appropriate.

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ECONOMIC INDICATORS - FEATURE

CONNECTING NATURE

Income/disposable income per capita

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Description

This indicator provides information about the change in individual's incomes living in proximity to the NBS. Although not a providing a complete picture – this information will provide input into assessments of the extent to which people are being pulled out of poverty and income inequality is being addressed in the vicinity of the NBS. 'Income' is defined as the total monetary payments received for labour, use of an individual's capital/land and any financial transfers (state or otherwise) over a specified period (usually one year). This measurement may also be called 'Gross Income'.

Methodology

Income/Disposable Income per Capita are regularly calculated and reported by national statistics offices based on income reported to Revenue Offices.

Level of expertise

Moderate

Data collection

Required data

Total Income / Disposable Income and Population in a given area

Data input type

Quantitative

Data collection frequency

Annually (actual data) and quarterly (estimated)

Scale

Regional - National

Connection with SDGs

Goal 1   Goal 8   Goal 10

Participatory process

No opportunities identified

References

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

Extended description

‘Disposable income’ is the amount of income remaining minus taxes and social security payments. Note that ‘Discretionary Income’ is a third measure that is often found in public reports on income levels and this is calculated as Disposable Income minus ‘Necessary Expenses’. Necessary expenses may be defined differently in different jurisdictions and so this is not included in the indicator as measurements would not be comparable.

Finally, Income/Disposable Income per Capita is the average of total incomes across the relevant population.

Strengths and weaknesses

+ The indicator is widely reported and generally understood

+ The indicator is a meaningful and comparable at multiple levels of aggregation

- The causal relationship between the NBS and per capita incomes may be difficult to establish

- The geographic scale at which the data is available may not be adequate for reporting NBS impact

Extended methodology

The specific components of Income / Disposable Income are:

Income = Ie (Income from Employment) + Il (Income from Land) + Ic (Income from Capital invested) + Is (Income from state or other transfers).

Disposable Income = I (Income) – T (taxes, including social security payments)

Income per Capita is calculated by dividing total income for all persons living in the area by the total number of persons. Note that Disposable Income per Household may also be reported, which is total income for all persons divided by total number of households.

Determining Incomes per Capita for a given area in proximity to an NBS will involve establishing the appropriate ‘buffer zone’ around the NBS and determining the relevant source for Income & Population data at that scale.

Understanding and identifying the buffer zone surrounding NBS and determining the relevant geographic area from which to report GDP is a critical component of this indicator. It may be useful to define the area surrounding the NBS similarly as defined in the indicator Distribution of public green space, e.g., land or properties with a 5 min walk from NBS (Madureira et al., 2011).

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Alternatively, proximity of land or property to NBS could be defined similarly to urban green space accessibility as in the indicator Accessibility of urban green spaces, i.e., land or businesses within a 300-500m distance from NBS (Tamosiunas et al., 2014).

From a data availability standpoint, however, it is likely to be more convenient to define the impact area in relation to existing administrative boundaries for which Income data is already reported. Note that administrative areas are often established based on population numbers (e.g., electoral districts, community healthcare zones, etc.). This means that the economic data is available for pre-defined geographic areas that may – or may not – align with the expected impact 'buffer zone' or be comparable to other impact indicators' geographic span of impact.

Therefore, it may be necessary to assess the proportion of a given administrative area's population / economy that is affected by the NBS in order to use existing data to represent overall impact. In Connecting Nature, we are trialling an approach that will establish thresholds of geographic coverage to determine what proportion of a given administrative area's measurements to include / what weight to assign. Our initial approach will be to set a maximum threshold of geographic coverage above which the entire administrative area's measurements will be included and a minimum threshold below which the area will not be included in the indicator measurement at all. In between these thresholds, it will be up to the relevant measurement body and NBS promoter to assess the relevant proportion of the population in the administrative area to include in the overall measurement.

The type and size of a given NBS, and the different economic and/or recreational opportunities and aesthetic values associated with the NBS, will largely determine the extent (in distance, population size and/or time) and magnitude of its impact on the affected community.

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ECONOMIC INDICATORS - FEATURE

CONNECTING NATURE

Upskilling & related earning increase

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Description

This indicator provides information about the change in an individual's skills and related earnings potential arising from activities directly related to the NBS. It is envisioned that this would arise from opportunities for people to receive training in new ('green job'?) skills via participation in activities organized directly by the NBS promoter or by organisations that are providing training at the behest of the NBS promoter.

Methodology

This is essentially a 'before-after' indicator that captures the impact of training and/or 'on-the-job' skills development opportunities afforded to individuals by the NBS.

Level of expertise

High – significant expertise is needed for the design / administration of the skills assessment (e.g., survey method, question selection). Once the initial data is collected, though, it is relatively straight-forward to repeat the data collection processes and analyse the data.

Data collection

Required data

- Training hours provided by NBS-related organisations
- Skills assessments of individuals before / after participation in NBS training / work
- Self-reported actual earnings by individuals before / after participation in NBS training / work
- Average earnings for specific jobs in the relevant area

Data input type

Quantitative

Data collection frequency

Ideally, at least 3 times: 1) prior to the NBS training (skills and earnings); 2) immediately (within 6 months of completion) following the training (skills and earnings); 3) several (3-5) years following completion of training (earnings only)

Scale

Site / individual specific – may be aggregated by programme over time.

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Extended description

This indicator is divided into two parts: one is a measure of training provided and/or skills acquired by individuals and the second is a measure of the increased earnings arising from the training/skills. Note that the earnings increase may be reported on either/both an actual or potential basis.

Strengths and weaknesses

+ The indicator provides a direct measure of the increased economic opportunities available to individuals arising from NBS activity

+ The indicator is a meaningful and comparable at multiple levels of aggregation

- Data collection is a bespoke process (not generally collected) and may be costly to produce measurements on an ongoing basis

Extended methodology

If the change in skills is being directly measured, then a baseline measurement of the relevant skills level(s) should be collected from all individuals participating in the training activities. Note that only training activities directly provided via the NBS promoter – or by third-parties at the behest of the NBS promoter – should be included. A base line earnings level (current salary / earnings from work) should also be gathered from individuals participating in the training.

There are numerous ways of measuring skills levels – more even that the range of different skills that are possible to define given that there are many composite measures of skills. In public reporting, measurements of qualifications achieved (level of education) are often used as a proxy measurement for skills in the population (See Eurostat 2016). There has also been a significant body of work on defining and measuring “21st Century Skills” or ‘competencies’ – which has been particularly active in the United States and Asia (Soland et al 2013). This has generally been applied at primary and secondary school levels.

Connection with SDGs

Goal 1 Goal 8 Goal 10

References

Elliott, D.S., Levin, S.L. and Meisel, J.B., 1988. Measuring the economic impact of institutions of higher education. Research in Higher Education, 28(1), pp.17-33

Eurostat (2016) Statistical Approaches to the Measurement of Skills – may be accessed at https://ec.europa.eu/eurostat/documents/3888793/7753369/KS-TC-16-023-EN-N.pdf/438b69b5-2fcb-4923-b9e2-fa7b59906438

Martinaitis, Ž., 2014. Measuring skills in Europe. European Journal of Training and Development, 38(3), pp.198-210

Soland, J., Hamilton, L.S., Stecher, B.M. (2013) “Measuring 21st Century Competencies: Guidance for Educators” Rand Corporation, accessed 1 July 2020 at http://asiasociety.org/files/gcen-measuring21cskills.pdf

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 730222

The measurement tool can only be determined by the NBS promoter based on the type of training being provided. References for the above tools / approaches are found above.

If the administration of a skills assessment is not deemed necessary or feasible, then a proxy for this component of the indicator may be the number of training / 'on-the-job learning' hours provided (usually within a calendar year) to individuals by NBS-related entities. This is generally more easily captured than before/after skills measurements, but is not as meaningful as it represents inputs to skills-development which may – or may not – result in the target skills development.

As mentioned above, current or most recent salary levels should be collected from individuals prior to their training / work opportunity and again following completion of the training programme. This is best done twice: once relatively soon after the training (within 6 months of completion) and again after a few years have passed to assess the long- term impact on earnings. This approach to data collection will provide 'actual' change in earnings information, but may be difficult to capture from individuals.

If actual data are not available, then estimated earnings impact may be calculated by using salary /earnings averages for the jobs for which individuals with the target skills are qualified and using this as a proxy for the earnings potential of these individuals. The (actual / potential) change in earnings is then calculated by subtracting the baseline earnings / salary from the post-training actual or potential earnings / salary. If this is measured at two different periods then then the length of time between post training earnings measurements should be reported.

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ECONOMIC INDICATORS - FEATURE

CONNECTING NATURE

Renewable energy produced

Original text by: Gabriele Guidolotti (1), Elizabeth Gil-Roldán (2), Chiara Baldacchini (1,3), Carlo Calfapietra (1). Project: proGIreg (Grant Agreement no. 776528). 24.35 Renewable energy produced. Indicator included in Dumitru, A. & Wendling, L. (2021). Evaluating the Impact of Nature-based Solutions: A Handbook for Practitioners. Appendix of Methods. Luxembourg: Publications Office of the European Union.

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(2) Starlab Barcelona SL, Barcelona, Spain
(3) Università degli Studi della Tuscia, Viterbo, Italy

Description

This indicator will evaluate the benefit obtained in terms of production of new energy on the NBS. Some of the NBS in proGIreg entail the installation of solar panels and other renewable energy producing installations. Therefore, the amount of energy produced (and therefore not demanded from the grid) will be accounted for.

Methodology

This data will be collected via the economic and labour questionnaire to be distributed to the entities in charge of the management of those NBS where energy production installations will be installed.

Level of expertise

The person in charge of administrating the NBS should be able to respond

Data collection

Required data

Entities administrating NBS

Data input type

None

Data collection frequency

Once after implementation

Scale

At NBS level

Connection with SDGs

Goal 7

Goal 8

Participatory process

None

CONNECTING NATURE

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

ECONOMIC INDICATORS - FEATURE

CONNECTING NATURE

Overall economic, social and health wellbeing

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Description

This indicator provides information about the change in the general well-being of individuals in the community in proximity to the NBS. General measures of well-being will include economic components (incomes and or consumption) as well as social and health components. As a 'cross-cutting' indicator this will provide strong evidence of the impact of the NBS on key aspects of peoples' lives and will be easily linked to existing data collection activities throughout Europe and the world.

Methodology

The approach to measuring HDI is widely available from UN sources, with the original methodology and measurement explanation found in Anand & Sen (1994). Their summary explanation is reproduced here for convenience (http://hdr.undp.org/en/content/human-development-index- hdi)

Level of expertise

Moderate (assuming the use of existing data can be mapped to the specific area impacted by the NBS)

Data collection

Required data

See definition of HDI above – which is generally collected from national census bureaus (by the UN) and reported at global, national and sub-national (states, etc.) level. For 2019, the UN data was gathered from the following sources:

- Life expectancy at birth: UNDESA (2019).
- Expected years of schooling: UNESCO Institute for
- Statistics (2019), ICF Macro Demographic and Health Surveys, United Nations Children's Fund (UNICEF) Multiple Indicator Cluster Surveys and OECD (2018).
- Mean years of schooling: UNESCO Institute for Statistics (2019), Barro and Lee (2018), ICF Macro Demographic and Health Surveys, UNICEF Multiple Indicator Cluster Surveys and OECD (2018).
- GNI per capita: World Bank (2019), IMF (2019) and United Nations Statistics Division (2019).

SDI-related data is generally gathered by a range of public data collection agencies and aggregated/reported by a designated agency / institute within the country at local area, regional and national levels. A typical example (from Ireland) may be found at: https://www.compass.ie/pobal-hp- deprivation-index-2016-launched/ which draws on Census data and is compiled using a methodology developed by Trutz Haase and Jonathan Pratschke. This index draws on a range of demographic, social class and labour market data – all of which are available at small area scales from the Central Statistics Office. For details regarding the construction of this index see Haase and Pratschke (2017).

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Extended description

The change in the aggregate HDI (Human Development index) or Social Deprivation Index (SDI) for people living in the vicinity of the NBS.

(HDI = GNI/capita; life expectancy at birth, years of education – as defined and reported by the United Nations – see below) OR (SDI has various definitions depending upon the region – see measurement discussion below)

Strengths and weaknesses

+ The indicator is easy to define and understand

+ The data are available and already collected (but perhaps not easy to disaggregate to the community area impacted – see weaknesses)

+ The HDI indicator is collected annually for all countries by the UN and so may be comparable across countries and their NBS implementations. SDIs are often calculated for populations in smaller geographic areas (see UK/Irl) and so may be more suited to NBS with smaller geographic footprints

- If the NBS has a very small geographic area of impact, it may be necessary to collect large quantities of data about individuals within this area in order to construct the relevant index

Extended methodology

“The HDI was created to emphasize that people and their capabilities should be the ultimate criteria for assessing the development of a country, not economic growth alone. The HDI can also be used to question national policy choices, asking how two countries with the same level of GNI per capita can end up with different human development outcomes. These contrasts can stimulate debate about government policy priorities."

Data input type

Quantitative

Data collection frequency

Before and after NBS implementation – but will be determined by the periodicity of the existing data collection and reporting processes

Scale

District to global scale

Connection with SDGs

Goal 1

Goal 4

Goal 10

Goal 3

Goal 8

Participatory process

No opportunities identified

References

Anand, S. and Sen, A.K. (1994) “Human Development Index: Methodology & Measurement”. Occasional Papers Series, UN Human Development Report Office, accessed Jun 2020 at https://ora.ox.ac.uk/objects/uuid:98d15918-dca9-4df1-8653- 60df6d0289dd/download_file?file_format=application/pdf&safe_filename=HDI_methodology.pdf&type_of_work=Report

Haase, T. & Pratschke, J. (2017) “The 2016 Pobal HP Deprivation Index for Small Areas (SA): Introduction and Reference Tables” accessed June 2020 at: http://trutzhaase.eu/deprivation-index/the-2016-pobal-hp-deprivation-index-for-small-areas/

Phillips, Robert L., Winston Liaw, Peter Crampton, Daniel J. Exeter, Andrew Bazemore, Katherine Diaz Vickery, Stephen Petterson, and Mark Carrozza (2016) “How other countries use deprivation indices – and why the United States desperately needs one”, Health Affairs, 35(11), pp.1991-1998. DOI 10.1377/hlthaff.2016.0709

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The Human Development Index (HDI) is a summary measure of average achievement in key dimensions of human development: a long and healthy life, being knowledgeable and have a decent standard of living. The HDI is the geometric mean of normalized indices for each of the three dimensions.

The health dimension is assessed by life expectancy at birth, the education dimension is measured by mean of years of schooling for adults aged 25 years and more and expected years of schooling for children of school entering age. The standard of living dimension is measured by gross national income per capita. The HDI uses the logarithm of income, to reflect the diminishing importance of income with increasing GNI. The scores for the three HDI dimension indices are then aggregated into a composite index using geometric mean. Refer to Technical notes for more details.

Social Deprivation Indices are generally specific to a country and their definition of social deprivation. However, in 2008, the World Health Organisation recommended an international approach to track social (and economic) determinants of health outcomes which laid the ground work for a number of countries' approaches to measuring social deprivation. Phillips et al (2016) provide an overview of how a range of countries calculate social deprivation with all of them incorporating components related to income, employment, housing status and education. Within a given country, using the relevant SDI index for areas affected by the NBS is likely to be a useful tool for comparing the impact over time and across regions.

Understanding and identifying the buffer zone surrounding NBS and determining the relevant geographic area from which to report HDI/SDI is a critical component of this indicator. It may be useful to define the area surrounding the NBS similarly as defined in the indicator Distribution of public green space, e.g., land or properties with a 5 min walk from NBS (Madureira et al., 2011). Alternatively, proximity of land or property to NBS could be defined similarly to urban green space accessibility as in the indicator Accessibility of urban green spaces, i.e., land or properties within a 300-500 m distance from NBS (Tamosiunas et al., 2014).

From a data availability standpoint, however, it is like to be more convenient to define the impact area in relation to existing administrative boundaries for which the HDI/SDI indicator is already reported. Note that administrative areas are often established based on population numbers (e.g., electoral districts, community healthcare zones, etc.). This means that the economic data is available for pre-defined geographic areas that may – or may not – align with the expected impact 'buffer zone' or be comparable to other impact indicators' geographic span of impact.

Therefore, it may be necessary to assess the proportion of a given administrative area's population / economy that is affected by the NBS in order to use existing data to represent overall impact. In Connecting Nature, we are trialling an approach that will establish thresholds of geographic coverage to determine what proportion of a given administrative area's measurements to include / what weight to assign. Our initial approach will be to set a maximum threshold of geographic coverage above which the entire administrative area's measurements will be included and a minimum threshold below which the area will not be included in the indicator measurement at all. In between these thresholds, it will be up to the relevant measurement body and NBS promoter to assess the relevant proportion of the population in the administrative area to include in the overall measurement.

The type and size of a given NBS, and the different economic and/or recreational opportunities and aesthetic values associated with the NBS, will largely determine the extent (in distance, population size and/or time) and magnitude of its impact on the affected community.

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ECONOMIC INDICATORS - FEATURE

CONNECTING NATURE

Change in natural capital

Original text by: Paul Nolan (1), Clare Olver (1), Raúl Sánchez (2), Jose Fermoso (2), Silvia Gómez, María González (2), Jose María Sanz (2), Esther San José (2). Project: URBAN GreenUP (Grant Agreement no. 730426). 23.1.1 Value of NBS calculated using GI-Val. Indicator included in Dumitru, A. & Wendling, L. (2021). Evaluating the Impact of Nature-based Solutions: A Handbook for Practitioners. Appendix of Methods. Luxembourg: Publications Office of the European Union.

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Description

GI-Val is The Mersey Forest's green infrastructure valuation toolkit. The current prototype is free and open source, and can be downloaded under a Creative Commons License from: https://www.merseyforest.org.uk/services/gi-val/.

Methodology

The toolkit provides a set of calculator tools, to help assess an existing green asset or proposed green investment. They are organised under eleven key benefits of green infrastructure.

Level of expertise

Technical / Expert

Data collection

Required data

General information about baseline conditions and NBs interventions for the area under examination

Data input type

Numeric data

Data collection frequency

Individual assessments

Scale

Plot to city scale

Connection with SDGs

Goal 3

Goal 11

Participatory process

Developing the toolkit's next iteration will require wide and sustained collaboration. To facilitate this process, interested parties are invited to pass the toolkit to others who might be able to incorporate it into their work and to provide feedback on their experience in using the toolkit, good and bad!

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Extended description

The GI-Val toolkit provides a simle framework to identify and broadly assess the benefits of proposed NBS investments and existing green assets, including direct contributions to the local economy and wider non-market returns for society and the environment.

The toolkit takes the form of a spreadsheet calculator and a user manual. There has been a great deal of research on the valuation of the benefits provided by the natural environment using a wide range of techniques. Many of these are academic and not accessible to project managers who need to be able to rely on sound data from easily accessible sources to provide a robust valuation that they can employ as justification to funders and/or developers.
To enable such a valuation to be carried out, The Mersey Forest has developed GI-Val. The GI-Val toolkit calculates monetary values for the social, economic and environmental benefits provided by green infrastructure.

The following fully-operational tools are currently available in the GI-Val toolkit and can, in combination, yield an overall value for implemented NBS:

- Tool 1.4. Reduced peak summer temperature
- Tool 1.6. Reduction in carbon emissions from buildings – cooling
- Tool 2.1. Energy and CO2 emissions savings from reduced volume of water entering combined sewers
- Tool 2.2. Savings in wastewater treatment costs to domestic and commercial water customers
- Tool 4.2. Reduced mortality rates from increased walking and cycling
- Tool 4.6. Avoided costs for air pollution control measures
- Tool 5.1. Residential land and property uplift
- Tool 8.1. Volume and value of tourism related expenditure
- Tool 9.1. Recreational value
- Tool 10.1. Willingness to pay for protection or enhancement of biodiversity
- Tool 11.1. Employment-based GVA generated by land management
- An independent assessment of GI Val by the Ecosystems
- Knowledge Network is available from this link, along with links to other tools:

https://ecosystemsknowledge.net/green-infrastructurevaluation-toolkit-gi-val

Sources of improved evidence
Suggestions for improving the tools
Ideas for new tools
The consortium who led the development of this toolkit has handed over the responsibilities for co-ordinating future work to the Green Infrastructure Value Network (GIVaN). Further information on the network can be found at: www.bit.ly/givaluationtoolkit

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SDG indicator 11.6.2. https://unstats.un.org/sdgs/metadata/files/Metadata-11-06-02.pdf

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Strengths and weaknesses

- Tool developed using English data.
- The toolkit remains a prototype and this means there are some green infrastructure benefits for which it cannot calculate a direct financial value. While there is a rich body of evidence that illustrates and demonstrates the different types of benefits deriving from quality green infrastructure, robust valuation techniques do not yet exist for all benefits. Therefore some valuations come with detailed caveats as they are based on limited evidence at this stage.
- The toolkit's calculation is designed to be useful for initial, indicative project appraisal, providing a range of figures indicating the potential impact of a green infrastructure intervention or the value of an existing green infrastructure asset. The toolkit does not assess the quality of the design or detailed management requirements of green infrastructure. It does not replace a full cost benefit analysis, but it provides a basic valuation at a much lower cost.
- Valuations such those made with a toolkit or cost benefit analysis also need to be seen as part of a much bigger picture. The valuation should not replace community engagement and local dialogue about what is valued about a place. Calculating economic value of green assets will always be a controversial technique and financial value should only be seen as one factor in decision-making.
- The reported GVA values include transfers from one organisation to another, which means that although GVA increases for the beneficiaries, it may not increase for the study area as a whole.

Extended methodology

The toolkit looks at how the range of green infrastructure benefits derived from an asset or investment can be shown:

- in monetary terms – applying economic valuation techniques where possible
- quantitatively – for example with reference to jobs, hectares of land, visitors
- qualitatively – referencing case studies or important research where there appears to be a link between green infrastructure and economic, social or environmental benefit but where the scientific basis for quantification and/or monetisation is not yet sufficiently robust.

The toolkit uses standard valuation techniques to assess the potential benefits provided by green infrastructure within a defined project area. These benefits are assessed in terms of the functions that the green infrastructure may perform, support or encourage, depending upon the type of project.

Once data are entered into the toolkit, financial values are generated for many NBS benefits. The toolkit identifies the marginal benefit and the additional value of the green infrastructure/NBS. Coded algorithms ensure that there is no 'double counting' of component values.

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ECONOMIC INDICATORS - FEATURE

CONNECTING NATURE

Reduced/avoided flood damage costs

Original text by: Ursula McKnight (1), Karsten Arnbjerg-Nielsen (1), Laddaporn Ruangpan (2), Zoran Vojinovic (2). Project: RECONECT (Grant Agreement no. 776866). 24.10 Reduced/avoided damage costs. Indicator included in Dumitru, A. & Wendling, L. (2021). Evaluating the Impact of Nature-based Solutions: A Handbook for Practitioners. Appendix of Methods. Luxembourg: Publications Office of the European Union.

(1) Department of Environmental Engineering, Technical University of Denmark, Denmark
(2) IHE Delft Institute for Water Education, Delft, the Netherlands

Description

Expected annual damage.
Determining direct damage is commonly done using depthdamage curves, which denote the damage that would occur at specific water depths per asset or per land-use class.

Methodology

In general the damage costs are calculated as expected annual damage, EAD, to account for random fluctuations in actual occurrences of hydro-meteorological events. This is why calculated hazard maps are used rather than direct observations.

Data collection

Required data

· Hazard maps covering the NBS site showing the hydrometeorological hazard(s) as a function of return period before and after the NBS is introduced. Typically this will be in the form of raster of shape files in a GIS environment.
· Value maps covering the NBS site showing what assets can be exposed and what cost is associated with exposure, typically as a function of e.g., inundation depth, (water) velocity, duration of exposure, etc. This data should be available in the same format as the hazard maps.
· Land use map

Extended methodology

The EAD is calculated by numerical integration between based on the following equation:

$$EAD = \frac{1}{2}\sum_{i=1}^{n}\left(\frac{1}{T_i} - \frac{1}{T_{i+1}}\right)(D_i + D_{i+1})$$

where Ti and Di are return period and calculated damage for return period i. The required number of calculation points are discussed in e.g., Olsen et al (2015). In general the majority of the calculation points should be close to the return period where damages start to occur, since very high return periods rarely contribute substantially to the overall risk in spite of their high cost (when they occur).

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ECONOMIC INDICATORS - FEATURE

CONNECTING NATURE

Social return on investment

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Description

This indicator seeks to capture the value of improvements in social well-being (in monetary terms) arising from nature- based solutions. It should be used only in cases where additional information relating to the notional monetary value of one or more social well-being indicators is needed for the purpose of funding applications, investor requirements or comparing the value of different projects for which there are a range of different impacts.

Methodology

Details on the procedure for measuring SROI are widely available through any number of public websites and associations. The website for the EU initiative "Responsible Research and Innovation (RRI)" is a good place to start when looking for further information.

Level of expertise

Very high

Data collection

Required data

- Amount (in monetary terms) of investment in the NBS being assessed for SROI
- indicators of social well-being value created by the NBS
- stakeholder-based attribution of monetary value to a unit of the social well-being indicator
- evidence-based attribution of the proportion of social well- being created to the NBS – generally linked to a clear theory of change, and examined for 'drop-off' over time
- evidence-based

Data input type

Qualitative and quantitative

Data collection frequency

If being used as a planning / forecasting tool then data collection will occur at the planning stages of the project

Scale

Will be defined based on the scale of measurement for the underlying social well-being indicators

Connection with SDGs

Goal 3, Goal 4, Goal 5, Goal 8, Goal 9, Goal 10, Goal 16

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

Extended description

Social Return on Investment (SROI) is generally reported as a ratio between the monetary value of outputs/outcomes and the monetary value of inputs. As such, it provides both a quantifiable cost-benefit analysis of a given project / programme, as well as a tool for comparing different investments either as a forecast or a post investment evaluation. Proponents of the SROI measurement approach claim that it takes a more 'holistic' view of the various impacts that a given project/programme has on beneficiaries, but this is a matter of debate – and also depends on the specific choices made by and resources available to the SROI assessment team. Calculating SROI can only be done if there are clearly identifiable social well-being output/outcome indicators of value arising from the target project/programme, and credible SROI reporting generally requires the services of a qualified SROI expert.

While the product of an SROI assessment is a quantifiable and comparable measure of expected or achieved return on resources deployed, the process of conducting an SROI assessment is also seen as a valuable activity as it explicitly involves stakeholders and beneficiaries in the assessment process. This is generally thought to increase the credibility of the measurement and also to raise the awareness of all stakeholders of the aims and value of the project. The specifics of this process are described in the "Extended methodology" section below.

Strengths and weaknesses

+ The indicator is a meaningful and comparable at multiple levels of aggregation and across different projects
+ It is a powerful tool for assessing 'value for money' (VfM) of projects with a range of social benefits
+ It is widely supported by a range of social investment NGOs, think-tanks, impact investors and associations, the EU and the WHO

- It is time-consuming and often quite expensive to conduct an SROI assessment
- it requires significant expertise to calculate, to explain and to evaluate its significance
- SROI – along with other approaches to social value measurement - has been widely criticised for incorporating estimated attributions of value, 'heroic' assumptions of causality and over-simplifying the unique and heterogeneous impacts of social innovation (see references section)

Participatory process

A core element of SROI assessment is the involvement of beneficiaries and stakeholders in the defining of value and of attribution of effects (see procedure section above). This engagement with stakeholders is generally seen to be a positive feature of the methodology as it increases stakeholder awareness of the project benefits and also accords beneficiaries with direct and meaningful input to the creation of the impact indicator.

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Extended methodology

The RRI 'Toolkit' has a link to a seminal SROI guidebook from the UK, "A guide to Social Return on Investment", from which the summary procedure included here is drawn.

SROI is a 6-stage process that begins with the definition of scope for the assessment and identifying the stakeholders who will be involved and the main outcomes (impacts) to be measured. If the work of defining the NBS project's 'theory of change' has already been done (as part of the development of another indicator measurement), then this should provide a good starting point for Stage 1: scope and stakeholder definition – which includes those expected to benefit from the project (beneficiaries) as well as those providing any maintenance or other services related to the NBS and those funding the project. Work on other social well-being indicators will also provide useful input to Stage 2: Mapping Outcomes. Each stage is outlined below – however this factsheet does not substitute for detailed step-by-step guidance available from the recommended sources if an SROI assessment is to be undertaken.

Stage 1: Establishing scope and identifying stakeholders
There are three steps in this stage: 1) establishing the scope of the analysis; 2) identifying stakeholders and 3) deciding how to involve stakeholders. In this stage the purpose of the SROI should be explicit – not only whether it is a forecast or a post- investment evaluation, but also defining (and agreeing) the goal of producing the measurement and the resources that are available to undertake the assessment. The 'audience' for the resulting measurement(s) should also be defined in this step. This may simply be the group of stakeholders – or may go beyond that group if there are objectives that require this – such as policy influence and/or knowledge sharing. It is important to decide which of the various activities or components of the NBS will be included as it may be possible only to examine a subset of all possible value producing components due to time / resource constraints. When considering the stakeholders, be sure to include those who might be negatively affected as well as those who are expected to be positively affected. Lastly, the decision about how to involve stakeholders is critical to ensure that the SROI includes those impacts that really matter to stakeholders and you can be completely transparent about how the valuation was developed and calculated.

Stage 2: Mapping Outcomes
As in the previous stage, this stage may be informed by work done in other indicator development exercises – particularly those that addressed social well-being impacts arising from the NBS. However, to do a proper SROI, the definition of outcomes must be co-produced with the identified stakeholders, so if this was not done in other impact indicator activities it will need to be done here. 'Mapping outcomes' involves figuring out what each stakeholder contributes (inputs) and/or receives (outputs / outcomes) from the various activities included within the scope of the SROI assessment. Identifying these is best done with the stakeholders as they are most likely to know about the actual inputs / outputs affecting and important to them. If the SROI is a forecasting exercise, then it may be possible to find estimates from previous / similar activities, relevant research and/or databanks produced for this purpose. Note that there may be 'chains' of outputs, outcomes arising over time from the NBS – which will need to be identified here. For example, an accessible park may provide greater opportunities for exercise for older people, which are taken up by some proportion of the population, and as a result these individuals are fitter and happier – which results in less healthcare expense and feelings of social isolation. Each of these outcomes will need to be defined and valued as appropriate.

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It is in this stage that a monetary value is assigned to inputs as this is the less complex of the valuation steps. Valuing a volunteer's time or the expected effort required by beneficiaries to generate outcomes can, of course, be complicated, but by and large, this aspect of valuation is generally much less challenging than the next stage of valuing outcomes.

SROI manuals recommend creating an 'Impact map' for the project being assessed, which is essentially a list of stakeholders, impacts (inputs/outputs) and activities that generate each impact for each stakeholder. Other approaches to measuring impact more generally begin with a 'Theory of Change' model, which supports SROI as well as other approaches to measuring social impact. A theory of change (ToC) model explains in a graphical way the causal links between inputs, activities, context and outcomes. Mayne (2015) provides a useful overview of Theory of Change models, which may be helpful in developing a wide range of impact indicators for NBS.

Stage 3: Evidencing and Valuing Outcomes

While the previous stages may be quite challenging for the assessment team to decide among the various alternatives for defining activities, stakeholders and outcomes, it is this stage that is the most complex stage of the SROI methodology and the one that creates the most controversy (although Stage 4 has its own unique challenges). Essentially this stage is about deciding how outcomes will be demonstrated and what represents their 'fair' value. Again, if there are already processes for gathering evidence of social well-being outcomes, then it would be advisable to 're- use' the data from these processes for assessing SROI. However, at a minimum, these indicators must be confirmed with the stakeholders identified in stages one and two and some effort needs to be made to balance objective and subjective indicators. More on this may be found in the Guide to Social Return on Investment (Nicholls et al 2012). Once the indicators of impact are agreed with stakeholders, the next step is to assign monetary values.

While it is likely that the monetary values assigned to each non-monetary input/output will be specific to the project, stakeholders and context, there are some efforts at creating standard monetary values for widely produced social outcomes in a given country. An example of a monetary value databank for social outcomes in the UK is the HACT Social Value Bank – for activities related to housing - and a paper explaining the relationship between this databank and SROI may be found here. The methodology behind these valuations is found in Trotter et al (2014) and Fujiwara (2013). Most NBS projects, however will need to develop their own monetary values through using benchmarks, published or proprietary cost data or tools specifically developed for this purpose. An overview of tools for this purpose may be found on the 'Sopact' site.

It should be noted here that the SROI ratio is generally formulated as the net present value of outcomes divided by the net present value of inputs. So it will be necessary to gather or estimate the ongoing delivery of outcomes over an agreed time period in order to fully align with the SROI approach (see Stage 5).

If the purpose of the SROI assessment is to deliver a post- investment / implementation evaluation, the next step will be to collect the data required to 'evidence' the outcomes of interest. It will be up to the evaluation team to decide how many periods of data are required and this should be related to the expected time frame of the impact.

Stage 4: Establishing Impact

This stage draws on the decisions and data collected in previous stages and then applies a calculation model that draws heavily on economics and social policy evaluation approaches to 'adjust' the raw impact figure for issues of deadweight, displacement, drop-off and attribution. As noted above, the steps for accomplishing this are detailed in Nicholls et al (2012) or any number of SROI guidebooks.

At the highest level, the SROI calculation multiplies each instance of an achieved outcome by the monetary value determined in Stage 3 and then adjusts this 'gross' valuation by estimates or evidence of:

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1. Deadweight – a concept from economics that represents the outcomes that would have happened over time even if the activity being assessed had not taken place. This is generally measured via reference to control groups (or other benchmark measures) of people who were not beneficiaries of the activity / NBS;
2. Displacement – a concept from social policy (and economics) that represents the extent to which outcomes generated by the activity being assessed eliminated, shifted or replaced other outcomes. A typical example of displacement is when a benefit (e.g, job, access to services) is made available to one individual/group that would have otherwise gone to a different individual/group;
3. Drop-off – this concept comes from education / training policy analysis and is a measure of the decrease in impact over time of a given activity. An example of drop-off is decreasing impact of a sustainability awareness programme on an individual's likelihood of changing their consumption patterns. This adjustment would only be used in cases where the expected impact of an NBS extends over multiple years;
4. Attribution – this is an assessment of how much of the outcome achieved was caused by the contribution of the NBS as opposed to other organisations / individual choices. Nicholls et al (2012) provides a good example: "alongside a new cycling initiative there is a decrease in carbon emissions in a borough. However, at the same time, a congestion charge and an environmental awareness programme began. While the cycling initiative knows that it has contributed because of the number of motorists that have switched to cycling, it will need to determine what share of the reduced emissions it can claim and how much is down to the other initiatives (p.59)"

These adjustments to gross outcomes are usually expressed as percentages and, again, Nicholls et al (2012) contains a good example of how the adjustments may be applied to the outcome values to calculate net impact.

Stage 5: Calculating SROI

Having completed all of the previous steps, the SROI assessor should now be in a position to calculate SROI. An overview is provided here, but it is recommended that those undertaking an actual SROI calculation refer to Nicholls et al (2012).

The basic model is a based on a net present value (NPV) calculation which is arrived at by estimating (or measuring – if it is a post implementation assessment) the amounts and number of years in which costs will be incurred and social value achieved and then applying a 'discount rate' for the time-value of money. For more on NPV and choosing a discount rate see HBR article here or to go to Nicholls et al (2012) for SROI specific examples.

The monetary equivalent value of social impact was estimated in Stage 3 and this value must be adjusted in each year by applying the adjustment percentages determined in Stage 4. The present value calculation for outcomes should only be done after the adjusted financial value of the social outcomes are calculated for each year. By applying the discount rate to the adjusted annual financial values for outcomes, the total present value of the NBS project is produced. This figure is divided by the total costs of the NBS to produce the SROI for the project as a ratio of benefits to costs. If the SROI is greater than 1, then the NBS creates value. If it is less than 1, then it does not.

SROI guidelines suggest that assessors undertake two additional analyses in order to provide further information about the SROI measurement produced. These are: 1) a sensitivity analysis – which provides information on the extent to which the result would change if the assumptions in any of the previous steps were altered, and 2) a 'payback period' calculation – which gives an idea of how long it would take for the NBS to pay back the initial investment. Both of these are standard financial calculations that may be applied to the figures generated (see Nicholls et al 2012).

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Stage 6: Reporting, using and embedding measurement

This last stage is an important one to build into to any SROI project plan as it will ensure that the hard work of the previous steps. The first step in this stage is to review the results with stakeholders and get their feedback on the credibility and significance of the measurement. There is also a degree of accountability to stakeholders given their significant interest in and contribution to the measurement. Beyond stakeholders the use of the SROI depends upon the aim of the original undertaking, with a forecast generally reported to potential investors / funders and an evaluation reported to this group plus others with an interest in how the project is meeting its aims. It is important to note that one of the main indicators of a successful SROI is the extent to which it is used to inform decisions and/or changes to the various elements of the NBS
over time.

Finally, it may be appropriate to get outside assurance of the validity of the SROI measure and this can be provided by an accredited SROI assurance provider. Information on assurance (or becoming an accredited SROI provider) may be found here – or by contacting SVI.

“Social Value International” (SVI) is an association of member organisations that are interested and/or experts in approaches to valuing social outcomes and interested parties are encouraged to connect with their local SVI association for support in applying SROI in their location.

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INDICATOR REVIEWS

PARTICIPATORY PLANNING AND GOVERNANCE

This last category of indicators does not focus on the outcome of Nature-based solutions, but on their planning delivery and stewardship process. Therefore, the reviews cover measures about the partners involved in the process, public-private collaboration or the co-production process. It also includes indicators to review the learning process and reflect upon the transformative nature of working with nature-based solutions collaboratively and cross-sectoral. In addition, indicators are offered to evaluate the organizational processes to improve the execution process of urban interventions.

INDICATOR REVIEWS

CORE

- Diversity of stakeholders involved
- Social equity: involvement of citizens from traditionally under-represented groups
- Transparency of co-production
- Policies adopted to promote NBS
- Activation of public-private collaboration
- Trust in decision-making and decision-makers
- Reflexivity - identified learning outcomes
- Common vision
- Innovative climate
- Open communication (internal & external)
- Collaboration between organizational members

FEATURE

- Procedural fairness
- Facilitation skills for co-production
- Strategic alignment
- Governance innovations for participatory governance
- Community involvement in NBS implementation
- Reflexivity - time for reflection
- Strategic approach
- Task significance
- Dealing with uncertainty
- Support, appreciation of merits and diversity, recognition
- Task and skill variety
- Team cohesion
- Good workload management
- Engagement
- Organizational trust

FOR MORE INFORMATION:
HTTPS://CONNECTINGNATURE.EU/INNOVATIONS/IMPACT-ASSESSMENT

PARTICIPATORY PLANNING AND GOVERNANCE INDICATORS - CORE

CONNECTING NATURE

Diversity of stakeholders involved

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Description

The indicator is defined in terms of the mix of stakeholders involved in a co-production process, based on their backgrounds and sectoral logics.

Methodology

Quantitative Procedure:
Scale inventory of types of actors per co-production/participatory process

Selective Tool:
MAP or Quintuple helix model. The numbers per category are added up and the proportion of each group is calculated. What is considered a good spread across the different groups often depends on the type of participation process.

Level of expertise

Low

Data collection

Required data

Essential: Time-sheets for each meeting/activity per participatory process

Essential: knowledge about stakeholder backgrounds/category

Desirable: reflective notes from organisers about reasons for over-/underrepresentation of certain groups

Data input type

Quantitative, qualitative if linked to reflections about reasons for over-/underrepresentation

Data collection frequency

Every six months, aligned with co-production / participatory processes
Most desirable after each meeting to reflect on diversity

Participatory process

This Indicator can only be calculated through a participatory data collection (timesheets).
Participatory methods (e.g., focus groups, narrative studies, participatory data collection methods, and/or participatory action research) may be applied to collect community-relevant information on over-/underrepresentation.

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Extended description

Co-production is all about diversity, meaning that diverse actors need to be involved on an equal basis (Bussu and Galanti 2018; Frantzeskaki and Kabisch 2016). Co-production in nature-based solution projects encompasses a wide range of opportunities for citizens, nongovernmental organisations, businesses and other stakeholders to co-design, co-implement and co-manage a nature-based solution. Including different perspectives, needs and knowledges does not only produce a more creative output but also ensures their accountability and applicability (Frantzeskaki and Kabisch 2016).

Actor mapping tools facilitate the identification of suitable participants based on different types of knowledge and backgrounds (van der Jagt et al. 2019; Hölscher et al. 2018; Wittmayer et al. 2012). While recognising the importance of other requirements, the diversity indicator looks at the diversity of knowledge and backgrounds rather than e.g. gender (see Indicator on social equity).

Avelino and Wittmayer (2016) introduced the Multi-actor Perspective (MAP) (Figure 1). The MAP draws on work by institutional scholarship, particularly the 'Welfare Mix' scheme by Evers and Laville (2004: 1740) and Pestoff (1992: 2537). This scheme distinguishes between four different sectors: state, market, community and third sector. The distinction of sectors is based on general characteristics and 'logics' of a sector (i.e. formal vs. informal, for-profit vs. non-profit, public vs. private). Notable is the category of 'third sector' as an intermediary sector between state, market and community. It includes the non-profit sector that is formalised and private, but also intermediary organisations that cross the boundaries between profit and non-profit, private and public, formal and informal (e.g. 'not-for-profit' social enterprises, universities, or cooperatives). The consideration of the third sector enables to more sharply specify what is usually referred to as 'civil society' (Avelino and Wittmayer 2016). Even if a co-production process includes actors from NGOs, citizens or grassroots initiatives can still remain underrepresented. The MAP takes the Welfare Mix scheme further and distinguishes between different individual and organisational actors that can take up different roles in relation to different sectors. The MAP can be used as an actor mapping tool in co-production processes, enabling to be more explicit about which actor categories and roles are included and to overcome a bias towards certain (groups of) actors and sector logics (Hölscher et al. 2018).

Connection with SDGs

Goal 10
Goal 11
Goal 16
Goal 17

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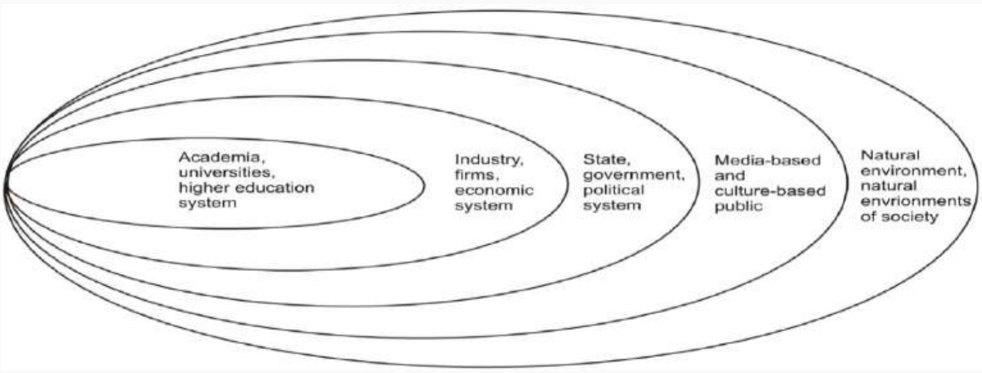
Figure 1: MAP: level of individual actors per sector (source: Avelino and Wittmayer 2016, p. 637)

Similarly, the Quintuple Helix model helps to identify five key audiences to be targeted as part of a co-production process (Carayannis et al. 2012; Figure 2): 1) Education system (e.g. academia, higher education, schools, kindergartens); 2) Economic system (e.g. industry(ies), firms, services, banks, entrepeneurs); 3) Political system (e.g. national/local governments, policymakers, law makers, politicians); 4) Civil society and media (e.g. local communities, community groups, NGO's, mainstream and local media, environmental media); 5) Natural environments of society (e.g. NBS experts from NGO's, policy makers, political bodies, experts and opinion leaders on NBS).

Figure 2: Quintuple Helix (Carayannis et al. 2012, p. 6)



Strengths and weaknesses

+ Relatively easy-to-measure indicator
+ Helps understanding whether a co-production process included a balanced participation of different stakeholders, views and perspectives
- Does not explicitly consider other forms of diversity and inclusivity related to social equity (e.g. representation of underrepresented groups, gender equality)

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Extended methodology

At the beginning of the meetings organized during a co-production/participatory process, stakeholders should be invited to sign a timesheet. The Indicator will be equal to the whole number of stakeholders involved during these meetings.

In a second step, the stakeholders are categorised based on the role/position they took in the process. There are two options to categorise the diversity of stakeholders:

Option A) Multi-Actor Perspective (MAP)

1) State: e.g. policymaker, politician, bureaucrat
2) Community: e.g. resident, neighbour
3) Market: e.g. firm, entrepreneur
4) Third Sector: e.g. activist, volunteer, researcher

Option B) Quintuple Helix

1) Education system: e.g. academia, higher education, schools, kindergartens
2) Economic system: e.g. industry(ies), firms, services, banks, entrepeneurs
3) Political system: e.g. national/local governments, policymakers, law makers, politicians
4) Civil society and media: e.g. local communities, community groups, NGO's, mainstream and local media, environmental media
5) Natural environments of society: e.g. NBS experts from NGO's, policy makers, political bodies, experts and opinion leaders on NBS

In a third step, the numbers per category are added up and the proportion of each group is calculated. What is considered a good spread across the different groups often depends on the type of participation process.

Qualitative Procedure:

Selective Tool:
Case study methodology – semi-structured interviews, case study analysis, participant and non-participant observation

Selective Tool:
Participatory data collections methods, such as focus groups

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PARTICIPATORY PLANNING AND GOVERNANCE INDICATORS - CORE

CONNECTING NATURE

Social equity: involvement of citizens from traditionally under-represented groups

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Description

The extent to which the nature-based solution planning, delivery and stewardship has led to the increased participation by typically underrepresented groups of people.

Methodology

Qualitative Procedure:
Selective Tool 1: case study methodology – semi-structured interviews, case study analysis, participant and non-participant observation
Selective Tool 2: participatory data collections methods, such as focus groups

Level of expertise

Methodology and data analysis requires high level expertise in social science research

Data collection

Required data

Information used to evaluate the performance of a particular NBS project with regard to the participation of vulnerable or traditionally under-represented groups can be obtained from project documentation and/or interviews with the project leaders and stakeholders (including representatives of the groups targeted).

Data input type

Qualitative

Data collection frequency

Before and after implementation of the NBS project

Participatory process

Participatory methods (e.g., participatory data collection methods, and/or participatory action research) may be applied to collect data on nature-based solutions participation processes and underlying reasons of levels of social equity, as well as perceived opportunities and challenges.

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Extended description

It is important to ensure social equity in the planning, delivery and stewardship of nature-based solutions. This means that such processes need to be attentive to the types of actors they are engaging, not only to tap into the diverse knowledge but also to ensure equal access to the nature-based solution and its benefits. For ensuring social equity it is important to explicitly go beyond the usual suspects to guarantee greater inclusion and participation of the weakest and give voice to critical perspectives (Bussu and Galanti 2018; Ferlie et al. 2019). Specifically, engaging vulnerable and/or under-represented groups in nature-based solutions projects enhances social cohesion and diversity whilst tapping into underdeveloped social capital. According to Boisjoly et al (2017), participation can potentially promote social equity, if it supports the interests of socially disadvantaged groups. When social equity is not included as an objective of participatory processes, the result is often a low representation of the interests of marginalised groups.
An underrepresented group describes a subset of a population that holds a smaller percentage within a significant subgroup (Ballinger 2018). Specific characteristics of an underrepresented group vary depending on the subgroup being considered, but they are often overlap vulnerable to being ignored, stigmatised and discriminated (ibid.). Types of underrepresented groups also vary depending on the context, but the following groups are often considered: women and girls, children, refugees, internally displaced persons, stateless persons, national minorities, indigenous people, migrant workers, disabled people, elderly persons, HIV positive persons and those suffering from AIDS, Roma/gypsies/Sinti, LGBTQ+.
Ways to increase participation vary from physical (e.g. accessible by wheelchair), digital (e.g. online access), financial (e.g. subsidies to participate in cultural activities), organisational (e.g. quotas in the workforce) (Bosch et al. 2017). Engaging diverse groups in the participatory planning, delivery and stewardship of nature-based solutions – for example through co-production – requires process formats based on mutuality, reciprocity and equality between different groups (e.g. experts, citizens), for example in terms of considering capabilities and time restrictions of different groups and giving equal voice to everyone (Turnhout et al. 2019; Djenontin and Meadow 2018; Voorberg et al. 2015). Communication and engagement need to consider the different capabilities, values, languages and resources of participants, as well as potential pre-existing cooperation or contestation between actors and institutional power structures (Wamsler 2017; Watson 2014). As the designers of public participation processes are not neutral, their perspective on social equity might influence who participates, how and to what end (Clark 2018).

Connection with SDGs

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Strengths and weaknesses

+ The indicator gives useful data for reducing inequalities
+ Easy to use
- May not provide a holistic assessment
- Certain amount of subjectivity is present

Extended methodology

The participation of vulnerable or traditionally under-represented groups in NBS projects or specific NBS project activities can be qualitatively assessed using a five-point Likert scale (Wendling et al. – task force):

Not at all – 1 — 2 — 3 — 4 — 5 — Excellent

1.Not at all: the project has not increased participation of groups not well represented in society.

2.Poor: the project has achieved little when it comes to participation of groups not well represented in society.

3.Fair: the project has somewhat increased the participation of groups not well represented in society.

4.Good: the project has significantly increased the participation of groups not well represented in society.

5. Excellent: Participation of groups not well represented in society has clearly been hugely improved due to the project.

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PARTICIPATORY PLANNING AND GOVERNANCE INDICATORS - CORE

CONNECTING NATURE

Transparency of co-production

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Description

This indicator is defined as the extent to which the co-production process is transparent about the purpose, decision-making structure, roles, content and results.

Methodology

Qualitative Procedure:
Selective Tool 1: case study methodology – semi-structured interviews, case study analysis, participant and non-participant observation
Selective Tool 2: participatory data collections methods, such as focus groups

Quantitative Procedure: Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)
Selective Tool: 4 items at measuring respondents' perception of transparency

Level of expertise

. Quantitative data collection requires no expertise
. Qualitative data collection requires medium level expertise in social science research

Data collection

Required data

. Essential: questionnaire scoring on transparency
. Desirable: qualitative data on reasons and causes for (in-)transparency, and implications for how the process and results are perceived

Data input type

Quantitative and qualitative, if participatory data collection methods, and/or participatory action research are opted for

Data collection frequency

Aligned with NBS co-production process, at least at the end of a co-production process or every 6 months if the process is longer

Participatory process

Participatory methods (e.g., participatory data collection methods, and/or participatory action research) may be applied to collect data on reasons and causes for (in-)transparency, and implications for how the process and results are perceived.

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Extended description

Transparency is one of the basic dimensions of good co-production and participatory governance processes. It especially important to ensure the legitimacy of the process, to create co-ownership over process and results and facilitate trust-building (Djenontin and Meadow 2018; Hölscher et al. 2019). In general terms, transparency means operating in such a way that it is easy for others to see what actions are performed. The relationship between transparency and participation is assumed to be reciprocal: while transparency is a requirement for 'good' participation, collaborative governance and co-production are a means to enhance transparency (Campanale et al. 2020). Participatory approaches reduce the information asymmetry and align preferences and incentives between service recipients and providers (Eriksson 2012, cf. Campanale et al. 2020).
The concept of transparency is most commonly used in literature as a key principle of 'good governance'. The normative belief is that governments should report about the 'why, how, what, and how' of their activities, through information made available to citizens in the most convenient way. As such, transparency is a way to show integrity, performance and accountability, and recently became a vehicle to increase legitimacy, trust in government, improve citizen engagement and participation, and curb corruption and maladministration (da Cruz 2015; Wu et al. 2015; Council of Europe 2017). Transparency in this context is more about how willing a government is to allow citizens to monitor its performance, processes and internal workings, rather than citizen participation therein.
While there are many definitions of transparency in this context, all of them hold the role of information accessibility at their core. For instance, Kaufmann and Kraay (2002) define transparency as "the increased flow of timely and reliable economic, social, and political information, accessible to all relevant stakeholders" (cf. del Sol 2013). In that sense, transparency is closely related to accountability: "Information should be available to those who can be affected by the decision-making and be understandable by its users. Accountability can be defined as the obligation of public sector organizations to account for their decisions and actions to the citizens and other stakeholders" (Campton et al. 2020; see also Wu et al. 2015). There are several indicators and frameworks to compare and promote best practices in transparency among public institutions such as municipalities and regional and national governments (Campanale et al. 2020).

Connection with SDGs

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An example of an extensive framework was developed by da Cruz (2015). It includes a participatory approach for selecting indicators, metrics, and the weighting scheme to assess governments or public authorities. It includes 76 indicators grouped by seven dimensions, including organizational information and operation of the municipality, relationship with citizens, public procurement and economic and financial transparency (ibid.).

From the uses of transparency within participatory governance and planning literature it becomes clear that transparency also relates to a process dimension. In this perspective, transparency is about the provision of information about how such processes are being structured and communicated. The participatory process should be transparent so that the participants and the wider public can see what is going on and how decisions are being made (Rowe and Frewer 2000). In a general sense, this type of transparency has an internal and external implication. The internal implication relates to the transparency towards the participants of the collaborative process. The external implications relate to the transparency of how the process and results are communicated to the broader audience. Information should be communicated through a variety of online and offline means (Rosenström and Kyllonen 2006). A genuine attempt to share information means that organisers actively ensure that all stakeholders are aware of, and understand, the relevant information (Laktić and Malovrh 2018). If any information needs to be withheld from the participants or the wider public, for reasons of sensitivity or security, it is important to admit the nature of what is being withheld and why, "rather than risking the discovery of such secrecy, with subsequent adverse reactions" (Rowe and Frewer 2000, p. 15).

A first condition for process transparency is information about the purpose of the process and the participation. Stakeholders should be informed about what the purpose of their participation and involvement is, who can participate and how, what they can influence and how the results will be used (Laktić and Malovrh 2018). This also includes the provisioning of relevant background materials (Rowe and Frewer 2000).

A second condition for process transparency is information about the process decision-making structure. Relevant information includes the manner of participants selection, decision-making procedures (Rowe and Frewer 2000; Laktić and Malovrh 2018; Rosenström and Kyllonen 2006). Specifically, the documentation of the process of reaching a decision (as well as the outcome) is liable to increase transparency (and hence the perceived credibility of the exercise) as well as the efficiency of the process (Rowe and Frewer 2000).

Another condition relates to the clarity of roles. The (co-)definition of roles and responsibilities in the process gives clarity about what is expected from actors and help them feel comfortable in and adopting their (new) roles and functions (Ferlie et al. 2019). There are typically different, but sometimes overlapping roles in participatory processes, including participants, facilitators, technical experts and initiators (Hölscher et al. 2019). Goals and roles need to be continually deliberated and adjusted (Djenontin and Meadow 2018).

A final condition for process transparency is the provisioning of information about the content and results, including relevant background materials, meeting minutes, updates about progress and changes within the process and well as results (Rowe and Frewer 2000; Laktić and Malovrh 2018; Rosenström and Kyllonen 2006).

Evaluating this type of process transparency is difficult, mainly because transparency is difficult to isolate (Rowe and Frewer 2000; Laktić and Malovrh 2018). Transparency also becomes blurred, relating to questions about transparency by whom, to whom (Campanale et al. 2020). While we define transparency as a responsibility mainly on the part of the organisers, also participants need to ideally be transparent about their motivations and interests, which they bring into such processes.

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Strengths and weaknesses

+ Provides insights into the way co-production processes are structured and communicated
+ Creates space and opportunity to reflect on co-production process
- Indicator veils complexity and multiple perceptions of transparency
- Qualitative data mining could be time-consuming

Extended methodology

The levels of transparency can be evaluated based on responses to survey questions using a five-point Likert scale.

(1) The stakeholders/I was aware about the goals of the process.

a. Strongly disagree
b. Disagree
c. Not sure
d. Agree
e. Strongly agree

(2) The stakeholders were/I was informed about how the results would be used.

a. Strongly disagree
b. Disagree
c. Not sure
d. Agree
e. Strongly agree

(3) The procedures and rules for decision-making and changes in the process were openly communicated.

a. Strongly disagree
b. Disagree
c. Not sure
d. Agree
e. Strongly agree

(4) The results of the process were regularly disseminated to a wider audience – via online and offline channels.

a. Strongly disagree
b. Disagree
c. Not sure
d. Agree
e. Strongly agree

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PARTICIPATORY PLANNING AND GOVERNANCE INDICATORS - CORE

CONNECTING NATURE

Policies adopted to promote NBS

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Adapted from Task Force Indicator "Adaptation of local plans and regulations to include NBS" (UNaLab): L. Wendling, V. Rinta-Hiiro, M. Dubovik, A. Laikari, J. Jermakka, Z. Fatima, M. zu-Castell Rüdenhausen, A. Ascenso, A. I. Miranda, P. Roebeling, R. Martins, R, Mendonça

Description

The extent to which the nature-based solution project has contributed to, or inspired, adaptation of/new policies by both public and private actors/agencies to support implementation and mainstreaming of nature-based solutions.

Methodology

Qualitative Procedure:
Selective Tool 1: case study methodology – semi-structured interviews, case study analysis, participant and non-participant observation
Selective Tool 2: participatory data collections methods, such as focus groups

Quantitative Procedure: Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)
Selective Tool: 1 item at measuring respondents' perception of policies adapted or implemented

Level of expertise

.Quantitative data collection on policies requires medium level of expertise on nature-based solutions policies
. Qualitative data collection and analysis of policies requires medium level of expertise in policy analysis and participatory methods

Data collection

Required data

.Essential: public policy documents, information on changes in municipal rules and regulations to support implementation and "mainstreaming" of nature-based solutions as a result of a nature-based solutions project
. Desirable: content analysis of policies, participatory data on perception of policies and effectiveness

Data input type

Quantitative (number of policies) and qualitative (content analysis of policies, data on perception of policies and effectiveness)

Data collection frequency

Aligned with NBS implementation and timing of targeted objectives

Participatory process

Participatory methods (e.g., focus groups) may be applied to develop an understanding about how the policies are perceived by diverse actors including local communities, and accounting for country/community-distinctive cultural, economic, legal, and political factors that shape the policies and their perception.

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Extended description

Nature-based solutions will need to be embedded in the existing policy mix including biodiversity protection measures, spatial planning, environmental assessment or economic incentives (Zwierzchowska et al. 2019; Nesshöver et al. 2017). For example, nature-based solutions require long-term planning, implementation and maintenance processes, including the sustainable designation of sufficient funds to be applied throughout the lifetime of a nature-based solutions (Kabisch et al. 2016). By positioning nature-based solutions in urban policy, nature-based solutions offer opportunities for encouraging mainstreaming of various – environmental, social and economic – targets into sectors in policy, business and practice and strengthening the basis for nature-based solutions planning, delivery and stewardship (Zwierzchowska et al. 2019; Nesshöver et al. 2017; Wamsler et al. 2017). So far, urban policies often don't appreciate the benefits of nature-based solutions enough and nature-based solutions have thus not been systematically implemented (Kabisch et al. 2016; Wamsler et al. 2017; Zwierzchowska et al. 2019).

A good way to recognise the extent to which nature-based solutions have become included and mainstreamed in urban policy as a result of collaboration processes is to review adopted or adapted urban policies to support nature-based solutions (Zwierzchowska et al. 2019). Policies are defined broadly to as a deliberate system of principles to guide decisions and achieve desired outcomes. A policy is a statement of intent, and is implemented as a procedure or protocol. Policies can be found in planning, strategic and programming documents of a city, that define the key challenges, problems and needs of a city, specify goals and directions (Zwierzchowska et al. 2019). Policies affect an organisation's mandates, in terms of its vision, mission, goals and objectives (Shafer and Choi 2005).

Scholars mention diverse important aspects related to nature-based solution policies. A main element concerns the definition of nature-based solutions.

To have the best chance of success, nature-based solutions policies should be based on a well-balanced, clear, widely accepted and implementable set of goals and key principles that ensure all dimensions of sustainability while allowing flexibility to accommodate different types of solutions (Nesshöver et al. 2017).

Connection with SDGs

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In general, nature-based solution policies need to address multiple environmental, social and economic goals and co-benefits across diverse societal challenges and dimensions (e.g. urban regeneration, wellbeing, resilience) (Raymond et al. 2017; Frantzeskaki et al. 2020). Nesshöver et al. (2017) identify three sets of principles for nature-based solutions: (1) dealing with uncertainty, complexity, ambiguity and conflicts to achieve equitable trade-offs; (2) considering adaptive management as approach in highly uncertain situations; and (3) ensure involvement of multiple stakeholders and a wider public.
Another dimension to understand urban policies related to nature-based solutions is to identify the included mechanisms and instruments underlying the implementation of the policy. Policies can be political, managerial, financial and administrative mechanisms, include diverse instruments (e.g. labels, taxes, regulations) and can in principle by developed, administered and promoted by state and non-state actors (Auld et al. 2014).
Ideally, understanding policies should also involve evaluation of effectiveness, including process, impact and efficiency evaluation (Auld et al. 2014). Process evaluation can also be thought of as the evaluation of implementation procedures, assessing whether observed outcomes are the result of flaws in the design or execution of a particular policy or programme. Impact evaluation assesses whether the policy accomplished its own goal. Efficiency evaluation assesses whether the outcome of a policy justified the associated costs (i.e., cost-benefit) or whether the costs were justified given the results, typically relative to the costs of enacting another policy to accomplish the same goal (i.e., cost- effectiveness).
Importantly, nature-based solutions policies should be developed through collaborative processes (Nesshöver et al. 2017; Shafer and Choi 2005). The nature-based solutions policy process is a continuous debate and influenced by changes in social and economic conditions, the emergence of new types of nature-based management activities, and the ebb and flow of debates among different stakeholders who are most influential at the time (Shafer and Choi 2005).

Strengths and weaknesses

+ Easy to implement measure to evaluate policy learning
+/- Easy to adapt to different questions but then indicator becomes more complex
- No measurement of implementation and effectiveness/impact of policies
- Data mining could be time-consuming

Extended methodology

1) Identification of policies

The extent of policy learning during or as a result of a nature-based solutions project can be evaluated using a five-point Likert scale (Bosch et al., 2017):

No impact — 1 — 2 — 3 — 4 — 5 — High impact

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1. No impact: the NBS project has not, at any level, inspired changes in municipal rules and regulations.
2. Little impact: the NBS project has led to localised discussion about the suitability of the current municipal rules and regulations.
3. Some impact: the NBS project has led to public discussion, leading to a change in municipal rules and regulations.
4. Notable impact: the NBS project has led to public discussion, leading to a change in municipal rules and regulations. This, in turn, has sparked discussion amongst other administrations about the suitability of current rules and regulations.
5. High impact: the NBS project has led to public discussion, leading to a change in municipal rules and regulations. This, in turn, has inspired other administrations to reconsider their respective rules and regulations

2) Describing policies (qualitative): policy design

In a second step, the policies can be further described in terms of their design. This allows to better understand the features of policies (e.g. instrument type, regulatory target) (Auld et al. 2014).

·Source of authority: (1) public (government-led and sanctioned, e.g. law, administrative guidelines, regulations, court orders); or (2) hybrid (originate from private authorities such as businesses, NGOs, partnerships)
·Type of instrument: (1) regulation (legal obligations); (2) expenditure (control of money, e.g. incentives or disincentives); (3) information provision (deployment and control of information, e.g. public outreach and education campaigns)
·Policy target: (1) citizens; (2) firms; (3) governments; (4) other
·Type of policy: (1) planning (policy encourages/requires target to change how and when it undertakes planning activities); (2) acting (policy encourages/requires target to undertake specific activities in its operation); (3) performing (policy encourages/requires target to achieve particular outcomes)

These categories can be used to generate additional numerical information to describe the types of policies, e.g. numbers of policy by public actors, number of policies by private actors, number of regulations etc.

3) Describing policies (qualitative): goals/principles

In a third step, the policies can be further described along the goals and principles they aim to achieve through nature-based solutions.
1) Social goals (e.g. wellbeing, health)
2) Environmental goals (e.g. resilience to climate change, biodiversity regeneration, pollution reduction)
3) Economic goals (e.g. supporting local businesses)
4) Other

These categories can be used to generate additional numerical information to describe the policies in terms of their goals, e.g. number of policies focusing on social goals.

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PARTICIPATORY PLANNING AND GOVERNANCE INDICATORS - CORE

CONNECTING NATURE

Activation of public-private collaboration

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Description

The indicator is defined as the number of collaborations between public and private actors activated for the planning, delivery and/or stewarding of a nature-based solution.

Methodology

Qualitative Procedure:
Selective Tool 1: case study methodology – semi-structured interviews, case study analysis, participant and non-participant observation

Selective Tool 2: participatory data collections methods, such as focus groups

Quantitative Procedure:
Number (counting number of collaborations activated)

Level of expertise

Medium: data collection on collaborations requires knowledge about existing and new collaborations

Data collection

Required data

. Essential: Information on public-private collaborations activated throughout each nature-based solution project planning, delivery and stewardship
. Recommended: Data on the types of public-private collaboration, including what type of actors were involved, what were the actors' respective goals and individual roles in the collaboration, how was the collaboration structured and how satisfied were the actors

Data input type

Quantitative (number of collaboration) and qualitative if data on the types of public-private collaboration is considered

Data collection frequency

Aligned with NBS implementation and timing of targeted objectives; at minimum before and after NBS implementation

Participatory process

Participatory methods (e.g., focus groups, participatory data collection methods, and/or participatory action research) may be applied to collect information on the types of public-private collaboration, including what type of actors were involved, what were the actors' respective goals and individual roles in the collaboration, how was the collaboration structured and how satisfied were the actors

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Extended description

Traditionally, most urban green initiatives were, and still are, initiated and governed by local governments (Sekulova and Anguelovski 2017; Dushkova and Haase 2020). However, public agencies tend to withdraw in long-term managing and financing, making interventions one-off measures or leaving them without maintenance funds (Nesshöver et al. 2017; Young and McPherson 2013). Meanwhile, the number of green spaces, especially community gardens, initiated and managed in a bottom-up fashion is increasing (Buijs et al. 2018; Sekulova and Anguelovski, 2017). The private sector has started to be dominant driving force in implementing nature-based solutions, particularly for green roofs and facades. Private initiatives often still need support from local governments in the form of land permits, funding, knowledge and linking to other practitioners (Frantzeskaki 2019).

Collaboration between various public and private actors can help overcoming fragmentation, disengagement and social exclusion girdling nature-based solutions planning through integrating multiple perspectives, needs and knowledges and opening up opportunities for innovation with multiple ecological, social and economic gains (Frantzeskaki 2019; Davies and Lafortezza 2019). Collaboration can be of importance for the social support of the nature-based solutions over time. Involvement of citizens and other stakeholders during project implementation ensures establishment of a common understanding of the project's longer-term maintenance or management needs, and provides managers and developers with critical input regarding the project's performance relative to stakeholder expectations. It can also be a matter of creating economic insurance, where different financial resources can be activated to sustain functionality over time.

For these reasons, public-private collaboration and co-management of nature-based solutions are advocated (European Commission, 2016; Pauleit et al., 2017; Kabisch et al. 2017). Often, the term public-private partnership (PPP) is employed to refer to a more or less formalised relationship formed between public and private sectors, with different levels of responsibilities, to deliver public services (Ahmadabadi and Heravi 2019; Chan et al. 2010). Collaborations between public and private actors in nature-based solutions planning, delivery and stewarding can however be much more diverse. They can involve formal and informal government-industry, government-research or citizen-government collaborations – to name but a few.

Connection with SDGs

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For example, Buijs et al. (2018) show how active citizens can significantly contribute to urban green infrastructure planning and implementation, by developing large parks with volunteers or designing a network of green corridors (Buijs et al. 2018). These collaborations can also be short-term or long-term – important is that at least one public and one private party is involved with the aim to collaborate on the planning, delivery and/or stewarding of a nature-based solution.
It is important to note that public-private collaborations are no magical recipe to overcome typical governance problems. Research on PPPs has focused on unveiling various reasons for pitfalls and shortcomings, including regulatory issues, inappropriate and complex financing structures (Ahmadabadi and Heravi 2019; Benítez-Ávila et al. 2018). While this indicator suggests to estimate the level of collaboration by counting the number of collaborations activated, it is therefore important to also consider the (reasons for) success and failure of these collaborations.

Strengths and weaknesses

+ Easy measure of public-private collaboration

+ Creates space and opportunity to reflect on collaboration (goals, outcomes, interests etc.)

- Does not reveal the quality of the collaboration and diversity in terms of (especially private) actors involved

- (Qualitative) data mining could be time-consuming

Extended methodology

Step 1 Identifying collaborations activated

Defining what collaboration is: the case wherein actors from public and private sectors unite to deliver public services. Collaborations can appear at all stages of the process, planning, delivery and stewardship. At this stage, participants are encouraged to consider the public-private collaborations activated throughout the project.

- Planning
- Delivery
- Stewardship

Step 2 Measurement or count data for number of collaborations activated

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PARTICIPATORY PLANNING AND GOVERNANCE INDICATORS - CORE

CONNECTING NATURE

Trust in decision-making and decision-makers

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Description

Political trust is defined as the willingness of citizens to be vulnerable to the actions of governmental decision-making and decision-makers based on their expectation that governments perform a particular action important to them, irrespective of their ability to monitor or control that other party.

Methodology

Qualitative Procedure:
Selective Tool 1: case study methodology – semi-structured interviews, case study analysis, participant and non-participant observation
Selective Tool 2: participatory data collections methods, such as focus groups

Quantitative Procedure:
Selective Tool: 9 items at measuring respondents' political trust

Level of expertise

. Methodology and data analysis requires medium level expertise in social science research
. Quantitative data collection requires no expertise
. Qualitative data collection requires medium level expertise in social science research

Data collection

Required data

. Essential: questionnaire scoring on trust
. Desirable: qualitative data on nature-based solutions governance processes and underlying determinants of levels of trust

Data input type

Quantitative and qualitative, if participatory data collection methods, and/or participatory action research are opted for

Data collection frequency

Aligned with NBS implementation and timing of targeted objectives

Participatory process

Participatory methods (e.g., participatory data collection methods, and/or participatory action research) may be applied to collect data on nature-based solutions governance processes and underlying reasons of levels of trust to reveal underlying challenges and opportunities.

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Extended description

Political trust comprises evaluations of the trustworthiness of governmental decision-making and decision-makers, based on three dimensions (Grimmelkhuijsen and Knies 2017):

1) perceived competence: the extent to which a citizen perceives a government organisation to be capable, effective, skilful and professional;
2) perceived benevolence: the extent to which a citizen perceives a government organisation to care about the welfare of the public and to be motivated to act in the public interest;
3) perceived integrity: the extent to which a citizen perceives a government organisation to be sincere, to tell the truth, and to fulfil its promises.

'Political trust' is used as a common term to measure how positively citizens regard governmental decision-making actors, institutions and processes (Seyd 2016). Political trust is considered both an important prerequisite for as well as outcome of good governance. The absence of trust shows citizens' dissatisfaction and withdrawal from the political process, and it may result in citizens who do not want to pay taxes or follow rules (Bouckaert and van de Walle 2003; van Ryzin 2011). The same holds true for nature-based solutions planning, delivery and stewardship: citizens are more likely to actively participate when they trust local decision-making and decision-makers, while at the same time co-production of nature-based solutions might enhance trust (cf. Djenontin and Meadow 2018; Ferretti et al. 2018).
However, political trust is a complex concept for which it is difficult to identify a commonly accepted definition (Bouckaert and van de Walle 2003; Seyd 2016; Parker et al. 2015). Trust has been the focus of multiple disciplines, including psychology, sociology, political science, economy and organisational science (Grimmelkhuijsen and Knies 2017). Despite the myriad of definitions and operationalisations of trust within and across disciplines, Grimmelkhuijsen and Knies (2017) identify agreement about two features related to trust: a degree of 'risk' and 'interdependence'. A trusts B to do X, which is in A's interest. This yields a risk because A cannot be certain as to whether B indeed carries out X. In the case of political trust, risk becomes relevant when governments exert a certain degree of power over citizens, which can be either used properly or abused.

Connection with SDGs

Goal 9
Goal 11
Goal 16
Goal 17

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The condition of interdependence implies that the interests of one party cannot be achieved without reliance on the other party. In the case of trust in government, if citizens want the government to solve pressing social problems, they are dependent on government organisations to deliberate on decisions, carry out policy measures, and monitor their effects. Government, on the other hand, depends on citizens to cooperate and act according to certain rules for its policies to have any effect (ibid.).

Based on these two conditions, definitions of political trust lean on Mayer et al.'s (1995, p. 712) definition of trust, which originates from organisational science literature (Seyd 2016; Grimmelkhuijsen and Knies 2017): trust is "the willingness of a party to be vulnerable to the actions of another party based on the expectation that the other will perform a particular action important to the trustor, irrespective of the ability to monitor or control that other party". In this definition, the expectation of the vulnerable party (i.e. citizen) is central: the trust of person A in another person or organisation B rests on a judgement by A about how far B will act in a way consistent with their (A's) interests (Seyd 2016). This expectation is based on the perceptions that people have of 'the other': trust in government consists of the extent to which it is considered 'worthy of trust' by its citizens (Grimmelkhuijsen and Knies 2017). Accordingly, trust is often measured via beliefs or judgements on A's part that B manifests particular features or qualities that induce trust (or distrust) in A – rather than an intention or behaviour (Seyd 2016). The content of a trust belief relates to A's judgement that B possesses the qualities that render them worthy of trust (ibid.; Grimmelkhuijsen and Knies 2017).

Based on this, and to gain a more specific understanding of how trust works and can be measured, Grimmelkhuijsen and Knies (2017) devised a 'citizen trust in government organisations scale'. The scale distinguishes between different dimensions to determine a governmental organisation's perceived trustworthiness: (1) perceived competence (the extent to which a citizen perceives a government organisation to be capable, effective, skilful and professional), (2) perceived benevolence (the extent to which a citizen perceives a government organisation to care about the welfare of the public and to be motivated to act in the public interest); and (3) perceived integrity (the extent to which a citizen perceives a government organisation to be sincere, to tell the truth, and to fulfil its promises). These dimensions respond to criticism about conventional measures of political trust, which employ single-item survey measures (ibid.; Seyd 2016). To trust rests on judgements about a number of different considerations, rather than comprising a singular, generalised evaluation.

Another concern is that survey items that squeeze a range of potential evaluations into a single expressed opinion risk understate the level of uncertainty and ambivalence in people's attitudes towards different governmental bodies or even people. Along these lines, scholars emphasise that the object of political trust (who/what is trusted) needs to be clearly defined. Political trust can relate to different levels and bodies of government, e.g. national, regional and local governments, the parliament or the civil service (Bouckaert and van de Walle 2003; Parker et al. 2015). Political trust can also relate to different type of people or office holders – politicians or public officials – as well as individual persons, e.g. the president or prime minister (Parker et al. 2015). Accordingly, Parker et al. (2015) contend that trust in government reflects trust in the federal or national government, which can be distinguished from trust in incumbent political leaders, trust in state government and presidential job evaluations.

In addition, there needs to be a clear separation between its components and its potential causes – especially when aiming to establish causal relations. Findings reveal that levels of trust cannot simply be attributed to the good or bad functioning of an institution; they may in fact be entirely unrelated to what government is or does (Bouckaert and van de Walle 2003).

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Economic and political performance, institutional context, political culture, changing behaviours and values, citizen-state relationships, opportunities for citizen participation and critical events might all be important factors influencing political trust (ibid.; Kim and Lee 2012; Parker et al. 2015). Thus, if one also aims to explain the feelings of (dis)trust that A has for B, the antecedents of that trust lie in three places: (a) the characteristics of A, notably their propensity to trust; (b) the characteristics or past behaviour of B, notably the extent to which these reveal trustworthy qualities; and (c) the context in which B operates, notably whether they are faced with appropriate incentives and sanctions. Importantly, the indicators to capture levels of trust must be clearly distinguished from those to capture the reasons for that trust (Seyd 2016).

Strengths and weaknesses

+ Important measure of citizens' perceptions of and satisfaction with local government related to the nature-based solution implementation
- Difficult to establish causal relations between measures of political trust and nature-based solutions implementation
- Data collection could be time-consuming

Extended methodology

The levels of political trust can be evaluated based on responses to survey questions using a five-point Likert scale: strongly disagree, disagree, neutral, agree, and strongly agree (Seyd 2016; Grimmelkhuijsen and Knies 2017).

(1) Perceived competence
1.a) The municipality of XX is capable.
1.b) The municipality of XX wastes a lot of public money.
1.c) Local politicians generally know what they are doing.

(2) Perceived benevolence
2.a) Local politicians act in the interest of citizens.
2.b) The municipality of XX carries out its duty very well.
2.c) Local politicians keep their commitments.

(3) Perceived integrity
3.a) In the main, local politicians tell the truth.
3.b) Governmental officials (e.g. civil servants)* tell us as little about what they get up to as they can.
3.c) When things go wrong, local politicians admit their mistakes.

*Civil servants are higher level non-political government paid officials. They are not elected to office—they applied for their posts and are senior public servants or government administrators.

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PARTICIPATORY PLANNING AND GOVERNANCE INDICATORS - CORE

CONNECTING NATURE

Reflexivity - identified learning outcomes

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Description

This indicator is defined in terms of the number of reflexive learning outcomes identified throughout nature-based solutions process. Reflexive learning outcomes are changes in the existing 1) rules guiding actors' practices, 2) relations between actors, and between the initiative and context, 3) practices as the common ways of working and 4) discourse related to the future of the initiative's sector (Beers & van Mierlo, 2017).

Methodology

Quantitative Procedure:
Counting number of learning outcomes identified

Qualitative Procedure:
Reflexive monitoring tools, case study methodology or participatory data collections

Level of expertise

.Methodology and data analysis require high expertise understanding of reflexivity and analytical skills but also knowledge about the context to ensure the changes are reflexive and not optimizing existing structures, cultures and practices.
. Quantitative data collection (counting number of learning outcomes and innovations) requires no expertise
. Qualitative data collection (facilitation of participatory sessions to identify reflexive learning outcomes) require high expertise in action-research and basic training in participatory data collection, appreciative inquiry and critical analysis.

Data collection

Required data

Essential:
. Group of practitioners with experiences in implementing the large-scale nature-based solution
. Goals they want to achieve with their nature-based solution
. Barriers and opportunities they faced and what they did to overcome or take them
Desirable: participatory identification of learning outcomes and the assessment of the type of reflexivity

Data input type

Quantitative (number of learning outcomes) and qualitative if data on the types and implications of learning outcomes are considered

Data collection frequency

Depending on experience of actors involved they can organize time to reflect upon their experiences and formulate learning outcomes themselves ones every 1-3 months to identify and every 6 months to revisit. When other methods are selected, and the analysis is done by experts, every 6 months to once a year is possible too.

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Extended description

Conventional governance, policy-making, planning and project management approaches aim to optimize existing processes starting from pre-defined problems and solutions. Only after a problem or solution is identified, a monitoring and evaluation process is designed. For example, indicators are selected to measure the effectiveness of the project(s) after implementation. This is done by experts and involves little participation of other actors. However, implementing nature-based solutions – especially on a large scale in cities – is complex: it touches on multiple goals and interests and requires innovative processes for collaboration, financing and design etc. It cannot be 'blueprint' planned beforehand. In addition, the context might change, new opportunities and barriers may present themselves. Therefore, the existing evaluation methods are not sufficient because they leave little room for collaborative learning, experimentation and adaptations during the planning, delivery and stewardship phase of the nature-based solution. Nature-based solutions planning, delivery and stewardship requires ongoing reflection about who is involved, who isn't, and who benefits and who doesn't, as well as adaptability to respond to new insights, demands and needs (Chatterton, Owen, Cutter, Dymski, & Unsworth, 2018; Ferlie, Pegan, Pluchinotta, & Shaw, 2019; Muñoz-Erickson, Miller, & Miller, 2017). This learning process is reflexive when participants are self-critical and reflect on the inherent political nature of how they build knowledge, the assumptions they make and the normative premises that guide them (Miller & Wyborn, 2018; Muñoz-Erickson et al., 2017). This requires a process of learning-by-doing and doing-by-learning in terms of goals achievement, adopt lessons learned into new or existing structures, strategies or practices and identify needs for adaptation (Beers & van Mierlo, 2017; Dentoni, Bitzer, & Pascucci, 2016; Frantzeskaki, Kabisch, & McPhearson, 2016). To support this process reflexive monitoring was developed as a method with specific tools developed for practitioners (van Mierlo et al., 2010), but there are other ways to increase the reflexivity of a learning process.

The learning process results in 'reflexivelearning outcomes' when knowledge (the what), actions (the how) and relations (the who) become substantively interwoven (Beers, Van Mierlo, & Hoes, 2016) as a result of a shared experience in how to overcome barriers or use opportunities and learning about how to deal with them. Thus, learning outcomes are reflexive, when not only new insights are gained, but when these insights are implemented into the context within which the learning actors operate.

Participatory process

Participatory methods (e.g., narrative studies, participatory data collection methods, and/or participatory action research) are crucial for this indicator to collect relevant information on learning outcomes and how these affect the context and different types of actors.

Connection with SDGs

Goal 11
Goal 16
Goal 17

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Reflexive learning outcomes can be operationalized in terms of changes in the existing 1) rules guiding actors' practices, 2) relations between actors, and between the initiative and context, 3) practices as the common ways of working and 4) discourse related to the future of the initiative's sector (Beers & van Mierlo, 2017). For application by the cities in the Connecting Nature project we developed a method to track and distill learning outcomes and reflect upon their reflexivity (Lodder, Sillen, Frantzeskaki, Hölscher, & Notermans, 2019).

Strengths and weaknesses

+ The learning process that results in reflexive learning outcomes is a practice-driven process in which the involved actors steer the direction in which the changes are needed.
+ Harvesting learning outcomes can work empowering for practitioners as these illustrate the innovative processes in the achievements in terms of barriers that are overcome, or opportunities taken.
+ Learning outcomes are rich qualitative data sources as they describe not only one experience but also how the experience influenced its context.
- The learning process and creating space for reflection to formulate learning outcomes can be challenging and complex to manage.
- The process can be a time intensive process for practitioners, facilitators and experts involved.
- Formulating reflexive learning outcomes requires practice from practitioners and facilitators.

Extended methodology

Quantitative procedure (counting number of learning outcomes identified)

Tool: Involved actors can start to list experiences in terms of how they overcame the barriers and used the opportunities they encountered. Then they can organise time to reflect upon the changes they established in terms of novel rules, relations, practices and discourses. In this way they can be reformulate their experiences as reflexive learning outcomes. This can be done by the practitioners themselves or by (external) experts who facilitate the learning process. The number of learning outcomes can then be counted per month or year.

Scale of measurement

Number of identified reflexive learning outcomes per month or year that can be specified in number of changes in the context based on reflexivity type (rules, and/or relations, and/or practices and/or discourse).

Qualitative procedure

Tool 1: Case study methodology – semi-structured interviews, case study analysis, participant and non-participant observation – can be used as a data source to formulate reflexive learning outcomes by (external) experts.

Tool 2: Other participatory data collections methods, such as focus groups can also be organised to collectively reflect upon the learning process and to formulate reflexive learning outcomes facilitated by (external) experts if needed.

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PARTICIPATORY PLANNING AND GOVERNANCE INDICATORS - CORE

CONNECTING NATURE

Common vision

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Description

Shared vision refers to a clear and common picture of a desired future state that members of an organization identify with themselves – essentially a vision that has been internalized by members of the organization.

Methodology

Quantitative Procedure: Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)

Selective Tool 1: Organizational sharedvision (Tjosvold, 1998; Wong, Tjosvold, & Liu, 2009)

Selective Tool 2: Vision scale (Pearce, & Ensley, 2004; Scully et al. 1994)

Level of expertise

. Quantitative data collection requires no expertise
. Qualitative data collection requires medium level expertise in social science research

Data collection

Required data

. Essential: questionnaire scores
. Desirable: qualitative data on organizational processes

Data input type

Quantitative and qualitative, if participatory data collection methods, and/or participatory action research are opted for

Data collection frequency

Aligned with NBS implementation and timing of targeted objectives

Participatory process

Participatory methods (e.g., participatory data collection methods, and/or participatory action research) may be applied to collect data on nature-based solutions organizational processes

Connection with SDGs

Goal 9
Goal 11
Goal 16
Goal 17

CONNECTING NATURE

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Extended description

Shared vision is closely associated with organizational learning, frequently identified as a factor influencing knowledge acquisition and knowledge dissemination activities (Hoe, 2007).
Shared vision was also defined as the organizational values that promote the overall active involvement of organizational members in the development, communication, dissemination, and implementation of organizational goals (Wang & Rafiq, 2009). Although an organization is designed to combine the abilities and efforts of those in various departments and groups, departments in many organizations have concluded that they are separate and distinct from one another. Typically, people within one department have a history of working together and have developed their own values and in-group feelings. In many organizations, the tangible, mutual rewards of working with other departments are neither specific nor highly motivating (Klein, Wesson, Hollenbeck, & Alge, 1999). A shared vision has been thought to contribute substantially to empowering and uniting employees (Kouzes & Posner, 1995).

Concepts related to the notion of shared vision have often been used to refer to social or psychological aspects of a cooperative relationship. For example, Murnighan (1994) suggests that psychological determinants of cooperation include similarity in partners' values, the perceived status and legitimacy of partners and the perception that interactive procedures are just. Rodriguez and Wilson (2000) call these psychological determinants of cooperation social bonds of relationships, which entail familiarity, friendship and confidence in relational exchange, suggesting that psychological/social aspects of cooperation pertain to elements like trust, shared values and other aspects of similarity.

The concept of shared vision is often used to refer to shared values and mutual goals and understanding in a cooperative relationship (Morgan & Hunt, 1994; Parsons, 2002), being related also to organizational culture, because organizational culture helps to convey a sense of identity in organizational members and may create commitment to the organization and its goals (Hakanson, 1995).
Shared vision is a necessary condition for exchange to occur (inside and outside the organization), because identification and combination of strategic resources can only be realized if the organization(s) have systems and cultures that are compatible enough to facilitate coordinated action (Dyer & Singh, 1998).

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Shared values and understandings between parties in an exchange relationship facilitate meaningful communication that is essential in both the exchange and combination required for knowledge creation, knowledge acquisition and exploitation (Nahapiet & Ghoshal, 1998; Yli-Renko, Autio, & Sapienza, 2001), being linked to organizational learning, innovativeness and performance (Hoe, 2007).A shared vision helps organizational members to see the potential value of their knowledge exchange and combination, and facilitate the attainment of consensus on the meaning of the information in relation to commonly understood goals (Slater & Narver, 1995). Therefore, shared vision boosts the likelihood of shared interpretation and evaluation of information acquired to achieve organizational goals (Sinkula, 1994). Therefore, shared vision helps integrate individual learning in organizational learning and promotes adaptive and convergent learning. Shared vision provides organizational members a sense of purpose and direction, and helps to hold together a loosely-coupled system and promote the integration of an entire organization (Orton & Weick, 1990). Therefore, shared vision can be viewed as a bounding mechanism for organizational resource exchange and integration (Tsai & Ghoshal, 1998), particularly when various opportunities emerge whilst limited organizational resources are available for deployment. Without a shared vision, the reality of an organization would be characterized by highly enthusiastic and committed individuals pulling the organization toward different directions. Shared vision channels entrepreneurial resources toward commonly recognized opportunities and boosts organizational capacity to fully exploit them (Wang & Rafiq, 2009).
Shared vision refers to a clear and common picture of a desired future state that members of an organization identify with themselves – essentially a vision that has been internalized by members of the organization. Shared vision is closely associated with organizational learning, frequently identified as a factor influencing knowledge acquisition and knowledge dissemination activities (Hoe, 2007).
Shared vision was also defined as the organizational values that promote the overall active involvement of organizational members in the development, communication, dissemination, and implementation of organizational goals (Wang & Rafiq, 2009).

Extended methodology

Organizational sharedvision (Tjosvold, 1998; Wong, Tjosvold, & Liu, 2009)

Scale: provide ratings on the extent to which the organization as a whole had a shared vision on a 5-point scale ranging from 1 (strongly disagree) to 5 (strongly agree).

1. Our organization tries to keep us informed about the overall organization.

2. Our organization encourages employees to feel we are one unit dedicated to a common purpose.

3. Our organization makes us feel responsible for its goals.

Scoring: cumulative

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Vision scale (Pearce, & Ensley, 2004)

Vision scale assessed how well team members shared in the development, creation, communication, and reinforcement of a common vision for the goals and desired future state of the team; or how the CEO/leader can create a shared vision

Scale: 5-point response format labeled as follows: ‘1=definitely not true through ‘5’=definitely true.

1, Because of my team members, I have a clear vision of our team’s purpose.

2. Because of my team members, I have a clear vision of who and what we are.

3. My team members provide the team’s vision of our organization to me.

4. My team provides a vision for our organization.

Vision scale (Scully et al. 1994)

Scale: 5-point response format labeled as follows: ‘1=definitely not true through ‘5’=definitely true.

1. The CEO provides a clear vision of where we are going.

2. The CEO provides a clear vision of who and what we are.

3. The CEO provides his/ her vision of our organization to me.

4. The CEO provides a vision for our organization.

5. There is no doubt that the CEO is very visionary.

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PARTICIPATORY PLANNING AND GOVERNANCE INDICATORS - CORE

CONNECTING NATURE

Innovative climate

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Description

Walker (2008) defines innovation as a process through which new ideas, objects, and practices are created, developed or reinvented, and which are new for the unit of adoption. An actual innovation must be more than an idea; implementation has to occur.

Methodology

Quantitative Procedure: Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)

Selective Tool 1: Support for innovation subscale from Team Climate Inventory (Anderson & West, 1998)

Selective Tool 2: Organizational innovation climate (Amabile, 1996; Chen & Hu, 2008; Yu, Yu, & Yu, 2013)

Level of expertise

. Quantitative data collection requires no expertise
. Qualitative data collection requires medium level expertise in social science research

Data collection

Required data

. Essential: questionnaire scores
. Desirable: qualitative data on organizational processes

Data input type

Quantitative and qualitative, if participatory data collection methods, and/or participatory action research are opted for

Data collection frequency

Aligned with NBS implementation and timing of targeted objectives

Participatory process

Participatory methods (e.g., participatory data collection methods, and/or participatory action research) may be applied to collect data on nature-based solutions organizational processes

Connection with SDGs

Goal 9
Goal 11
Goal 16
Goal 17

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Extended description

In Connecting Nature, we define innovative climate as a measure of knowing and adopting new organizational practices. An innovation climate is an atmosphere within an organization that fosters and propagates creative mechanisms to achieve organizational outcomes and has in place various traits among organization members that are conducive to creative and innovative ideas (Ronquillo, 2011).

Support for innovation means `. . . the expectation, approval and practical support of attempts to introduce new and improved ways of doing things in the work environment' (West, 1990, p. 38).

Organizational innovation climate has the following operational definition: “the perception of the work environment by the members of an organization including the working conditions, encouragement from superiors, team support, and resources in the work environment” (Amabile, 1996; Chen & Hu, 2008; Yu, Yu, & Yu, 2013).

Resources help fostering a healthy working environment and mitigate the effects of stressors on performance and wellbeing. Resources such support between colleagues, meaningful and challenging work and feedback can help individuals and institutional development. Importantly, fostering good collaboration and communication within and across teams helps building a strategy against the pullbacks of silo thinking and move towards an authentic collaborative approach.

The organizations can offer support for innovation by both communicating the desirability of innovative work behaviours and by suitably rewarding such behaviours (James, Hartman, Stebbins, & Jones, 1977). Likewise, supervisors can also encourage innovative work behaviours by providing the information (data, expertise, political intelligence), resources (materials, space, time) and social-political support (endorsement, legitimacy, backing) necessary to develop and apply innovative ideas (Kanter, 1988).

When there is a climate of support for innovation (organizational expectations for innovative behaviours and outcomes are expressed and rewarded), when the organization is willing to experiment with innovative ideas and rewards are given in recognition of excellent performance, employee innovation increases (Anderson & West, 1998), both at number of suggestions from employees and implementation levels (as the extent to which suggestions had been implemented) (Axtell el al., 2000).

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Baer and Frese (2003) explored innovation as an antecedent of performance at the organizational level, and found that the relationship between process innovativeness and organizational performance was enhanced by high levels of climate for personal initiative and psychological safety. Also, the study conducted by Choi, Anderson, and Veillette (2009) offers support for the idea that unsupportive organizational climate is negatively related to creativity, especially for those employees low on creative ability.

An environment that encourages individuals to be creative or innovative or an environment that is safe for risk taking is likely to enable an individual to take a risk in terms of suggesting a new idea or trying something new (Hammond et al., 2011). Amabile (1997) suggested that work environments affect the components that contribute to creativity, as a source for organizational innovation. Specifically, work environments influence creativity at individual or team-level through three major components: expertise, creative-thinking skill, and intrinsic motivation. A study on public organizations in finance and insurance industries showed that indeed, organizational innovation climate affects employees' innovative behaviour (Yu, Yu, & Yu, 2013).

Miron, Erez and Naveh (2004) argued that organizational culture's strength depends on the level of homogeneity in members' perceptions and beliefs, or on the degree of variability in employees' perceptions of the organizational values and endorsed practices. Their study also showed that an innovative culture does not necessarily compete with a culture of quality and efficiency, and organizations may maintain a balance between all three dimensions. A culture of attention-to-detail was conducive to performance quality when interacting with conformity as a personal characteristic, and it was also complementary to efficiency when interacting with conscientiousness. Innovative performance does not impede quality and efficiency, and in fact these three performance outcomes were positively correlated. Being creative does not necessarily contradict being efficient, as there is no relationship between creativity and efficiency.

Extended methodology

Team Climate Inventory (Anderson & West, 1998)

A self-report measure intended to capture climate for innovation within groups at work.

Scale: 5-point scale ranging from 1 strongly disagree) to 5 (strongly agree)

1. The team is always moving toward the development of new answers.
2. In this team, we take the time needed to develop new ideas.
3. Assistance in developing new ideas is available.
4. The team is open and responsive to change.
5. People in this team cooperate in order to help develop and apply new ideas.
6. People in this team are always searching for fresh, new ways of looking at problems.
7. Members of the team provide and share resources to help in the application of new ideas.
8. Team members provide practical support for new ideas and their application.

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Organizational innovation climate (Amabile, 1996; Chen & Hu, 2008; Yu, Yu, & Yu, 2013)

A self-report measure intended to capture organizational-level innovation climate.

Scale: 5-point scale ranging from 1 strongly disagree) to 5 (strongly agree)

1. Our company often encourages employees to propose new ideas.
2. Employees in our company have been praised for their innovation behavior.
3. Employees in our company challenge each other's ideas through positive thinking.
4. Superiors in our company expect that their staff can work in a more creative way.
5. Our company offers a sufficient budget to support development of an innovative project.
6. It is acceptable in our company for a staff member to fail to achieve the expected outcome while carrying out an innovative learning plan.
7. Superiors in our company value the contribution made by each member of their staff.
8. The staff in our company can freely exchange ideas.

In both tools higher scores indicate higher organizational support for innovation

Qualitative Procedure:

Adapted key questions from quantitative procedures and tools to assess the process with the stakeholders.

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PARTICIPATORY PLANNING AND GOVERNANCE INDICATORS - CORE

CONNECTING NATURE

Open communication (internal & external)

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Description

Collaboration and communication between employees and departments refer to the interaction and sharing of information, knowledge, ideas, and resources between employees from the same department as well as from different departments, including the creation of space for interaction and sharing (i.e., regular meetings, conferences, intranet, etc.).

Methodology

Quantitative Procedure: Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)
4 selective tools

Qualitative Procedure: evaluation of the processes involved in internal and external communication
3 selective tools

Level of expertise

. Quantitative data collection requires no expertise
. Qualitative data collection requires medium level expertise in social science research

Data collection

Required data

. Essential: questionnaire scores
. Desirable: qualitative data on organizational processes

Data input type

Quantitative and qualitative, if participatory data collection methods, and/or participatory action research are opted for

Data collection frequency

Aligned with NBS implementation and timing of targeted objectives

Participatory process

Participatory methods (e.g., participatory data collection methods, and/or participatory action research) may be applied to collect data on nature-based solutions organizational processes

Connection with SDGs

Goal 9
Goal 11
Goal 16
Goal 17

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Extended description

Inter-departmental collaboration represents the willingness of departments to work together, having mutual understanding, having a common vision, sharing resources, and achieving collective goals.

Traditionally, many organizations have suffered from what is often called the functional silos problem. The issue is more prevalent in institutions and an organization under state's governing, as it implies a more bureaucratic and formalized way of work. This problem occurs when members of functional units stay focused on matters internal to the function and minimize their interactions with members of other functions. In this sense, the functional departments create artificial boundaries or "silos" that discourage rather than encourage more integrative thinking and active coordination with other parts of the organization. Therefore, there is a need to improve the collaboration between members of the same work team, even if these members are from different departments of the organization.

The establishment of new work-related collaborations, inter- and intra-departments, stakeholders and broad communities is required in NBS projects, as different knowledge and perspectives are needed to be aligned in the City Hall. This requires motivation from those involved, openness to new partnerships, space to create the context for formal and informal dialogue, and finding a common objective and interests. If the conditions are not met, and the communication is not optimal, the support and knowledge needed from colleagues, stakeholders, and communities to implement and scale-up NBS are endangered.

The process by which collaboration and communication is so vital for innovation and NBS implementation and scaling-up is two-fold:by using job-relevant information and through interacting with others, employees can evaluate the usefulness of their new ideas and solutions, and it provides cognitive resources for creativity. Not only that the employees can evaluate the usefulness of their ideas, but when they exchange with others inside and outside their departments or work units, they are exposed to different ideas and ways of thinking.

For short, collaboration and communication relate to strengthening relationships between individuals, understanding more clearly each other's work (individuals and departments) and a better flow of information between the employees involved in NBS projects from other departments.

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Individuals are more engaged and willing to collaborate between different departments and stakeholders when they are personally motivated to work together on projects which require bringing together multiple roles, expertise and functions. Therefore, is important to clarify „what it is in for" all the members (permanent or transitory) of the team working on NBS project, shifting the focus from working on „to do lists" (compulsory, not that engaging and exciting) on cooperation based on individual motivation.

Recommendations:

- Be genuine and curious about the people you work with
- Uncover areas of commonality: learn more about the people you depend on in NBS project and let them know you
- Speak directly and openly about any concern in your team and with colleagues from other departments.

Extended methodology

Quantitative Procedure:

Interdepartmental communication scale from Communication Satisfaction Questionnaire (Downs & Hazen, 1977; Zwijze-Koning & de Jong, 2007), assess the perceived quality of information exchange flow, and the perceived satisfaction with the information received – what is communicated and if it is satisfactory or not.

Scale: 7-point Likert Scale; 1 = Entirely disagree, 2= Mostly disagree, 3 = Somewhat disagree, 4 = Neither agree nor disagree, 5 = Somewhat Agree, 6 = Mostly agree, 7 = Entirely agree

1. The amount of information exchanged between the departments is about right.
2. All departments respect and admire each other's work.
3. Communication with employees in other departments is accurate and free-flowing.
4. I receive information about the changes in the organization.
5. I receive information about departmental policies and goals.
6. People in my organization have great ability as communicators.

Scoring: summative scale

Information exchange measure for communication in and out of the work unit (Subramaniam & Youndt, 2005). The four-item scale taps into information exchanges with people inside and outside one's unit within the organization, assessing the perceived quality of information exchange flow (Gong, Cheung, Wang, & Huang, 2012).

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Scale: 7-point Likert Scale, from 1 = Strongly disagree to 7 =Strongly agree

1. Me and my colleagues are skilled at collaborating with each other to diagnose and solve problems.
2. I share information with my colleagues and learn from one another.
3. I interact and exchange ideas with people from different areas of the company.
4. Me and my colleagues apply knowledge from one area of the company to problems and opportunities that arise in another.

Scoring: summative scale

Workplace Relational Civility Scale (WRC; Di Fabio & Gori, 2016) assesses three dimensions: relational decency (RD) at work (decency in relationships, respect for the self and others, assertiveness, ability to express convictions, relational capacity), relational culture (RCu) at work (politeness, kindness, high level of education, courteousness), and relational readiness (RR) at work (sensibility towards others, ability to read the emotions of others, concern for others, delicacy, empathy, compassion, and attention to the reactions of others).

Instructions:

Characteristics that affect the ways of being and relating to people are shown below. The statements refer to people's interpersonal relationships at work. In the first part (A), please describe how you acted or behaved toward others (colleagues and /or superiors) over the past 3 months. In the second part (B), please describe how others (colleagues and superiors) acted or behaved toward you (in the past 3months). Please mark with a cross all statements expressing your preference, choosing from: (1) Not at all; (2) A little; (3) Somewhat; (4) A lot; (5) A great deal. Please complete Parts A and B.

Scale: the response format adopted is a Likert scale with five answer options (1=not at all; 2=a little; 3=somewhat; 4=a lot; 5=a great deal).

(A) Me with others

1. I was able to express my values and my beliefs calmly to others.
2. I was able to express my point of view without being disrespectful toward others.
3. I respected the opinions of others.
4. I communicated my disagreement with others without being aggressive.
5. I was polite toward others.
6. I was generally kind toward others.
7. I always behaved mannerly toward others.
8. I made comments that valorized others.
9. I was interested in the emotional condition of others.
10. I was sensitive about the difficulties of others.
11. I realized the effect of my words on others.
12. I was attentive to the needs of others.
13. I easily recognized the feelings of others.

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B) The others with me

1. Others were able to express their values and their beliefs calmly to me.
2. Others were able to express their point of view without being disrespectful toward me.
3. Others respected my opinions.
4. Others communicated their disagreement with me without being aggressive.
5. Others were polite toward me.
6. Others were generally kind toward me.
7. Others always behaved mannerly toward me.
8. Others made comments that valorized me.
9. Others were interested in my emotional condition.
10. Others were sensitive about my difficulties.
11. Others realized the effect of their words on me.
12. Others was attentive to my needs.
13. Others easily recognized my feelings.

Scoring: summative scale.

Part (A)
Relational decency, items: 1,2,3,4
Relational culture, items: 5,6,7,8
Relational readiness, items: 9,10,11,12,13
Part (B)
Relational decency, items: 1,2,3,4
Relational culture, items: 5,6,7,8
Relational readiness, items: 9,10,11,12,13

Interaction Outside Organization scale from The Work Design Questionnaire (WDQ; Morgeson & Humphrey, 2006), reflects the extent to which the job requires employees to interact and communicate with individuals external to the organization, assessing the satisfaction with the quantity of information flow outside the organization. This interaction could take place with suppliers, customers, or any other external entity.

Scale: 5-point strongly disagree (1) to strongly agree scale (5).

1. The job requires spending a great deal of time with people outside my organization.
2. The job involves interaction with people who are not members of my organization.
3. On the job, I frequently communicate with people who do not work for the same organization as I do.
4. The job involves a great deal of interaction with people outside my organization.

Scoring: summative scale

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Quantitative Procedure:

Evaluation of the processes involved in internal and external communication related to shared interests, knowing and understanding each others' vision related to NBS project development and implementation

- What are your interests in NBS project? How about your team? How about the interests of other departments in the NBS project?
- What are the personal benefits (sharing/gaining knowledge and ideas, personal development in terms of knowledge and skills, etc.) of engaging in the NBS project, for you, your team and other colleagues from other departments? What they gain from their involvement?
- What you, your team members or colleagues from other departments enjoy the most to do (how to contribute) (share knowledge, acquire knowledge, mentor, coach, have more or diverse responsibilities, etc.)?

Evaluation of the processes involved in internal and external communication related to existing practices in the organization

- Are there the prerequisites of working together in place?
- Does your team work effectively with other team members or with other teams? What can be improved in this respect?
- Does your team seek best practice from other teams and other parts of the City Hall?
- Does different departments' members respect and trust each other? How trust can be ensured between different departments in your City Hall?

Evaluation of the processes involved in internal and external communication related to shared values, resources/capabilities, group decision-making, and needs.

- What value do we create together?
- What capabilities do we need to deliver the value?
- How will we resolve conflicts and make decisions while maintaining trust?
- What do we need from each other to succeed?

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PARTICIPATORY PLANNING AND GOVERNANCE INDICATORS - CORE

CONNECTING NATURE

Collaboration between organizational members

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Description

The interactions between individuals from the same departments or different departments based on sharing knowledge and resources with the purpose of working together to achieve collective goals.

Methodology

Quantitative Procedure: Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)

Selective Tool: Team Boosting behavior scale (Fortuin, van Mierlo, Bakker, Petrou & Demerouti, 2021) assesses individual interpersonal behaviours in teams, characterized by dominance and energy, positive expressivity, and a social focus. This scale has 18 items, and three dimensions: mood enhancing behaviours, energizing behaviours and uniting behaviours, with 6 items each.

Level of expertise

. Quantitative data collection requires no expertise
. Qualitative data collection requires medium level expertise in social science research

Data collection

Required data

. Essential: questionnaire scores
. Desirable: qualitative data on organizational processes

Data input type

Quantitative and qualitative, if participatory data collection methods, and/or participatory action research are opted for

Data collection frequency

Aligned with NBS implementation and timing of targeted objectives

Participatory process

Participatory methods (e.g., participatory data collection methods, and/or participatory action research) may be applied to collect data on nature-based solutions organizational processes

Connection with SDGs

Goal 9
Goal 11
Goal 16
Goal 17

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Extended description

Traditionally, many organizations have suffered from what is often called the functional silos problem. The issue is more prevalent in institutions and an organization under state's governing, as it implies a more bureaucratic and formalized way of work (Bundred, 2006; Hansen, 2009). This problem occurs when members of functional units stay focused on matters internal to the function and minimize their interactions with members of other functions. In this sense, the functional departments create artificial boundaries or "silos" that discourage rather than encourage more integrative thinking and active coordination with other parts of the organization. Therefore, there is a need to improve the collaboration between members of the same work team, even if these members are from different departments of the organization.

The establishment of new work-related collaborations, inter- and intra-departments, stakeholders and broad communities is required in NBS projects, as different knowledge and perspectives are needed to be aligned in the City Hall. This requires motivation from those involved, openness to new partnerships, space to create the context for formal and informal dialogue, and finding a common objective and interests. If the conditions are not met, the support and knowledge needed from colleagues, stakeholders, and communities to implement and scale-up NBS are endangered. Moreover, the ability to build and manage relationships within the organization is a "necessary antecedent" for the organization to build successful inter-organizational collaborations (Hillebrand & Biemans, 2004).

Collaboration between employees and departments refers to the interaction and sharing of information, knowledge, ideas, and resources between employees from the same department as well as from different departments, including the creation of space for interaction and sharing (i.e., regular meetings, conferences, intranet, etc.). More specifically, inter-departmental collaboration represents the willingness of departments to work together, having mutual understanding, having a common vision, sharing resources, and achieving collective goals. Thus, collaboration relates to strengthening relationships between individuals, understanding more clearly each other's work (individuals and departments) and a better flow of information between the employees involved in NBS projects from other departments.

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Individuals are more engaged and willing to collaborate between different departments and stakeholders when they are personally motivated to work together on projects which require bringing together multiple roles, expertise and functions. Therefore, is important to clarify „what it is in for" all the members (permanent or transitory) of the team working on NBS project, shifting the focus from working on „to do lists" (compulsory, not that engaging and exciting) on cooperation based on individual motivation.
"Collaborative communities encourage people to continually apply their unique talents to group projects -- and to become motivated by a collective mission, not just personal gain or the intrinsic pleasures of autonomous creativity" (Adler, Heckser, & Prusak, 2011). Collaboration allows organizations to leverage employees' talents, to coordinate knowledge, and to respond more quickly to global opportunities (Weiss & Hughes, 2005). Inter-departmental collaboration was found to increase organizations' innovation performance (Cuijpers, Guenter, & Hussinger, 2011), the number of potentially useful ideas (Milliken & Martins, 1996), workforce flexibility (Troy, Hirunyawipada, & Paswan, 2008), and possibly it stimulates new ways of thinking and working (Wenger, 1999). Moreover, organizations that rely on collaborative work were able to reduce error rates by 75% over six years and achieve a 10% annual increase in productivity and also making products more innovative and technologically sophisticated (Adler, Heckser, & Prusak, 2011). Although considered one of the most important precursors of innovations coming out of the organization, collaboration at inter-departmental level is not without drawbacks (Swink & Song, 2007), being associated with less efficient decision-making and conflicts over technical issues and resources (Troy et al., 2008), as well as with project delays (Cuijpers et al., 2011). It was found that intra-organizational collaboration is potentially disruptive of existing structures and practice, challenging the existing models or systems of leadership and management (Diamond & Rush, 2012). Thus, it is important to be aware of and balance the costs and benefits of inter-departmental collaboration across innovation project portfolio.
Collaborative work environments are built through organizational efforts towards (1) defining and building a shared purpose, (2) cultivating an ethic of contribution, (3) developing processes that enable people to work together in flexible but disciplined projects, and (4) creating an infrastructure in which collaboration is valued and rewarded. Thus, for an organization to foster efficient inter-departmental collaboration, it needs to develop new organizational capabilities to create the atmosphere of trust as well as the coordinating mechanism to make it scalable. In order to do so, the organizations need to learn to:

- Define a shared purpose that guides what people at all levels of the organization are trying to achieve together

- Shared purpose - a description of what everyone in the organization is trying to do
- A long and complex process
- Multidimensional, practical, and constantly enriched in debates about concrete problems

- Cultivate an ethic of contribution in which the highest value is accorded to people who look beyond their specific roles and advance the common purpose

- Looking beyond their specific roles and advance the common purpose
- Going beyond one's formal responsibilities to solve broader problems, not just applying greater effort
- Emphasizes working within the group and eliciting the best contributions from each member for the common good

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Trust in collaborative communities arises from the degree each member believes the other members of the group are able and willing to further the shared purpose.

- Develop scalable procedures for coordinating people's efforts so that process-management activities become truly interdependent

- The key coordinating mechanism of a collaborative community is a process for aligning the shared purpose within the projects (techniques: kaizen, process mapping and formal protocols for brainstorming, participatory meeting management and decision making with multiple stakeholders

- Create an infrastructure in which individuals spheres of influence overlap and collaboration is both valued and rewarded

Extended methodology

Team Boosting behavior scale (Fortuin, van Mierlo, Bakker, Petrou & Demerouti, 2021)

Mood-enhancing behaviors
1 I make sure that there is laughter in our team
2 In my team, I make jokes
3 I try to entertain my team mates
4 I add a cheerful touch to our team
5 I break a negative atmosphere in our team with a joke
6 I tell stories when we meet

Energizing behaviors
7 I take initial action to set our team in motion
8 I am the first to take action in our team
9 In our team, I set the example by doing
10 I propose new ideas for our team
11 I stimulate our team
12 I convince my team mates to join the action

Uniting behaviors
13 I strengthen the ties between my team mates
14 I strengthen the ties with my team mates
15 I respond to my fellow team members' need
16 I approach my team mates in a personal way
17 I assess the atmosphere in our team
18 I involve all my team mates in what we do

Summative scale. The items are scored on a seven-point frequency scale: 0 = (almost) never, 6 = (almost) always.

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PARTICIPATORY PLANNING AND GOVERNANCE INDICATORS - FEATURE

CONNECTING NATURE

Procedural fairness

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Description

The extent to which the decision-making process was perceived as fair by the participants.

Methodology

Qualitative Procedure:

Selective Tool 1: case study methodology – semi-structured interviews, case study analysis, participant and non-participant observation

Selective Tool 2: participatory data collections methods, such as focus groups

Quantitative Procedure:
Selective Tool: 6 items at measuring procedural fairness

Level of expertise

. Quantitative data collection requires no expertise

. Qualitative data collection requires medium level expertise in social science research

Data collection

Required data

. Essential: questionnaire scoring on procedural fairness

. Desirable: qualitative data on reasons and causes for procedural fairness or lack hereof, and implications for how the process and results are perceived

Data input type

Quantitative and qualitative, if participatory data collection methods, and/or participatory action research are opted for

Data collection frequency

Annually; at minimum, before and after NBS implementation

Participatory process

Participatory methods may be applied to collect information about perceptions of diverse actors to reveal challenges and opportunities, power dynamics, as well as reflect on outcomes with regards to procedural fairness

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

Extended description

Procedural fairness refers to “the fairness of the processes used to produce [...] decisions” (Lauber et al, 2010). It is important in relation to participatory planning and governance of nature-based solutions as it gives interested or affected parties the opportunity to take any legitimate role in a decision-making process. This implies that all stakeholders have equal opportunities to express and defend opinions as well as to request evidence and justification from other stakeholders (Rosentröm and Kyllönen 2007; Laktic and Malovrh 2018). Procedural fairness requires basic ground rules (e.g. on timetables, procedures) that ensure legitimacy, accountability and inclusivity of the process, treat everyone as equals and give clarity to how discussions and data are treated can build trust (Ferlie et al. 2019; Frantzeskaki 2019; Ferretti et al. 2018; Chatterton et al. 2018).

Strengths and weaknesses

+ Easy measure of how process was organized and perceived by participants
- Simplified measure with little information about what kind of groups were involved, and what it implies for roles, relationships and empowerment

Extended methodology

Responses to survey questions using a five-point Likert scale based on (Lauber et al 2010): strongly disagree, disagree, neutral, agree, and strongly agree

(1) Impartiality: whether organising party/decision-maker was impartial during the process
(2) Honesty: whether organising party/decision-maker was honest during the process
(3) Equal opportunity: whether all participants had an equal opportunity to participate in the process
(4) Representation: whether all viewpoints were adequately represented during the process
(5) Voice: whether all participants had the opportunity to voice their opinions during the process
(6) Influence: whether participants influenced the final decision

Connection with SDGs

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Goal 11
Goal 16
Goal 17

References

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PARTICIPATORY PLANNING AND GOVERNANCE INDICATORS - FEATURE

CONNECTING NATURE

Facilitation skills for co-production

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Description

Facilitation skills for co-production refer to the availability of personal qualities of an individual to lead groups through key meetings and gatherings towards intended outcomes.

Methodology

Qualitative Procedure:
Selective Tool 1: participatory data collection methods, such as focus groups, semi-structured interviews, case study analysis, participant and non-participant observation
Selective Tool 2: when looking for a candidate who could facilitate a co-production process, s/he could use the questionnaire as a self-assessment. In addition, the employees could look at their past experiences, who they have worked with and for specific facilitation training.

Quantitative Procedure:
Selective Tool: 8 items at measuring respondents' perception of their/the facilitator's facilitation skills for co-production

Level of expertise

. Quantitative data collection requires no expertise

. Qualitative data collection (case study and participatory methodology, for example) requires medium level expertise in social science research

Data collection

Required data

. Essential: Questionnaire of facilitation (self-)assessment

. Desirable: Qualitative data on how the facilitation was perceived, what could be done better and how it affected the co-production process/outcomes

Data input type

Quantitative and qualitative, if participatory data collection methods, and/or participatory action research are opted for

Data collection frequency

Aligned with NBS implementation, especially the implementation of workshops.
Assessment can be done before or after workshops. Before: (self-)assessment of facilitator and/or initiating/organising team. After: Let each participant complete the facilitation assessment questionnaire at the end of a workshop.

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Extended description

Workshops and interactive meetings with multiple actors are at the core of co-production processes. A workshop can be generally viewed as a structured meeting that is led by a facilitator and that emphasises participatory involvement (Weyers and Rankin 2007). One of the salient characteristics of such events is that the facilitator plays a pivotal role in their ultimate success or failure. Thus, facilitation skills are a key precondition for co-production (Reed and Abernethy 2018; Djenontin and Meadow 2018; Chatterton et al. 2018).

Facilitation is about making meetings participative and more effective: “Facilitation is the art of leading people through processes towards agreed-upon objectives in a manner that encourages participation, ownership and creativity by all those involved” (Cserti 2019). Bens (2009) defines a facilitator as someone “who contributes structure and process to interactions so groups are able to function effectively and make high-quality decisions. A helper and enabler whose goal is to support others as they achieve exceptional performance.”

A facilitator has a wide range of tasks to perform in co-production processes. Cserti (2019) summarise three key roles of facilitators: A ‘catalyst’ that makes possible the transformation of input (ideas, opinions) to desired outcome without being an active part of the conversation itself. A ‘conductor’ of an orchestra who synchronises all participants, optimally guiding the use of their instruments toward the desired result – a harmonic musical expression of the musicians’ complex interactions, creativity, and expertise. A ‘coach’ who helps the group form a constructive way of working together, identify its needs and wishes, and reach the outcome they would jointly like to achieve.

In line with these roles, facilitation skills are complex (ibid.; Bens 2009). They involve skills for designing, planning and preparing a workshop or meeting (e.g. asking the right questions, process design, agenda planning, communication with stakeholders), running the process and facilitating a workshop or meeting (e.g. creating an inclusive environment, communicating clear guidelines and instructions, empathy, active listening, consensus-building, managing time, flexibility), and recording results (e.g. recording and keeping visible agreements made, points of consensus, decisions and action item).

Participatory process

Participatory methods (e.g., focus groups, participatory data collection methods, and/or participatory action research) may be applied to collect community-relevant information on facilitator’s skills and how it affected their perception of the co-production process.

Connection with SDGs

Goal 9
Goal 10
Goal 11
Goal 16

References

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For co-production processes, facilitation skills need to be ensured by those initiating and guiding the process; they can emerge from the initiating team (e.g. city government) or participants composition, they can be mobilised elsewhere (e.g. by hiring a professional facilitator), and fostered by institutional support (e.g. professional development training) (Hölscher et al. 2018; Djenontin and Meadow 2018). 'Skill' in this context can be defined as "personal qualities" (Green 2013 p. 5). Skills are acquired through both experience and training and represent the power of an individual to make that knowledge investment productive in the job or in real life (OECD 2017).

Bens (2009) developed a Facilitator Self-Assessment checklist that can be applied for different levels of skills and allows people identify both current competences and skills they need to acquire most. Level I consists of core skills required to lead routine discussions and manage meetings effectively. Level II consists of the ability to design complex decision processes and manage difficult situation. Level III involves designing and leading activities that are part of a planned change efforts. The questions for each level cover different levels of facilitation skills related to the ability to manage a group discussion, effective meeting design, fostering participation and making clear and accurate summaries and notes.

Weyers and Rankin (2007) developed a Facilitation Assessment Scale (FAS) to measure and analyse the impact of the facilitator and facilitation process on the outcomes of workshops. The assessment questionnaire consists of four compulsory categories of effective workshop facilitation: Firstly, the facilitator's aptitude focuses on the extent to which they can be viewed as both content experts and as skilled interpreters and promoters of the data and ideas. Secondly, his/her presentation skills refer to the presentation of data and the facilitator's ability to involve participants. Thirdly, the learning process assesses the quality of the communication and appropriateness of the material and data that was communicated. Fourthly, the workshop context focuses on the contextual elements that might have a positive or negative impact on goal attainment, including quality of the venue, the learning material and educational aids and tools.

Strengths and weaknesses

+ Provides detailed overview of available facilitation skills and whether additional skills need to be sourced

+ Can give explanation into impact of co-production processes

+ Easy to implement ex ante and ex post (e.g. selection of questions integrated in questionnaire after a workshop)

- Risk of stakeholder fatigue when there are multiple questionnaires after a workshop

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Extended methodology

Items aimed at assessing facilitator's skills (Weyers and Rankin 2007; Bens 2009).

1) The facilitator is knowledgeable about the subjects/issues to be/that were covered

2) The facilitator can/could link the material to the participants' level of knowledge

3) The facilitator is/was skilled at active listening, paraphrasing, questioning and summarising key points.

4) The facilitator is/was able to manage time and maintain a good pace.

5) The facilitator knows/knew techniques for encouraging active participation and generating ideas.

6) The facilitator encourages/encouraged participant involvement.

7) The facilitator is/was able to organise workshops

8) The facilitator is/was able to help a group achieve consensus and gain closure even in polarized situations.

Response options:

a. Strongly disagree
b. Disagree
c. Not sure
d. Agree
e. Strongly agree

The Indicator will be equal to the sum of the average number of each question (sum of responses per question divided by respondents), divided by number of questions. The facilitator skills can be evaluated using a five-point Likert scale (Weyers and Rankin 2007):

Poor — 1 — 2 — 3 — 4 — 5 — Very good / excellent

1. Poor (1 – 1.79)
2. Fair (1.8 – 2.59)
3. Average (2.6 – 3.39)
4. Good (3.4 – 4.19)
5. Very good / excellent (4.2 – 5)

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PARTICIPATORY PLANNING AND GOVERNANCE INDICATORS - FEATURE

CONNECTING NATURE

Strategic alignment

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Description

Strategic alignment means that nature-based solutions are strategically linked to the city governments' goals, decisions, actions and resources, and vice versa.

Methodology

Qualitative Procedure:
Selective Tool 1: case study methodology – semistructured interviews, case study analysis, participant and non-participant observation
Selective Tool 2: participatory data collections methods, focus groups, collaborative participatory data collection, semistructured interviews

Quantitative Procedure:
Selective Tool: 3 items at measuring respondents' perception of strategic alignment

Level of expertise

. Methodology and data analysis requires medium level expertise in the city's policy and governance processes and conditions

. Quantitative data collection requires no expertise

. Qualitative data collection requires medium level expertise in social science research and the city's policy and governance processes and conditions

Data collection

Required data

. Essential: Questionnaire of strategic alignment assessment
. Desirable: Data on processes of strategic alignment, perceived opportunities and barriers for collaboration and alignment, and outcomes related to a nature-based solution implementation in a city

Data input type

Quantitative and qualitative, if participatory data collection methods, and/or participatory action research are opted for

Data collection frequency

Aligned with NBS implementation and timing of targeted objectives

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Extended description

As complex societal problems cannot be addressed through siloed approaches but require the active search for synergies in terms of how different problems relate to one another and how addressing one problem might reproduce another. Multifunctional solutions like nature-based solutions offer the potential to address multiple policy priorities and goals simultaneously. Therefore, the governance of nature-based solutions cannot be separated from urban governance of other policy priorities and goals such as mobility, health, climate resilience etc., and requires cross-sectoral, multi-scale and inclusive approaches in terms of who is best placed to ensure development, delivery and ongoing sustainability of the nature-based solution and how effective governance networks can be fostered (Buijs et al., 2018; Pauleit et al., 2016; Kabisch et al., 2017). This requires alignment with broader social, political and business priorities and goals of a city and of a city region.

Strategic alignment is widely discussed in organisation and business management literatures. In general terms, strategic alignment is the process of aligning an organisation's decisions, actions and resources such that they support the achievement of strategic goals. In other words, it means that all elements of an organisation, and each activity and project are arranged in such a way as to best support the fulfilment of its long-term purpose (Trevor and Varcoe 2016). Strategic alignment also means fit between an organisation's strategic priorities and its environment (Walter et al. 2012). In relation to urban governance, Hölscher et al. (2019) define strategic alignment as the orientation towards shared sustainability and resilience goals in the long-term that provide common reference points for concerted action and helps to move from problem-focused to solution-oriented approaches. This means, essentially, that every task should be able to be linked to an overarching vision.

Strategic alignment with regard to nature-based solutions means that nature-based solutions are strategically linked to the city governments' goals, strategies and agendas, and vice versa. Strategic alignment has many benefits for nature-based solutions implementation. Overall, several studies found that the level of strategic alignment of an organisation explains a large degree of the difference in performance between organisations (Al Khalifa 2016; Walter et al. 2012).

Positioning individual issues and priorities such as nature-based solutions within broader goals serves to identify synergies and trade-offs across sectors, scales and time (McPhearson et al. 2017). As complex societal problems cannot be addressed through siloed approaches but require the active search for synergies in terms of how different problems relate to one another and how addressing one problem might reproduce another. Multifunctional solutions like nature-based solutions offer the potential to address multiple policy priorities and goals simultaneously.

Participatory process

Participatory methods may be applied to collect data on nature-based solutions governance processes to reveal challenges and opportunities for strategic alignment, as well as to reflect on outcomes.

Connection with SDGs

Goal 9
Goal 11
Goal 13
Goal 16
Goal 17

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Therefore, the governance of nature-based solutions cannot be separated from urban governance of other policy priorities and goals such as mobility, health, climate resilience etc., and requires cross-sectoral, multi-scale and inclusive approaches in terms of who is best placed to ensure development, delivery and ongoing sustainability of the nature-based solution and how effective governance networks can be fostered (Buijs et al., 2018; Pauleit et al., 2016; Kabisch et al., 2017). This requires alignment with broader social, political and business priorities and goals of a city and of a city region.

Strategic alignment is widely discussed in organisation and business management literatures. In general terms, strategic alignment is the process of aligning an organisation's decisions, actions and resources such that they support the achievement of strategic goals. In other words, it means that all elements of an organisation, and each activity and project are arranged in such a way as to best support the fulfilment of its long-term purpose (Trevor and Varcoe 2016). Strategic alignment also means fit between an organisation's strategic priorities and its environment (Walter et al. 2012). In relation to urban governance, Hölscher et al. (2019) define strategic alignment as the orientation towards shared sustainability and resilience goals in the long-term that provide common reference points for concerted action and helps to move from problem-focused to solution-oriented approaches. This means, essentially, that every task should be able to be linked to an overarching vision.

Strategic alignment with regard to nature-based solutions means that nature-based solutions are strategically linked to the city governments' goals, strategies and agendas, and vice versa. Strategic alignment has many benefits for nature-based solutions implementation. Overall, several studies found that the level of strategic alignment of an organisation explains a large degree of the difference in performance between organisations (Al Khalifa 2016; Walter et al. 2012). Positioning individual issues and priorities such as nature-based solutions within broader goals serves to identify synergies and trade-offs across sectors, scales and time (McPhearson et al. 2017). It also helps local policymakers or practitioners build the case and communicate how nature-based solutions can generate wider benefit. In turn, this will help build alliances with different partners who have different interests (Loorbach et al. 2015). For example, a nature-based solution could support people getting healthier by providing space for exercise and help to increase biodiversity and stormwater management. These benefits could be communicated to organisations working to improve residents health and wellbeing, to those working to improve the natural environment, to maintaining open spaces and to development planning organisations.

Strategic alignment builds on buy-in and support (Walter et al. 2012). Thus, it needs to be co-created to ensure that all interests are heard, increase ownership, deal with conflicts, safeguard against overlooking issues of social justice and mediate good compatibility between knowledge and different contexts (Loorbach et al. 2015; Wittmayer et al. 2014). Strategic alignment also implies that resources are deployed towards new behaviours, processes and practices (and way from older, less strategic areas) (Myler 2013). This means that a vision is also translated into (political, financial and institutional) incentives and conditions for working towards the vision, and that the contribution of each project to the strategic goals is evaluated. This involves incorporating long-term and multi-scale thinking into decision-making, implementation processes and performance reviews as well as decisively clarifying costs, benefits and responsibilities at systemic levels for taking up action in alignment with the long-term goals (Loorbach 2014; Hodson and Marvin 2010).

Trevor and Varcoe (2016) present a simple test to evaluate strategic alignment of an organization, based on two crucial dimensions: (1) Fit between strategy and organisation's purpose. Purpose is what the organisation is trying to achieve. Strategy is how the organisation will achieve it. Purpose is enduring – it is the north star towards which the company should point. Strategy involves choices about what activities and projects to do to achieve the purpose. In relation to nature-based solutions, this question means how well the nature-based solutions are linked to fulfil the city's goals. (2) Organisational support for the achievement of the strategy. This includes all of the required capabilities, resources (including human), and management systems necessary to implement the strategy. If nature-based solutions are a key strategic priority, the organisational structure needs to facilitate this. To maintain strategic alignment, an organisation's people, culture, structure and processes have to flex and change as the strategy itself shifts.

CONNECTING NATURE

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

Strengths and weaknesses

+ Innovative measure to check how well an organization (city government) is supportive of nature-based solutions and able to establish synergies across different priorities and departments

- Complex concept and measure, followed by considerable limitations in quality of measurement

- Measure does not account for identifying synergies and trade-offs between nature-based solutions and priorities and goals

Extended methodology

Items aimed at strategic alignment (based on Trevor and Varcoe 2016; Hölscher et al. 2019).

1.Nature-based solutions are linked to other city strategic priorities, strategies and goals.

2.The city government supports the implementation of nature-based solutions by providing and investing in capabilities, resources and management systems necessary.

3.The city government supports innovative ways to cooperate, pool resources and build synergies across sectors for nature-based solutions implementation.

Response options:

a.Strongly disagree
b.Disagree
c.Not sure
d.Agree
e.Strongly agree

The Indicator will be equal to the sum of the average number of each question (sum of responses per question divided by respondents), divided by number of questions. The strategic alignment can be evaluated using a five-point Likert scale:

Poor — 1 — 2 — 3 — 4 — 5 — Very good / excellent

1. Poor (1 – 1.79)
2. Fair (1.8 – 2.59)
3. Average (2.6 – 3.39)
4. Good (3.4 – 4.19)
5. Very good / excellent (4.2 – 5)

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PARTICIPATORY PLANNING AND GOVERNANCE INDICATORS - FEATURE

CONNECTING NATURE

Governance innovations for participatory governance

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Description

Governance innovations for participatory governance refer to the creation of those novel mechanisms, processes and rules that support participation.

Methodology

Qualitative Procedure:
Selective Tool: participatory data collection methods, such as focus groups, semi-structured interviews, case study analysis, participant and non-participant observation

Quantitative Procedure:
Selective Tool: 1 item at measuring respondents' perception of governance innovations.

Level of expertise

. Methodology and data analysis requires medium level expertise in social science research and the governance of the city in question

. Quantitative data collection requires no expertise

. Qualitative data collection requires medium level expertise in social science research

Data collection

Required data

. Essential: questionnaire to collect different perspectives on the governance innovations for participation

. Desirable: qualitative data on nature-based solutions governance processes to reveal challenges and opportunities for governance innovations, as well as reflect on outcomes.

Data input type

Quantitative and qualitative, if participatory data collection methods, and/or participatory action research are opted for

Data collection frequency

Aligned with NBS implementation and timing of targeted objectives

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

Extended description

The planning, delivery and stewarding of nature-based solutions requires participatory governance approaches (Frantzeskaki et al. 2020; Hölscher et al. 2019; van der Jagt et al. 2017). Participatory governance will enhance the social support of the nature-based solution and awareness of its changing functional design over time. Moreover, the engagement of a large variety of actors is also a matter of creating economic insurance, where different financial resources can be activated to sustain functionality over time. For these reasons, participatory approaches to co-design, co-creation and co-management ('co-co-co') of NBS are advocated (European Commission, 2016). For example, Buijs et al. (2018) show how active citizens can significantly contribute to urban green infrastructure planning and implementation, for example by developing large parks with volunteers or designing a network of green corridors. As they show a large diversity of citizen-local government collaborations and different pathways for upscaling innovative discourses and practices, they term this 'mosaic governance' that can facilitate a combination of long-term, more formalised strategic approaches with more incremental approaches that correspond with localised, fragmented and informal efforts of local communities.

Generally speaking, participatory governance is embodied in processes that empower citizens to participate in public decision-making. Around the world, a growing number of local governments are experimenting with innovative practices that seek to expand the space and mechanisms for citizen participation in governance processes beyond elections.

Putting in place the mechanisms for participatory governance requires governance innovations. In general terms, governance innovations can be diverse – they refer to novel rules, regulations and approaches, as well as skills, competencies and structural capacities of actors to address a public problem in more efficacious and effective ways, lead to better policy outcomes and enhance legitimacy (Hertie School of Governance 2017; Anheier and Korreck 2013; OECD 2018). Governance innovations that facilitate participatory governance refer to the creation of those novel conditions (e.g. resources, cognitive, social and normative capacities) that support collaborative decision-making (cf. Kerkhoff and Lebel 2015; Wyborn 2015).

Participatory process

Participatory methods (e.g., participatory data collection methods, and/or participatory action research) may be applied to collect data on nature-based solutions governance processes to reveal challenges and opportunities for governance innovations, as well as reflect on outcomes.

Connection with SDGs

Goal 9
Goal 11
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Goal 17

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Innovative governance conditions for participatory governance refer to the provision and institutionalisation of participatory mechanisms in city governance. Pieterse (2000) provides an overview of participatory governance methods and tools, including citizen juries, referenda and participatory diagnostic tools. Similarly, the Hertie School of Governance (2017) identifies several democratic innovations, which refer to new mechanisms for citizens' engagement in decision-making (e.g. referendums, citizens' assemblies, participatory budgeting). The institutionalisation of participatory governance will depend on political will, establishing an accurate picture of the variety of urban stakeholders and formulating a policy on participation for the municipality (Pieterse 2000). Such conditions also include the extent to which information is readily available and citizens are aware of opportunities for participation (Pieterse 2000; Galukande-Kiganda and Boitumelo Mzini 2019).

In addition, several authors identify capacities for co-production, or co-productive capacities (Hölscher et al. 2019b; Kerkhoff and Lebel 2015; Wyborn 2015). Next to strategies, programmes and goals that are in place, these capacities also address which type of knowledge and skills existing for participatory governance. For example, Frantzeskaki et al. (2020) highlight that for collaborative decision-making, specific skills such as negotiation and collaboration are needed.

Strengths and weaknesses

+ Provides insights into extent to which nature-based solutions process contributed to governance innovations for particiaption

- Difficult to assess and data collection could be time consuming

- Does not address the quality of participation and issues of power and equity

Extended methodology

A five-point Likert scale can be used to evaluate the extent of governance innovations for participation:

No innovations for participation — 1 — 2 — 3 — 4 — 5 — Very high level of innovation for participation

1. Not innovation: No innovation for participation
2. Low level of innovation: Participation is considered as hoc in few governance activities in projects of the city
3. Moderate level of innovation: Participation is embedded in city strategies, but not required as part of city projects and activities
4. High level of innovation: Participation is embedded in city strategies and required for any type of city project and activity
5. Very high level of innovation: Participation is embedded and mainstreamed in city strategies, projects and activities and capacities (knowledge, skills) for ensuring good participation are supported and ensured

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PARTICIPATORY PLANNING AND GOVERNANCE INDICATORS - FEATURE

CONNECTING NATURE

Community involvement in NBS implementation

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Adapted from Task Force Indicator "Community involvement in NBS implementation" (UNaLab): L. Wendling, V. Rinta-Hiiro, M. Dubovik, A. Laikari, J. Jermakka, Z. Fatima, M. zu-Castell Rüdenhausen, A. Ascenso, A. I. Miranda, P. Roebeling, R. Martins, R, Mendonça

Description

The extent to which citizens and other stakeholders have been involved in the delivery and stewardship of nature-based solutions.

Methodology

Qualitative Procedure:
Selective Tool: participatory data collection methods, such as focus groups, semi-structured interviews, case study analysis, participant and non-participant observation

Quantitative Procedure:
Selective Tool: 1 item at measuring respondents' perception of community involvement in NBS implementation

Level of expertise

. Quantitative data collection requires no expertise
. Qualitative data collection requires medium level expertise in psycho-social research

Data collection

Required data

. Essential: information on public participation processes during the implementation phase of NBS project
. Desirable: qualitative data on community involvement and perceptions of diverse actors to reveal challenges and opportunities, power dynamics, as well as reflect on outcomes.

Data input type

Quantitative and qualitative, if narrative studies, participatory data collection methods, and/or participatory action research are opted for

Data collection frequency

Annually; at minimum, before and after NBS implementation

Participatory process

Participatory methods may be applied to collect community-relevant information on community involvement and perceptions of diverse actors to reveal challenges and opportunities, power dynamics, as well as reflect on outcomes

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

Extended description

Traditionally, most urban green initiatives were, and still are, initiated and governed by local governments (Sekulova and Anguelovski 2017; Dushkova and Haase 2020). However, public agencies tend to withdraw in long-term managing and financing, making interventions one-off measures and leaving them without maintenance funds (Nesshöver et al. 2017; Young and McPherson 2013). Meanwhile, the number of green spaces, especially community gardens, initiated and managed in a bottom-up fashion is increasing (Buijs et al. 2018; Nesshöver et al. 2017). There is a wide range of opportunities for citizens, nongovernmental organisations, businesses, and other stakeholders to become involved in co-creating, co-implementing and co-management nature-based solutions.
Community involvement in nature-based solutions planning, delivery and stewardship can enhance mutual ownership over the nature-based solution, and increase the salience of the solution because it reflects different needs, priorities, norms and values characterising specific local neighbourhoods (Kabisch et al. 2017; Pauleit et al. 2017).

Strengths and weaknesses

+ Easy measure of community involvement that gives indications on levels of ownership and collaboration established through a nature-based solution project
- Simplified measure with little information about social equity and differences in what groups are involved, how the collaboration is set up and what implies for roles, relationships and power dynamics between different actors

Extended methodology

A five-point Likert scale based on Arnstein's (1969) ladder of citizen participation can be used to evaluate the extent of citizen's power in determining the implementation program:

No involvement — 1 — 2 — 3 — 4 — 5 — High involvement

1. Not at all: No community involvement.
2. Inform and consult: An essentially complete project is presented to the community for information only, or in order to receive community feedback. The consultation process primarily seeks community acceptance of the project at the implementation stage.
3. Advise: The project implementation is done by a project team. Community actors are invited to ask questions, provide feedback and give advice. Based on this input the planners may alter how the project is implemented.
4. Partnership: Community actors are invited by project managers and developers to participate in the implementation process. The local community is able to influence the implementation process.
5. Community self-development: The project planners empower community actors to manage the project implementation and evaluate the results.

Connection with SDGs

Goal 10
Goal 11
Goal 16
Goal 17

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CONNECTING NATURE

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PARTICIPATORY PLANNING AND GOVERNANCE INDICATORS - FEATURE

CONNECTING NATURE

Reflexivity - time for reflection

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Description

This indicator is defined as the sum of the time invested in reflection on how implementing nature-based solutions contributes to changing its context (e.g. the spatial planning system) by taking a step back from the daily activities to look the bigger picture. Reflection time is defined in terms of time spent participating in reflection meetings and sessions as well as learning about the methods and tools (e.g. reflexive monitoring tools, but other methods can be applied as well) that support this process and practicing with the skills.

Methodology

Quantitative Procedure:
counting number of hours spent on reflection per week/month

Scale of measurement
Hours or days per week or month

Level of expertise

. Tracking time for reflection require medium level expertise in terms of understanding of reflexivity
. Quantitative data collection (listing activities and counting number of hours/days spent on them) requires no expertise
. Qualitative data collection (facilitation of participatory sessions to identify reflexive learning outcomes) require high expertise in action-research and basic training in participatory data collection, appreciative inquiry and critical analysis.

Data collection

Required data

Essential: timesheets of total amount of time spent on reflection
Desirable:
. Overview of reflexive monitoring activities
. How much time was spent per activity
. Reflection about barriers and opportunities for, gains etc. from spending time reflecting

Data input type

Quantitative (time for reflection) and qualitative if data on barriers, opportunities etc. are considered.

Data collection frequency

Monthly

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Extended description

Conventional governance, policy-making, planning and project management approaches aim to optimize existing processes starting from pre-defined problems and solutions. After a problem or solution is identified a monitoring and evaluation process is designed by selecting suitable evaluation methods. For example, by selecting indicators to measure the effectiveness of the project(s) after implementation. This is done by experts and requires a low level of participation of other actors. Implementing large-scale nature-based solutions is a complex process that includes innovative processes that are hard to oversee and plan on beforehand. Therefore, time for reflection is needed to create room for collaborative learning, experimentation and adaptations during the planning, delivery and stewardship phase of the nature-based solution.

Time for reflection can contribute to increase the reflexivity of the actors when they reflect on how their daily activities contribute to systemic change and why this is needed. Beers & van Mierlo (2017) studied the relation between learning in and reflexivity of system innovation (in this case a nature-based solution) and argue that collective reflection on changing context helps to increase its reflexivity. Time for reflection includes the interweaving of knowledge (the what), actions (the how) and relations (the who) (Beers, Van Mierlo, & Hoes, 2016). It builds on a shared experience of involved actors in how to identify and overcome barriers or use opportunities. Specifically, spending time on reflection means constantly reflecting about who is involved, who isn't, and who benefits and who doesn't, as well as adaptability to respond to new insights, demands and needs (Chatterton, Owen, Cutter, Dymski, & Unsworth, 2018; Ferlie, Pegan, Pluchinotta, & Shaw, 2019; Muñoz-Erickson et al., 2017). Thus, investing time in reflection is not only about generating new insights, but also on how these insights are influencing their context.

Time for reflection can be facilitated through various methods. Reflexive monitoring is a concrete method to structure and guide the learning process embodied in time for reflection in the context of system innovations such as nature-based solutions (Sol, van der Wal, Beers, & Wals, 2018; van Mierlo, 2012; van Mierlo, Arkesteijn, & Leeuwis, 2010; van Mierlo, Leeuwis, Smits, & Woolthuis, 2010).

Participatory process

Participatory methods (e.g., narrative studies, participatory data collection methods, and/or participatory action research) are crucial for this indicator to collect relevant information on reflexive learning processes and how these affect the context and different types of actors.

Connection with SDGs

Goal 9
Goal 11
Goal 16
Goal 17

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Reflexive monitoring allows to capture and assess processes of learning-by-doing and doing-by-learning in terms of goals achievement, adopt lessons learned into new or existing structures, strategies or practices and identify needs for adaptation (Beers & van Mierlo, 2017; Dentoni, Bitzer, & Pascucci, 2016; Frantzeskaki, Kabisch, & McPhearson, 2016). Herewith, reflexive monitoring can also involve developing institutional mechanisms to include outside actors to be part of the design and review process (Muñoz-Erickson, Miller, & Miller, 2017).

Strengths and weaknesses

+ It is easy to track the time simply given to reflection

- The amount of time does not say anything about the quality of how the time was spend (e.g. what was the result in terms of learning, skills of insights though analysis and quality of reflexive learning outcomes)

Extended methodology

Qualitative procedure

Tool 1: reflexive monitoring tools (see e.g. van Mierlo, Regeer, et al., 2010) or the Connecting Nature reflexive monitoring process for cities (Lodder et al., 2019).

Tool 2: case study methodology – semi-structured interviews, case study analysis, participant and non-participant observation.

Tool 3: participatory data collections methods, such as focus groups

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PARTICIPATORY PLANNING AND GOVERNANCE INDICATORS - FEATURE

CONNECTING NATURE

Strategic approach

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Description

The strategic approaches and strategic processes centre on a cycle of learning from experiences, of evaluating actions, of aligning the people with the decisions, of choosing the right time to act and of taking action. The cycle is continuous through learning, alignment, timing and action.

Methodology

Quantitative Procedure: Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)

Selective Tool: The Strategic Leadership Questionnaire, Operational efficiency and Organizational creativity scales (Duursema, 2013).

Level of expertise

. Quantitative data collection requires no expertise
. Qualitative data collection requires medium level expertise in social science research

Data collection

Required data

. Essential: questionnaire scores
. Desirable: qualitative data on organizational processes

Data input type

Quantitative and qualitative, if participatory data collection methods, and/or participatory action research are opted for

Data collection frequency

Aligned with NBS implementation and timing of targeted objectives

Participatory process

Participatory methods (e.g., participatory data collection methods, and/or participatory action research) may be applied to collect data on nature-based solutions organizational processes

Connection with SDGs

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Extended description

Leadership is the process of influencing others to understand and agree about what needs to be done and how to do it, and the process of facilitating individual and collective efforts to accomplish shared objectives related to NBS project creation, implementation and scaling-up. The leaders, at all levels of the organization, have an essential role in supporting change that accompanies NBS projects, offering a clear vision for the future, engaging and motivating employees, making sure that the tasks related to NBS implementation are not building up the workload, and offering support for the resources needed to implement and scale-up NBS. Individual at all levels can develop and use leadership abilities and skills in order to offer a clear vision for the future to colleagues and stakeholders, to empower them to act accordingly to the shared vision, objectives and strategies.
By definition, strategic leadership links the strategic function with the leadership function, or in other words, defining the vision and moral purpose of the organization and translate them into action. It means building the direction as well as the capacity for the organization to achieve a directional shift or change (Davies & Davies, 2012). The strategic leader has a key role in creating urgency and momentum for organizational learning, thinking broadly and imaginatively, and working with others to help them to think about how to use models to support improvement (Davies & Davies, 2004).

Specifically, strategic leaders involve themselves in five key activities:

- Direction setting
- Translating strategy into action
- Aligning the people and the organization to the strategy
- Determining effective intervention points
- Developing strategic capabilities (Davies & Davies, 2004).

Direction setting refers to the function of strategy, translating the vision and moral purpose into action. It is a delivery mechanism for building the direction and the capacity for the organization to achieve that directional shift or change. The function of strategy is therefore to translate the moral purpose and vision of the organization into reality.

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Translating strategy into action means to develop strategic and organizational processes. Davies (2002) suggested a four-stage ABCD approach of translating strategy into action: articulate (strategy), build (images, metaphors, experiences), create (dialogues – conversations, cognitive/mental map, shared understanding), and define (strategic perspective, outcome orientation, formal plans). The articulation of the strategy can take place orally through strategic conversations, the strategic purpose and direction of the organization can be transmitted; written in the form of formal statements or plans, distinguishable from operational short term plans; or structural which refers to the organizational infrastructure supporting and developing the strategic approach (e.g., strategy meetings). After setting the direction, it is necessary to build a common understanding of what is possible through shared images and experiences. This entails awakening the people in the organization to alternative perspectives and experiences, as well as building an agreement with the organization that continuation of the current way of working is inadequate if the organization wants to be effective in the future. The leadership needs to create through dialogue a shared conceptual or mental map of the future. What strategic leaders are able to do is step back and articulate the main features of the current organization, and lead others to define what the future of the organization will be. This may involve the process of enhancing participation and motivation to understand the necessity for change, through strategic conversations by (Davies, 2003). Significantly it draws on high-quality information both from within and outside the organization which is part of the strategic analysis that underpins the dialogue. Then, the leadership needs to define desired outcomes and the stages of achieving those outcomes. This will establish a clear picture of the new strategic architecture of the organization. Tichy and Sharman (1993) identify this stage as involving the identification of a series of projects that need to be undertaken to move the organization from its current to its future state.

Aligning the people and the organization to the strategy entails processes such as strategic conversations, strategic participation, strategic motivation, as well as building capacity.

Determining effective intervention points (the right things at the right time) is a leadership challenge manifested in not only knowing what and knowing how but also knowing when (Boal and Hooijberg, 2001) and, as important, knowing what not to do (Kaplan and Norton, 2001).

Developing strategic capabilities refers to those abilities, skills and competencies to support the development of the organization, such as creativity in problem solving, teamwork, or a problem solving culture within the organization rather than a blame culture for the staff.

If leaders are also to be strategic leaders they need to understand themselves, their organization and others in the organizational community and the wider community and to draw from multiple sources of wisdom. They need to be context focused (contextual wisdom). Strategic leaders need to care about others in order to want to involve them and need self-confidence in order to involve them. They need to be people-focused (people wisdom). Individuals can make a difference but strength comes from staff working together to achieve the same goals (Barth, 1990). If people are working together, decisions and implementation of decisions will tend to be better as there will be a higher level of trust and morale. Finally, they need to both understand and lead the processes and approaches that contribute to a strategic approach (procedural wisdom).

Related to the skills and abilities for strategic leaders, some were identified in the literature, such as imagination and creativity (Mintzberg, 1994), the capability to deal with new challenges and pressures, awareness and knowledge, the capability to think outside the box and to connect and create ideas (Goldman, Scott, & Follman, 2012), or to see cognitively distant occasions (Gavetti, 2011).

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Thus, a strategic leader is responsible with envisioning what a desirable future for the organization will be and create strategic conversations to build viable and exciting pathways to create the capacity to achieve that future. Strategy can be seen as providing a set of compass points and direction against which short-term activities can be set, with the specification that long term and short term should not be seen as sequential (i.e., one done first and then the other), but rather they should be seen as parallel action with one informing the other. Strategic leaders are also often “change champions”, building coalitions of staff to create conditions for change embedding new ways of working. These leaders also face unique challenges, such as in managing conflict or living with the ambiguity of knowing what they want to achieve but not being able to move towards it as quickly as they would like (Davies & Davies, 2012).

Extended methodology

The Strategic Leadership Questionnaire, Operational efficiency and Organizational creativity scales (Duursema, 2013)

Operational Efficiency is defined as preparation of detailed plans on how to achieve a critical duty, whereas Organizational Creativity is defined as suggesting new ideas that may convince the clients of the entity. Data can be collected by means of an online/offline questionnaire (survey) asking participants to rate the degree to which a set of behavioral strategic leadership statements suits the respondent’s behavior. The behavioral items are scored along a continuous 5 points Likert-type scale, with answers ranging from “totally agree” (score 5) to “totally disagree” (score 1).

Operational efficiency:
1. Checks work progress against agreed-upon objectives
2. Formulates clear objectives
3. Reassures time schedules and deadlines
4. Works according to a structured system in order to ensure an optimal service level
5. Plans in detail how to accomplish an important task

Organizational creativity:
1. Consciously makes room for creativity
2. Stimulates thinking outside-the-box
3. Facilitates the experimentation with new ideas
4. Engenders proactive behavior
5. Persuasively sells new ideas in the organization

Response options: totally disagree (1), disagree (2), in-between (3), agree (4), totally agree (5).

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PARTICIPATORY PLANNING AND GOVERNANCE INDICATORS - FEATURE

CONNECTING NATURE

Task significance

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Description

Task significance is the degree to which work is perceived as impacting other people's well-being, both inside and outside of an organization. Task significance, along with skill variety and task identity, is proposed to generate a sense of meaningfulness at work, which then leads to internal work motivation, high job performance, job satisfaction, and low absenteeism/turnover (Allan, Duffy, & Collisson, 2018).

Methodology

Quantitative Procedure: Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)

Selective Tool 1: Task Significance Subscale from Work Design Questionnaire (Morgeson & Humphrey, 2006 each.

Selective Tool 2: Task Significance (Grant, 2008)

Level of expertise

. Quantitative data collection requires no expertise
. Qualitative data collection requires medium level expertise in social science research

Data collection

Required data

. Essential: questionnaire scores
. Desirable: qualitative data on organizational processes

Data input type

Quantitative and qualitative, if participatory data collection methods, and/or participatory action research are opted for

Data collection frequency

Aligned with NBS implementation and timing of targeted objectives

Participatory process

Participatory methods (e.g., participatory data collection methods, and/or participatory action research) may be applied to collect data on nature-based solutions organizational processes

Connection with SDGs

Goal 9
Goal 11
Goal 16
Goal 17

CONNECTING NATURE

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Extended description

Resources help fostering a healthy working environment and mitigate the effects of stressors on performance and wellbeing. Resources such support between colleagues, meaningful and challenging work and feedback can help individuals and institutional development. Importantly, fostering good collaboration and communication within and across teams helps building a strategy against the pullbacks of silo thinking and move towards an authentic collaborative approach.

Task significance is the feeling that one's work impacts others in a significant manner (Grant 2007; 2008). When individuals perceive their work has value to others (i.e., high task significance), they are likely to experience personal achievement as a result of better performance, thus engaging in continuous efforts to improve work processes (Marinova et al., 2015).

The job characteristics model (JCM; Hackman & Oldman, 1976) identifies the conditions necessary for people to become intrinsically motivated and have high work performance. The model suggests that five job dimensions (skill variety, task identity, task significance, autonomy, and feedback) lead to three critical psychological states (meaningfulness, responsibility, and knowledge of results), which then lead to positive outcomes, such as high work performance and job satisfaction. Studies support the assumptions of this model, showingthat perceiving one's work as improving the welfare of others leads to experiencing one's work as meaningful (Allan, 2017), and that meaningful work fully mediate the relation between task significance job performance (Allan, Duffy, & Collisson, 2018).

Thus, task significance is the degree to which a job influences the lives or work of others, whether inside or outside the organization (Hackman & Oldham, 1975). People who feel their work is meaningful and/or serves some greater social or communal good report better psychological adjustment, report greater well-being (Arnold, Turner, Barling, Kelloway, & McKee, 2007), and report greater job satisfaction (Kamdron, 2005), view their work as more central and important (Harpaz & Fu, 2002), place higher value on work (Nord, Brief, Atieh, & Doherty, 1990), have positive emotional/affective attachments to the organization (Mesa,Llopis, Granero, & Peñuela, 2019), and also report greater work unit cohesion (Sparks & Schenk, 2001).

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A growing body of research using controlled, experimental studies is also showing that task significance manipulations can increase job performance and productivity. Grant (2007) proposed a model for prosocial work motivation, which argued that the extent to which people feel motivated to engage in prosocial work is influenced by the nature of the contact with the people who benefit from their work. Specifically, greater frequency, physical proximity, duration, depth, and breadth of contact with beneficiaries in a work environment result in greater perceived task significance by employees, which subsequently increases job performance. Grant (2007) tested this model with call center employees who sought scholarship money from university alumni. Employees who interacted directly with students who benefitted from the scholarship donations earned 3 times as many donations from alumni than employees who did not interact with students beforehand. Grant (2008) replicated and extended these findings with life-guards and different samples of fund-raising callers. He observed that increases in task significance led to large increases in objective job performance.
As task significance is a subjective impression that is socially constructed through interpersonal interactions, employees' perception of it can be shaped through direct contact with the beneficiaries of their efforts, which in turn enhances employees' awareness of the effect of their actions (Hu et al., 2015), motivating employees to invest additional time and energy in their work to achieve positive outcomes for others. Thus, favouring direct interactions with beneficiaries (either colleagues or people beyond the organisations), or gathering data highlighting the positive impact that employees' activities have on third parties can be effective interventions to help employees perceive that their actions are positively related and connected to other people (Mesa et al., 2019).

Extended methodology

Task Significance Subscale - Work Design Questionnaire (Morgeson & Humphrey, 2006)

A self-report measure intended to capture the degree to which individuals perceive their work as impacting other, within or outside their organization.

The questions in this section concern characteristics of the job itself. Using the scale below, please indicate the extent to which you agree with each statement. Remember to think only about your job itself, rather than your reactions to the job.

Scale: 5-point scale ranging from 1 strongly disagree) to 5 (strongly agree)

1. The results of my work are likely to significantly affect the lives of other people.
2. The job itself is very significant and important in the broader scheme of things.
3. The job has a large impact on people outside the organization.
4. The work performed on the job has a significant impact on people outside the organization.

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Task Significance (Grant, 2008)

4 items adapted from existing measures of task significance (Hackman & Oldham, 1975; Morgeson & Humphrey, 2006)

Scale: 5-point scale ranging from 1 strongly disagree) to 5 (strongly agree)

1. My job provides opportunities to substantially improve the welfare of other people.
2. Other people can be positively affected by how well my job gets done.
3. My job enhances the welfare of others.
4. My job provides opportunities to have positive impact on others on a regular basis.

Scoring. Sum up the scores (responses) on each item. Higher scores indicate greater perceived task significance.

Qualitative Procedure:

Adapted key questions from quantitative procedures and tools to assess the process with the stakeholders.

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PARTICIPATORY PLANNING AND GOVERNANCE INDICATORS - FEATURE

CONNECTING NATURE

Dealing with uncertainty

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Description

Individual level: uncertainty tolerance: the set of negative and positive psychological responses—cognitive, emotional, and behavioral—provoked by the conscious awareness of ignorance about particular aspects of the world (Hillen et al., 2017). For short, when we think of uncertainty in the workplace, we understand it as "knowing and adopting new organizational practices".

Methodology

Quantitative Procedure: Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)
4 selective tools

Qualitative Procedure: adapted key questions from quantitative procedures and tools could be linked to semi-structured interviews, focus groups etc.

Level of expertise

. Quantitative data collection requires no expertise
. Qualitative data collection requires medium level expertise in social science research

Data collection

Required data

. Essential: questionnaire scores
. Desirable: qualitative data on organizational processes

Data input type

Quantitative and qualitative, if participatory data collection methods, and/or participatory action research are opted for

Data collection frequency

Aligned with NBS implementation and timing of targeted objectives

Participatory process

Participatory methods (e.g., participatory data collection methods, and/or participatory action research) may be applied to collect data on nature-based solutions organizational processes

Connection with SDGs

Goal 9 Goal 16
Goal 11 Goal 17

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Extended description

Dealing with uncertainity at organizational level
Clampitt, Williams and Korenak (2000) provided a matrix of uncertainty management as a result of the contrast between two dimensions of the employees' uncertainty tolerance level and the willingness of organization to embrace uncertainty. Some organizations manage uncertainty by embracing it, openly discussing changes in their customer base and competitors, fostering innovation, encouraging meaningful dialogue, and de-emphasizing rigid planning processes. Others, however, tend to avoid uncertainty by following inflexible control procedures or policies, ignoring changing circumstances, overly relying on success recipes, and artificially bolstering organizational successes by overlooking shortcomings (Clampitt & Williams, 2005).

By the late 1970s, researchers estimated that the typical organization experienced one substantial change at least every four or five years (Kotter & Schelesinger, 1979). This is especially true not only for private organizations and businesses, but also for public institutions which recurrently are dealing with changes produced by social processes and dynamics or changes resulted from power shifts due to elections. Today, the rate of change has accelerated so that organizations are experiencing sequential as well as simultaneous change (Conner, 1993). In other words, uncertainty abounds, while the presumption of certainty fades. Thus, organizations and leaders can no longer ignore uncertainty and assume they operate in stable environments. Since most organizations operate in changing, complex, confusing, and ambiguous environments, shunning uncertainty creates an organizational conundrum.

Uncertainty refers to the extent to which variability exists within a specific context and the degree to which an individual is able to predict that variability (Scott, 1990). It is consisting primarily of three components: (a) lack of clarity in information; (b) long time spans of waiting before receiving definitive feedback; and (c) general uncertainty of causal relationships (Lawrence & Lorsch, 1967). In the context of work, uncertainty has been studied in terms of the extent to which the work environment is predictable, stable, and structured (Champoux, 2011). Certainty of one's environment, therefore, is related in part to the predictability, stability, and clarity of the employees' interactions with others (colleagues, superiors, organization as a whole).

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Uncertainty in organizations can be viewed as well as assessed through two different levels: organizational and individual. At the organizational level, a lack of specific work resources is one of the sources of uncertainty, namely role ambiguity and role conflict (Schmidt, Roesler, Kusserow, & Rau, 2014). At the individual level, the focus is on the persons' tendency to consider the possibility of a negative event occurring as unacceptable, irrespective of the probability of occurrence (Buhr & Dugas, 2002; Carleton, Norton, & Asmundson, 2007). In other words, uncertainty in organizational context can be on one hand, a result of organizational resources, and more specifically, a lack thereof, and on the other hand, a result of employees' tendencies, cognitive and/or emotional orientation (Furnham, 1995).

Role ambiguity results from a lack of information and therefore missing clarity in a specific job position, which leads employees to be uncertain about their role, job objectives, and associated responsibilities. The expectations of colleagues and supervisors also may be unclear. Role conflict arises when a person is confronted with two or more conflicting or opposing role expectations and the corresponding role demands of others. This leads to a psychological conflict in which the employee will not be capable of fulfilling every expected role at the same time. Role stress can occur in every job position, irrespective if the organization is in a process of change or not (Kahn, Wolfe, Quinn, Snoek, & Rosenthal, 1964). Both concepts contain an objective and a subjective component. Objective role ambiguity refers to certain conditions in the individual's environment, whereas subjective role ambiguity relates to the amount of ambiguity that a person in this environment perceives. The same concept can be applied to role conflict. Objective role conflict results from the environment (e.g., involved persons), whereas subjective role conflict is expressed in the psychological conflict that results from environmental conditions (Kahn et al., 1964).

(In)Tolerance for uncertainty was conceptualized as a continuum between certainty and uncertainty (Clampitt, Williams, & Korenak, 2000). Thus, the degree to which individuals embrace uncertainty describes their tolerance level. Intolerance of uncertainty can be seen as a filter through which individuals view their environment, which might be best described as a predisposition to find uncertainty unacceptable (Buhr & Dugas, 2002). Intolerance of uncertainty is related to worry, to obsessions/compulsions, and weakly related to panic sensations (Dugas et al., 2001), as well as performance on moderately ambiguous tasks (Ladouceur, Talbot, & Dugas, 1997).

It is intolerance of the notion that negative events may occur and there is no definitive way of predicting such events. Indeed, people who are intolerant of uncertainty are likely to interpret all ambiguous information as threatening (Heydayati, Dugas, Buhr, & Francis, 2003), contributing to significant somatic stress reactions (e.g., increased heart rate and blood pressure; Greco & Roger, 2001; 2003). High intolerance of uncertainty may impair problem-solving skills, leading to inaction and avoidance of ambiguous situations (Dugas, Freeston, & Ladoucer, 1997).

Individuals, as well as organizations, are uncomfortable with uncertainty due to the inherent lack of predictability, complexity, and "unsurity", and try to reduce the amount of uncertainty. Individuals naturally experience uncertainty and seek to reduce it by gathering more information (Berger & Calabrese, 1975). It is "wanting knowledge rather than lacking knowledge (that) promotes information seeking in initial encounters with others" (Kellerman & Reynolds, 1990). For example, newly hired employees use a variety of overt and covert techniques to reduce certain types of organizational uncertainty (Teboul, 1994). In times of major change, many employees seek information, even rumors, to decrease their uncertainty levels (Clampitt & Berk, 1996; Eisenberg & Riley, 1988). While some individuals try to reduce uncertainty by seeking information, others minimize or ignore uncertainty by focusing their attention elsewhere. Other individuals acknowledge uncertainty but become fearful and disempowered (Hillen, Gutheil, Strout, Smets, & Han, 2017). Likewise, most organizations seek out tools that reduce the perceived uncertainty, such as strategic planning, cost-benefit analysis and the like, which are designed to categorize, quantify, and reify the future (Clampitt et al., 2000).

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Extended methodology

Intolerance of Uncertainty Scale (IUS-27; Freeston et al., 1994)

Includes 27 items relating to the idea that uncertainty is unacceptable, reflects badly on a person, and leads to frustration, stress, and the inability to take action. This instrument was developed to assess emotional, cognitive, and behavioural reactions to ambiguous situations, implications of being uncertain, and attempts to control the future. Buhr and Dugas (2002) found support for a four-factor structure: were Uncertainty Leading to Inability to Act (10 items), Uncertainty Being Stressful and Upsetting (12 items), Unexpected Events are Negative and Should be Avoided (7 items), and Uncertainty Being Unfair (5 items). Items are scored on a Likert scale ranging from 1 (not at all characteristic of me) to 5 (entirely characteristic of me), yielding possible scores from 27 to 135. Higher scores are indicative of a higher intolerance towards uncertainty. Despite the reported multifactor structures, the IUS is most commonly summed as a total scale score (Antony, Orsillo, & Roemer, 2001).

1 Uncertainty stops me from having a strong opinion.
2 Being uncertain means that a person is disorganized.
3 Uncertainty makes life intolerable.
4 It's unfair having no guarantees in life.
5 My mind can't be relaxed if I don't know what will happen tomorrow.
6 Uncertainty makes me uneasy, anxious, or stressed.
7 Unforeseen events upset me greatly.
8 It frustrates me not having all the information I need.
9 Uncertainty keeps me from living a full life.
10 One should always look ahead so as to avoid surprises.
11 A small unforeseen event can spoil everything, even with the best planning.
12 When it's time to act, uncertainty paralyses me.
13 Being uncertain means that I am not first rate.
14 When I am uncertain, I can't go forward.
15 When I am uncertain, I can't function very well.
16 Unlike me, others seem to know where they are going with their lives.
17 Uncertainty makes me vulnerable, unhappy, or sad.
18 I always want to know what the future has in store for me.
19 I can't stand being taken by surprise.
20 The smallest doubt can stop me from acting.
21 I should be able to organize everything in advance.
22 Being uncertain means that I lack confidence.
23 I think it's unfair that other people seem to be sure about their future.
24 Uncertainty keeps me from sleeping soundly.
25 I must get away from all uncertain situations.
26 The ambiguities in life stress me.
27 I can't stand being undecided about my future.

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Intolerance of Uncertainty Scale (IUS-12; Carleton, Norton, & Asmundson, 2007)

It is the short form of the 27 items Intolerance of Uncertainty Scale. This instrument was found to have two factors, namely Inhibitory Anxiety, describing uncertainty inhibiting action or experience, and Prospective Anxiety, involving fear and anxiety based on future events. However, the recommendation is that IUS-12 scores should be based on a simple sum of items, with the total score being used for evaluating a general intolerance of uncertainty. Scoring is done exactly as for the longer version of this instrument, with the same Likert scale ranging from 1 to 5.

Prospective Anxiety factor:
1. Unforeseen events upset me greatly.
2. It frustrates me not having all the information I need.
3. One should always look ahead so as to avoid surprises.
4. A small, unforeseen event can spoil everything, even with the best of planning.
5. I always want to know what the future has in store for me.
6. I can't stand being taken by surprise.
7. I should be able to organize everything in advance.

Inhibitory Anxiety factor:
8. Uncertainty keeps me from living a full life.
9. When it's time to act, uncertainty paralyses me.
10. When I am uncertain I can't function very well.
11. The smallest doubt can stop me from acting.
12. I must get away from all uncertain situations.

Uncertainty Management Matrix (UMM) (Clampitt, Williams, & Korenak, 2000)

It owas developed to help explain the process by which employees and organizations manage uncertainty, and thus accounts both for individual tolerance to uncertainty through Personal Uncertainty Scale, as well as for organizational tolerance to uncertainty, through Work Environment Uncertainty Scale. Personal Uncertainty Scale contains 11 items reflecting three dimensions of an employee's desire to embrace uncertainty: perceptual, process, and outcome. A high score indicates a greater tolerance for uncertainty and is viewed as more desirable. Work Environment Uncertainty Scale contains 11 items that reflect three underlying dimensions of an organization's desire to embrace uncertainty: perceptual, expressed and outcome. A high score indicates the organization has a greater tolerance for uncertainty and is viewed as more desirable. Employees first must choose whether or not to perceive the uncertainty contained in the environment (i.e., Perceptual Uncertainty). Next, they must decide if they are going to process it (i.e., Process Uncertainty). Finally, they must determine how to respond to uncertain situations (i.e., Outcome Uncertainty). No doubt, these stages often occur concurrently. But the stages are not necessarily contingent on one another. The research suggests that a person may not be very adept at perceiving uncertainty but may, in fact, process it rather well. Likewise, a person might be skillful at perceiving the uncertainty in the environment but be helpless in dealing with it. Likewise, organizations may decide to avoid or embrace the latent environmental uncertainty (i.e., Perceptual Uncertainty). They may choose to encourage or discourage discussion of uncertainty (i.e., Expressed Uncertainty).

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Finally, they may choose how to act in the uncertain environment (i.e., Outcome Uncertainty). The ability to effectively manage any single aspect of this process is not necessarily related to the others. Some organizations are quite effective at perceiving uncertainty but do not know how to appropriately respond. Others put on conceptual blinders to uncertainty but respond quite well once they are aware of it. Both positive and negative statements on both scales are measured on a 1 (strongly disagree) to 7 (strongly agree) Likert type scale. Most respondents can complete the scales in less than 10 minutes. Scoring is relatively straightforward, by calculating the response scores on each item and adding them.

Personal Uncertainty Scale
4. I'm comfortable making a decision on my gut instincts. (Process)
8. I'm comfortable using my intuition to make a decision. (Process)
13. I'm willing to make a decision based on a hunch.(Process)
25. I'm comfortable deciding on the spur-of-the-moment.(Process)
7. When I start a project, I need to know exactly where I'll end up. (-) (Outcome)
24. I need a definite sense of direction for a project. (-)(Outcome)
12. I need to know the specific outcome before starting a task. (-) . (Outcome)
21. I don't need a detailed plan when working on a project.(Outcome)
15. I actively try to look at situations from different perspectives. (Perceptual)
9. I'm always on the lookout for new ideas to address problems. (Perceptual)
5. I actively look for signs that the situation is changing. (Perceptual)

Work Environment Uncertainty Scale
35. My organization doesn't want employees to admit that they are unsure about something. (-) (Expressed)
31. In my organization, being unsure about something is a sign of weakness. (-)(Expressed)
43. My organization doesn't encourage employees to discuss their doubts about a project. (-) (Expressed)
50. My organization discourages employees from talking about their misgivings. (-) (Expressed)
33. My organization wants to know all the alternatives before making a decision. (Perceptual)
45. My organization actively looks for signs that the situation is changing. (Perceptual)
29. My organization is always on the lookout for new ideas to address problems. (Perceptual)
37. Even after my organization makes a decision, it will re-evaluate the decision when the situation changes. (Perceptual)
49. My organization wants precise plans before starting a job or project. (-) (Outcome)
47. My organization doesn't need a detailed plan when working on a project. (Outcome)
40. My organization needs to know the specific outcome before starting a project. (-)(Outcome)

! Items marked with (-) are reversed coded items!

16-item intolerance of ambiguity scale (Budner, 1962)

It could be also used to assess personal tolerance to ambiguous situations. This scale uses the definition of ambiguity in terms of three fundamental aspects of a stimulus: novelty, complexity, and insolubility. Items are scored on a 7 point Likert scale ranging from 1 (strongly disagree) to 7 (strongly agree). High scores indicate a greater intolerance for ambiguity. To score the instrument, the even-numbered items must be reverse-scored. That is: 7 = 1, 6 = 2, 5 = 3, 4 = 4, 3 = 5, 2 = 6, 1 = 7.

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After reversing the even-numbered items, sum the scores for all 16 items to get your total score. The three subscales can also be computed to reveal the major source of intolerance of ambiguity – novelty (N), complexity (C), or insolubility (I). Here are the items associated with each subscale: Novelty score (2, 9, 11, 13), Complexity score (4, 5, 6, 7, 8, 10, 14, 15, 16), and Insolubility score (1, 3, 12).

1 An expert who doesn't come up with a definite answer probably doesn't know too much
2 I would like to live in a foreign country for awhile
3 There is really no such things as a problem that can't be solved
4 People who fit their lives to a schedule probably miss most of the joy of living
5 A good job is one where what is to be done and how it is to be done are always clear
6 It is more fun to tackle a complicated problem than to solve a simple one
7 In the long run, it is possible to get more done by tackling small, simple problems rather than large and complicated ones
8 Often the most interesting and stimulating people are those who don't mind being different and original
9 What we are used to is always preferable to what is unfamiliar
10 People who insist upon a yes or no answer just don't know how complicated things really are
11 A person who leads an even, regular life in which few surprises or unexpected happenings arise really has a lot to be grateful for
12 Many of our most important decisions are based on insufficient information
13 I like parties where I know most of the people more than ones where all or most of the people are complete strangers
14 Teachers who hand out vague assignments given one a chance to show initiative and originality
15 The sooner we all acquire similar values and ideals the better
16 A good teacher is one who makes you wonder about your way of looking at things

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PARTICIPATORY PLANNING AND GOVERNANCE INDICATORS - FEATURE

CONNECTING NATURE

Support, appreciation of merits and diversity, recognition

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Description

Organizational support refers to the degree of organizational encouragement andresource capability regardingthe work environmentof employees (Eisenberger et al.,1990). In Connecting Nature, we see support, appreciation of merits and diversity, recognition as a culture of respect, acknowledgement and integration of diverse perspectives and expertise.

Methodology

Quantitative Procedure: Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)
5 selective tools

Qualitative Procedure: adapted key questions from quantitative procedures and tools to assess the process with the stakeholders

Level of expertise

. Quantitative data collection requires no expertise
. Qualitative data collection requires medium level expertise in social science research

Data collection

Required data

. Essential: questionnaire scores
. Desirable: qualitative data on organizational processes

Data input type

Quantitative and qualitative, if participatory data collection methods, and/or participatory action research are opted for

Data collection frequency

Aligned with NBS implementation and timing of targeted objectives

Participatory process

Participatory methods (e.g., participatory data collection methods, and/or participatory action research) may be applied to collect data on nature-based solutions organizational processes

Connection with SDGs

Goal 9
Goal 11
Goal 16
Goal 17

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Extended description

According to organizational support theory (Eisenberger, Huntington, Hutchison, & Sowa, 1986), the development of perceived organizational support is encouraged by employees' tendency to assign the organization humanlike characteristics. In other words, in order to determine theorganization's readiness toreward increased work effortand to meetsocio emotional needs, employeesdevelop global beliefs concerningthe extent towhich the organization values theircontributions and caresabout their well-being.Perceived organizational support (POS) is also valued as assurance that aid will be available from the organization when it is needed to carry out one's job effectively and to deal with stressful situations (George, Reed, Ballard, Colin, & Fielding, 1993). Organizational support theory also addresses the psychological processes underlying consequences of POS. First, POS should produce a felt obligation to care about the organization's welfare and to help the organization reach its objectives. Second, the caring, approval, and respect connoted by POS should fulfil socio emotional needs, leading workers to incorporate organizational membership and role status into their social identity. Third, POS should strengthen employees' beliefs that the organization recognizes and rewards increased performance (i.e., performance-reward expectancies). These processes should have favourable outcomes both for employees (e.g., increased job satisfaction and heightened positive mood) and for the organization (e.g., increased affective commitment and performance, reduced turnover). A series of longitudinal studies examined the interrelationships among work experiences, POS, affective commitment, and employee turnover. The results showed that the organizational rewards, procedural justice, and supervisor support had unique associations with POS and that POS mediated the relationship between these work experiences and affective commitment (Rhoades, Eisenberger, & Armeli, 2001).
A meta-analysis reviewing more than 70 studies indicated that 3 major categories of beneficial treatment received by employees (i.e., fairness, supervisor support, and organizational rewards and favourable job conditions) were associated with POS. POS, in turn, was related to outcomes favourable to employees (e.g., job satisfaction, positive mood) and the organization (e.g., affective commitment, performance, and lessened withdrawal behavior).

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These relationships depended on processes assumed by organizational support theory: employees' belief that the organization's actions were discretionary, feeling of obligation to aid the organization, fulfilment of socio emotional needs, and performance-reward expectancies (Rhoades & Eisenberger, 2002). A more recent meta-analysis by Riggle, Edmonson, and Hansen (2009) confirmed the attitudinal outcome findings with more studies. Another meta-analysis tested the antecedents and outcomes of POS, as well as the processes proposed by organizational support theory. The findings showed that POS strongly depends on employees' attributions concerning the organization's intent behind their receipt of favourable or unfavourable treatment. In turn, POS initiates a social exchange process wherein employees feel obligated to help the organization achieve its goals and objectives and expect that increased efforts on the organization's behalf will lead to greater rewards. POS also fulfils socio-emotional needs, resulting in greater identification and commitment to the organization, an increased desire to help the organization succeed, and greater psychological well-being. Taken as a whole, the results suggest that POS plays a central role in the employee–organization relationship and has important implications for improving employees' well-being and favourable orientation toward the organization (Kurtessis et al., 2017).

Because perceived support should strengthen affective attachments to the organization, employees with high perceived support would be predicted to express stronger feelings of affiliation and loyalty. Perceived support should also be associated with expectancies that high performance would produce material rewards, such as pay and promotion, as well as social rewards, including approval and recognition. These assumptions were tested and found to be true: employees who perceived high support expressed stronger feelings of affiliation and loyalty to the organization (employee commitment) and showed more voluntary and anonymous suggestions for improving the organization (employee innovation) (Eisenberger, Fasolo, & Davis-LaMastro, 1990).

Organizations can communicate the desirability of innovative work behaviours by suitably rewarding such behaviors (James et al., 1977). Moreover, organizations can support and facilitate knowledge sharing, as a prerequisite of individual employee innovation behaviours (Darroch, 2005). Lin (2006) proposed and tested a model where organizational support, understood as the degree of organizational encouragement and resource capability regarding knowledge sharing, influences the intentionto facilitate knowledge sharingthrough organizational perceptionsof innovation characteristics (perceived relative advantage and compatibility) and interpersonal trust. The results showed that organizational support is positively associated with organizational perceptions of innovation characteristics and interpersonal trust, which in turn are positively related to organizational intention to facilitate knowledge sharing.

Perceptions of organizational support also depend on more proximal organizational representatives, such as supervisors and workgroups, which employees identify with the organization (Eisenberger, Stinglhamber, Vandenberghe, Sucharski, & Rhoades, 2002; Self, Holt, & Schaninger, 2005). Because supervisors act as agents of the organization, who have responsibility for directing and evaluating subordinates' performance, employees would view their supervisor's favourable or unfavourable orientation toward them as indicative of the organization's support (Eisenberger et al., 1986; 2002). Colleagues can also represent a source of support (peer support). They may contribute to shaping and implementing the organization's values and objectives, and their provision of both instrumental and socio-emotional resources may represent a significant influence on POS (Hayton, Carnabuci, & Eisenberger, 2012; Ng & Sorensen, 2008). Instrumental forms of social support involve resources that help employees accomplish specific tasks or objectives, including information, expertise, professional advice, political access and advocacy, equipment, and supplies. Expressive forms of social support include approval, praise, intimacy, and emotional closeness and are important for fulfilling emotional and social identity needs (Ibarra & Smith-Lovin, 1997).

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Help from others in resolving problems at work and creating stable, positive, social relationships can be seen as a functional definition of peer support.

Practically, in order to increase support, it is important to:
- Listen to others, being tolerant and helping other colleagues
- Share both success and risks
- Talk openly with colleagues about problems and trying to find together a solution
- Explain why other colleagues are important to the work objectives
Offer encouragement and recognition.

Extended methodology

Perceived Organizational Support Scale (Rhoades, Eisenberger, & Armeli, 2001), a self-report measure intended to capture the extent to which employees perceive that the organization values their contribution and cares about their well-being.

Respondents indicate the extent of agreement with each statement on a 7-point Likert-type scale (1= strongly disagree,1 = strongly agree).

1. My organization really cares about my well-being.
2. My organization strongly considers my goals and values.
3. My organization shows little concern for me. (R)
4. My organization cares about my opinions.
5. My organization is willing to help me if I need a special favor.
6. Help is available from my organization when I have a problem.
7. My organization would forgive an honest mistake on my part.
8. If given the opportunity, my organization would take advantage of me. (R)

Higher scores indicate higher perceived organizational support. Items marked with “R” are reversed items.

Organizational rewards (Rhoades, Eisenberger, & Armeli, 2001) is used toassess beliefs concerning thefavorableness ofopportunities for recognition,pay, and promotion.

Respondents answer on a5-pointLikert-type scale (1= very unfavorable,5 = veryfavorable).

1. Recognition for good work.
2. Opportunity for advancement.
3. Opportunity for high earnings.

Higher scores indicate stronger beliefs concerning the favorableness of opportunities for recognition, pay, and promotion.

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Perceived Organizational Support Scale (POS; Eisenberger, Huntington, Hutchinson, & Sowa, 1986) is a self-report measure to assess possible feelings that individuals might have about the company or organization for which they work.

Listed below is a series of statements that represent possible feelings that individuals might have about the company or organization for which they work. With respect to your own feelings about the particular organization for which you are now working—[name of organization]—please indicate the degree of your agreement or disagreement with each statement by checking one of the seven alternatives below each statement.

1 = strong disagreement; 2 = moderate disagreement; 3 = slight disagreement; 4 = neither agreement nor disagreement; 5 = easy agreement; 6 = moderate agreement; 7 = strong agreement.

1. The organization values my contribution to its well-being.
2. If the organization could hire someone to replace me at a lower salary it would do so. (R)
3. The organization fails to appreciate any extra effort from me. (R)
4. The organization strongly considers my goals and values. (S)
5. The organization would ignore any complaint from me. (R)
6. The organization disregards my best interests when it makes decisions that affect me. (R)
7. Help is available from the organization when I have a problem. (S)
8. The organization really cares about my well-being. (S)
9. The organization is willing to extend itself in order to help me perform my job to the best of my ability. (S)
10. Even if I did the best job possible, the organization would fail to notice. (R) (S)
11. The organization is willing to help me when I need a special favor.
12. The organization cares about my general satisfaction at work. (S)
13. If given the opportunity, the organization would take advantage of me.(R)
14. The organization shows very little concern for me. (R) (S)
15. The organization cares about my opinions. (S)
16. The organization takes pride in my accomplishments at work. (S)
17. The organization tries to make my job as interesting as possible.

Items denoted with (S) are used in the shortened nine-item version of the measure. Items denoted with (R) are reverse scored. Higher the scores, higher the perceived organizational support.

Feedback and recognition (Bakker & Demerouti, 2014), a self-report measure

The following questions concern the feedback that you receive about your work. For each question, choose the answer that best describes your situation.

5-point Likert Scale: 1-Never, 2-Sometimes, 3-Regularly, 4-Often, 5-Very often

1. I receive sufficient information about my work objectives.
2. My job offers me opportunities to find out how well I do my work.
3. I receive sufficient information about the results of my work.

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COpenhagen PsychoSOcial Questionnaire (COPSOQ; Kristensen, Hannerz, Hogh, & Borg, 2005; Pejtersen, Kristensen, Borg, & Bjorner, 2010), measuring the degree to which employees feel recognised for their work.

The response options are: Always; Often; Sometimes; Seldom; Never/hardly ever

Social support from colleagues
1. How often do you get help and support from your colleagues?
2. How often are your colleagues willing to listen to your problems at work?
3. How often do your colleagues talk with you about how well you carry out your work?

Social support from supervisors
1. How often is your nearest superior willing to listen to your problems at work?
2. How often do you get help and support from your nearest superior?
3. How often does your nearest superior talk with you about how well you carry out your work?

Recognition
The response options are: To a very large extent; To a large extent; Somewhat; To a small extent; To a very small extent
1. Is your work recognised and appreciated by the management?
2. Does the management at your workplace respect you?
3. Are you treated fairly at your workplace?

Scoring: All the above tools have summative scales. Higher scores reflect greater levels of perceptions for support and recognition from the organization (superiors and colleagues).

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PARTICIPATORY PLANNING AND GOVERNANCE INDICATORS - FEATURE

CONNECTING NATURE

Task and skill variety

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Description

Skill variety (multiple skills used to perform one's job) is the degree to which a job requires various activities, requiring the worker to develop a variety of skills and talents. Employees can experience more meaningfulness in jobs that require several different skills and abilities than when the jobs are elementary and routine (Hackman & Oldham, 1975)
Task variety (performance of multiple tasks in order to accomplish one's job) is defined as the degree to which the job requires that the employee perform a wide range of tasks (Morgeson & Humphrey, 2006; Sims, Szilagyi, & Keller, 1976).

Methodology

Quantitative Procedure: Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)
Selective Tool: The Work Design Questionnaire (WDQ; Morgeson, & Humphrey, 2006)

Qualitative Procedure: adapted key questions from quantitative procedures and tools to assess the process with the stakeholders

Level of expertise

. Quantitative data collection requires no expertise
. Qualitative data collection requires medium level expertise in social science research

Data collection

Required data

. Essential: questionnaire scores
. Desirable: qualitative data on organizational processes

Data input type

Quantitative and qualitative, if participatory data collection methods, and/or participatory action research are opted for

Data collection frequency

Aligned with NBS implementation and timing of targeted objectives

Participatory process

Participatory methods (e.g., participatory data collection methods, and/or participatory action research) may be applied to collect data on nature-based solutions organizational processes

Connection with SDGs

Goal 9
Goal 11
Goal 16
Goal 17

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Extended description

Task variety (performing more tasks) and skill variety (using more skills) are two job characteristics related to experiencing one's job as meaningful and worthwhile, which, in turn, influences employees' internal work motivation. Increased skill variety can lead employees to experience a higher chance of performing a challenging and interesting job that can positively affect their satisfaction (Hackman & Oldham, 1976).

High task variety has the functional value of making work-related goals achievable and contributing to personal growth, offering valuable opportunities to use different skills and fostering an experience of meaningfulness and motivation (Hackman and Oldham, 1976; Humphrey, Nahrgang, & Morgeson, 2007). Research shows that task and skill variety are related to individual well-being (Van den Broeck et al., 2015), on-the-job learning opportunities (Van Ruysseveldt, Verboon, & Smulders, 2011), and performance (Smith et al., 2009).

In contrast, low task variety means a lack of opportunity to use valued skills (Loukidou et al., 2009; Zaniboni, Truxillo, & Fraccaroli, 2013), reflecting a possible lack of work stimulation (Demerouti, Bakker, Nachreiner, & Schaufeli, 2001). Low task variety may require additional effort to maintain attention and performance and is likely to result in a lack of stimulation and motivation, displeasure and even more negative affective states, such as frustration or anger, being associated with counterproductive work behaviours (Morf, Feierabend, & Staffelbach, 2017).

Results from a meta-analytic study showed that task variety is positively related to job satisfaction and perceived performance, but also to job overload, whereas skill variety is positively related to job satisfaction, involvement and motivation (Humphrey et al., 2007). Research also show that task and skill variety are related with important other organizational and individual outcomes, such as mental health (Law et al., 2020), innovative work behaviours (Koch & Adler, 2019; Lambriex-Schmitz, Van der Klink, Beausaert, Bijker, & Segers, 2020), creativity (Yoo, Jang, Ho, Seo, & Yoo, 2019), or social informal learning activities (Froehlich, Segers, Beausaert, & Kremer, 2019).

Taking all this into consideration, task and skill variety represent important characteristics to consider in a process of organizational development and readiness for implementing NBS, having the role of supporting employees in this endeavor, as it increases motivation to continue working when encountering adversities and challenges, increases the meaning of the work done and even drives employees to find innovative and creative solutions.

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Extended methodology

The Work Design Questionnaire (WDQ; Morgeson, & Humphrey, 2006)

Four-item scale to assess the degree to which a job requires workers to perform a wide range of tasks on the job, and a four-item scale to assess the degree to which a job requires workers to use a wide range of skills to perform the job.

Items are on a 5-point Likert scale ranging from 1 (“strongly disagree”) to 5 (“strongly agree”).

Task Variety
1. The job involves a great deal of task variety.
2. The job involves doing a number of different things.
3. The job requires the performance of a wide range of tasks.
4. The job involves performing a variety of tasks.

Skill Variety
1. The job requires a variety of skills.
2. The job requires me to utilize a variety of different skills in order to complete the work.
3. The job requires me to use a number of complex or high-level skills.
4. The job requires the use of a number of skills.

Scoring: both scales have summative scores, meaning that the responses from each item are summed up to indicate the overall score for task and skill variety. Higher scores indicate greater skill and task variety.

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PARTICIPATORY PLANNING AND GOVERNANCE INDICATORS - FEATURE

CONNECTING NATURE

Team cohesion

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Description

Team cohesion is the degree to which team members work together as they pursue the team's goals (Mach, Dolan, & Tzafrir, 2010), referring to those processes related to internal, team and departmental functioning It is defined as 'a dynamic process that is reflected in the tendency of a group to stick together and remain united in the pursuit of its instrumental objectives and/or for the satisfaction of member affective needs' (Carron, Brawley, & Widmeyer, 1998).

Methodology

Quantitative Procedure: Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)
6 selective tools

Qualitative Procedure: adapted key questions from quantitative procedures and tools to assess the process with the stakeholders

Level of expertise

. Quantitative data collection requires no expertise
. Qualitative data collection requires medium level expertise in social science research

Data collection

Required data

. Essential: questionnaire scores
. Desirable: qualitative data on organizational processes

Data input type

Quantitative and qualitative, if participatory data collection methods, and/or participatory action research are opted for

Data collection frequency

Aligned with NBS implementation and timing of targeted objectives

Participatory process

Participatory methods (e.g., participatory data collection methods, and/or participatory action research) may be applied to collect data on nature-based solutions organizational processes

Connection with SDGs

Goal 9
Goal 11
Goal 16
Goal 17

CONNECTING NATURE

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Extended description

Before embarking on a new, meaningful adventure and begin to diffuse the innovations related to implementing NBS in your City, consider the organizational characteristics and processes involved in delivering and scaling up NBS too, which can hinder or boost the project.

Two separate processes are involved in any NBS project: one refers to work conditions (such as ambiguity, uncertainty, and overload) and one refers to relational characteristics (such as collaboration, support, conflicts). Therefore, you and your team will need to build relevant resources, to deal with work stressors and not last, to foster a culture of innovation to further build upon for next projects too. But NBS are not only innovative in new ways of working, but also require building new relationships, new teams and horizontal working more than other projects would do. Thus, special attention is required to the relational aspect of work, to cooperation and collaboration, more specifically, to ways to foster good relationships between the core-team working on the NBS exemplar, between the team and other departments, between the team and people in the City Hall who have strategic leadership, between the team and new actors, and so on.

A team has a common goal or purpose where team members can develop effective, mutual relationships to achieve team goals (Harris & Harris, 1996). The importance of teamwork relies on the simple fact that teams are often empowered to accomplish tasks not available to individuals (Scarnati, 2001). For team members to work efficiently together, a good collaboration between them is necessary, translated into working informally together, sharing ideas, information and resources (Morgan, Salas, & Glickman, 1994). Collaboration requires participants' mutual engagement and trust and focuses them on the achievement of a common objective (Msanjila & Afsarmanesh, 2008). At its best it serves as a crucible through which people of differing expertise, perspectives, and backgrounds enhance each other's capabilities to form something new. When effective, it synthesizes differences among participants in ways that deliver a competitive advantage to the organization (Weiss & Hughes, 2005). Thus, a good communication between team members fosters trust, understanding and inspiration (Barrett, 2006).

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A good collaboration and teamwork require a mix of interpersonal, problem solving, and communication skills needed for a group to work together towards a common goal (Tarricone & Luca, 2002), in order to foster a good working atmosphere (Hamilton, 2007; Nolan & Küpers, 2009), to enhance the well-being of its members (Mastroianni & Storberg-Walker, 2014) and to facilitate individual and team performance (Beal, Cohen, Burke, & McLendon, 2003; Mullen & Copper, 1994). When relationships in the workplace are characterized by cooperation, trust, and fairness, the reward center of the brain is activated which encourages future interactions that promote employee trust, respect, and confidence, with employees believing the best in each other and inspiring each other in their performance (Geue, 2018).

Successful teamwork means that the team members are motivated (Basford & Offermann, 2012), engaged, and aim to achieve at the highest level (Bradley & Frederic, 1997; Wageman, 1997), promote learning and new ideas and skills acquisition (Scarnati, 2001; Smith, 1996), that the team members are willing to give and receive constructive criticism and provide authentic feedback, and that feelings can be expressed freely within the team (Harris & Harris, 1996). Also, the members of a cohesive team are fully aware of their specific team roles, relationships assignments and responsibilities (Harris & Harris, 1996), thus understanding what is expected of them in terms of their contribution to the team and the NBS project, and that they are aware of team processes, best practices and new ideas. Strong 'within-group' ties with co-workers (characterized by frequent social interactions) provide opportunities to facilitate innovative thinking. Strong ties developed by social interactions assist innovators in the search for inspiration, sponsorship, and support within the workplace (Wang, Fang, Qureshi, & Janssen, 2015).

Salas, Grossman, Hughes and Coultas (2015) reviewed the literature on team cohesion and how this concept is defined and measured, arguing that it is a multidimensional and multileveled construct. The identified dimensions are related to the tasks the team must perform in order to reach organizational objectives (attraction or bonding between group members that is based on a shared commitment to achieving the group's goals and objectives), to the social aspects of the group (closeness and attraction within the group that is based on social relationships within the group), to the belongingness (degree to which members of a group are attracted to each other), to group pride (extent to which group members exhibit liking for the status or the ideologies that the group supports or represents, or the shared importance of being a member of the group), and morale (individuals' high degree of loyalty to fellow group members and their willingness to endure frustration for the group).

In sum, cohesive, functional teams, share knowledge, coordinate behaviors, and trust one another (Mathieu, Maynard, Rapp, & Gilson, 2008). Teamwork is an adaptive, dynamic, and episodic process that encompasses the thoughts, feelings, and behaviors among team members while they interact toward a common goal (Salas, Shuffler, Thayer, Bedwell, & Lazzara, 2015).

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Extended methodology

Social community at work from COpenhagen PsychoSOcial Questionnaire (COPSOQ; Kristensen, Hannerz, Hogh, & Borg, 2005; Pejtersen, Kristensen, Borg, & Bjorner, 2010)

It is used to assess the employees perceptions related to their sense of community in the workplace, and wow they perceive the atmosphere and cooperation between co-workers. People feel a sense of belonging at work, and they feel that they matter to each other and to the organization.

The response options are: Always = 5; Often = 4; Sometimes = 3; Seldom = 2; Never/hardly ever = 1

1. Is there a good atmosphere between you and your colleagues?
2. Is there good co-operation between the colleagues at work?
3. Do you feel part of a community at your place of work?

Scoring: add up the scores from each item in order to reflect the overall score for perceptions regarding social community at work. Higher scores indicate greater perceptions of workplace social community.

Social relations at work from COpenhagen PsychoSOcial Questionnaire (COPSOQ; Kristensen & Borg, 2003)

Is a self-report measure for assessing attitudes related to one's workplace social interactions.

1. Do you work isolated from your colleagues?
(Always, Often, Sometimes, Seldom, Never/hardly ever)
2. Is it possible for you to talk to your colleagues while you are working?
(Always, Often, Sometimes, Seldom, Never/hardly ever)
3. How many at your place of work can you talk to about something personal, which is important to you?
(Number of persons___________)
4. Are you part of a group in your work?
(Always, Often, Sometimes, Seldom, Never/hardly ever)

Scoring: add up the scores from each item in order to reflect the overall score for perceptions regarding social relations at work. Higher scores indicate better workplace social relations.

Horizontal informal communication scale from Communication Satisfaction Questionnaire (Downs & Hazen, 1977)

It assesses employee's perceptions of the grapevine in their workplace, and the extent to which informal communication is accurate and free flowing.

Response measure consists of a seven-point scale with one being "very satisfied" and seven being "very dissatisfied".

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1. There is a good atmosphere between colleagues in my department.
2. If I want, I can also discuss personal matters with my colleagues.
3. My colleagues offer me support.
4. Informal communication is active and accurate.
5. The 'grapevine' is active in my organization.

Scoring: add up the scores from each item in order to reflect the overall score for perceptions regarding horizontal informal communication. Higher scores indicate better workplace communication.

Social support scale from The Job Demands-Resources Questionnaire (Bakker, & Demerouti, 2014)

The following questions concern the collaboration with your colleagues. For each question choose the answer that is the most applicable to you.

Scale: 1-Never, 2-Sometimes, 3-Regularly, 4-Often, 5-Very often

1. If necessary, can you ask your colleagues for help?
2. Can you count on your colleagues to support you, if difficulties arise in your work?
3. In your work, do you feel valued by your colleagues?

Scoring: add up the scores from each item in order to reflect the overall score for the perceived social support and collaboration from colleagues at work. Higher scores indicate better workplace social support from co-workers.

Feedback scale from The Job Demands-Resources Questionnaire (Bakker, & Demerouti, 2014)

It assesses the degree of perceived feedback related to ones' work.

The following questions concern the feedback that you receive about your work. For each question, choose the answer that best describes your situation.

Scale: 1-Never, 2-Sometimes, 3-Regularly, 4-Often, 5-Very often

1. I receive sufficient information about my work objectives.
2. My job offers me opportunities to find out how well I do my work.
3. I receive sufficient information about the results of my work.

Scoring: add up the scores from each item in order to reflect the overall score. Higher scores indicate better feedback an employee receives related to accomplishing his/her work related tasks and objectives.

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Workplace Friendship Scale (Nielsen, Jex, & Adams, 2000)

It assesses friendship opportunities, as well as prevalence in the workplace.

Scale: 5-point Likert-type scale ranging from 1 (strongly disagree) to 5 (strongly agree).

Friendship Opportunity Dimension

1. I have the opportunity to get to know my coworkers.
2. I am able to work with my coworkers to collectively solve problems.
3. In my organization, I have the chance to talk informally and visit with others.
4. Communication among employees is encouraged by my organization.
5. I have the opportunity to develop close friendships at my workplace.
6. Informal talk is tolerated by my organization as long as the work is completed.

Friendship Prevalence Dimension

1. I have formed strong friendships at work.
2. I socialize with coworkers outside of the workplace.
3. I can confide in people at work.
4. I feel I can trust many coworkers a great deal.
5. Being able to see my coworkers is one reason why I look forward to my job.
6. I do not feel that anyone I work with is a true friend. (R)

Scoring: summative scale. One of the items is reverse scored, marked with (R).

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PARTICIPATORY PLANNING AND GOVERNANCE INDICATORS - FEATURE

CONNECTING NATURE

Good workload management

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Description

In Connecting Nature, we define good workload management as prioritizing, clarity, sufficient information and work resources, thus encompassing three concepts:
- Autonomy
- Role clarity
- Workload

Methodology

Quantitative Procedure: Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)
6 selective tools

Qualitative Procedure: adapted key questions from quantitative procedures and tools to assess the process with the stakeholders

Level of expertise

. Quantitative data collection requires no expertise
. Qualitative data collection requires medium level expertise in social science research

Data collection

Required data

. Essential: questionnaire scores
. Desirable: qualitative data on organizational processes

Data input type

Quantitative and qualitative, if participatory data collection methods, and/or participatory action research are opted for

Data collection frequency

Aligned with NBS implementation and timing of targeted objectives

Participatory process

Participatory methods (e.g., participatory data collection methods, and/or participatory action research) may be applied to collect data on nature-based solutions organizational processes

Connection with SDGs

Goal 9
Goal 11
Goal 16
Goal 17

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730222

Extended description

Autonomy: individual's freedom in deciding how work should be done, and employee control over their work. It promotes creativity and encourages the use of skills, encourages independent decision-making, and also may improve organization of tasks. Autonomy represents a consistent job resource studied as antecedent of innovative and creative work behaviours (Liu, Chen & Yao, 2011; Sia & Appu, 2015; Wang, 2016). Providing employees with freedom and independence to determine which procedures should be used to carry out a task increases the likelihood that they will be willing to implement them within their job (Hammond et al., 2011). Thus, by offering freedom related with the work activities and decision-making, autonomy enables employees to experiment with different work approaches and methods, it enables them to find ideas and develop them further through the small-scale application of these ideas. In jobs with a lot of autonomy, employees tend to participate more in knowledge sharing (Cabrera, Collins, & Salgado, 2006).

Role clarity: clarity in the expectations, the procedures/methods and the benefits/consequences associated with a role; there are no contradictory expectations or requests or goals regarding one's work. For short, role clarity refers to whether the tasks and work relationships are well-defined as well as well understood by the employees. Role clarity influence performance, engagement, trust and well-being, being important to have in a change context, as is associated with adaptable and resilient employees.

Role clarity (or role ambiguity) refers to the presence or absence of adequate role-relevant information due either to restriction of this information or to variations of the quality of the information (objective) or to the subjective feeling of having as much or not as much role relevant information as the person would like to have (subjective) (Lyons, 1971). Role clarity is associated with greater job satisfaction (Kroposki, Murdaugh, Tavakoli, & Parsons, 1999) and job performance (Fried et al., 2003). Role clarity is also found to have an influence on employees' innovative work behaviors (Kundu, Kumar, & Lata, 2019). Role ambiguity was also found to be important in the relationship between quality of leader-member interactions and organizational citizenship behaviours. Specifically, when employees perceive high-quality relationships with their superiors, they also experience less role ambiguity and exhibit more valued work behaviours (Zhang, Jiang, & Jin, 2020).

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Because organizational change is one of the important contributors for role ambiguity and because it may increase negative feelings of tension, anxiety and fear (Kahn, Wolfe, Quinn, Snoek, & Rosenthal, 1964), maintaining an adequate understanding of employee roles should be on the agenda when implementing changes in any organizational setting. Role clarity was also found to be important in implementing change, alongside with other contextual factors, such as social support and meaningful work (Nielsen & Randall, 2009)
Workload is a work demand, which could be quantitative (the amount of work to be done) or qualitative (the difficulty of the work) (Jex, 1998).

Workload as a work demand is a major component of the demand-control model of stress (Karasek, 1979), suggesting that jobs with high demands, such a high workload, can put psychological strain on an employee, especially when the individual has low control over the job. Workload is also relevant to the job demands-resources model (JD-R; Demerouti, Bakker, Nachreiner, & Schaufeli, 2001), illustrating that jobs are perceived as stressful when demands (e.g., workload) exceed the individual's resources to deal with them. Therefore, having a high workload can be stressful for employees, as it is being associated with feelings such as "there is too much to do", "too little time to accomplish assignments", or "a work that is too difficult". It is also associated with decrease in the quantity and quality of work outputs, lowers employees well-being, creativity and initiative, being related to feeling of not being able to get any rest or recovery from work (Brun & Cooper, 2009). Based on Gardner's (1986) activation theory, higher levels of workload should result in increased task motivation. Andrews and Farris (1972) found a positive effect of workload on the performance measures of usefulness, productivity, and innovation in NASA scientists and engineers. They found that high-performing scientists and engineers perceived a higher workload and those that reported a higher workload tended to be more motivated in their work. In another more recent study, Wu, Parker, and de Jong (2014) found that workload had a positive relationship with innovation behaviors as rated by peers. Therefore, as long as it is not extreme, workload can be considered a challenge demand which can lead to an increase in innovative behaviours.

Research also shows that there is a relationship between role clarity and workload: high role clarity have the potential to ameliorate the effects of high work overload, if there is support from their organization. In other words, if employees have considerable work to do, but they know what to do, and feel supported, then the psychological strain they perceive is lower (Bliese & Castro, 2000).

Extended methodology

Autonomy subscale from The Job Demands-Resources Questionnaire (Bakker & Demerouti, 2014)

The following questions refer to your personal work situation and your experience of it. For each question, please choose the answer that is most applicable to you.

5-point Likert Scale: 1-Never, 2-Sometimes, 3-Regularly, 4-Often, 5-Very often

1. Do you have flexibility in the execution of your job?
2. Do you have control over how your work is carried out?
3. Can you participate in decision-making regarding your work?

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Hassless subscale from The Job Demands-Resources Questionnaire (Bakker & Demerouti, 2014)

The following questions are about hassles at work. Indicate for each statement to what extent you agree. 5-point Likert Scale.: 1-Strongly disagree, 2-Disagree, 3-Do not agree, do not disagree, 4-Agree, 5-Strongly agree

1. I have to deal with administrative hassles.
2. I have many hassles to go through to get projects/assignments done.
3. I have to go through a lot of red tape to get my job done.
4. I am confronted with unexpected hassles at work.
5. I have many hassles to go through to get my work done.

Autonomy subscales from The Work Design Questionnaire (WDQ; Morgeson & Humphrey, 2006)

Work Scheduling Autonomy
1. The job allows me to make my own decisions about how to schedule my work.
2. The job allows me to decide on the order in which things are done on the job.
3. The job allows me to plan how I do my work.

Decision-Making Autonomy
1. The job gives me a chance to use my personal initiative or judgment in carrying out the work.
2. The job allows me to make a lot of decisions on my own.
3. The job provides me with significant autonomy in making decisions.

Work Methods Autonomy
1. The job allows me to make decisions about what methods I use to complete my work.
2. The job gives me considerable opportunity for independence and freedom in how I do the work.
3. The job allows me to decide on my own how to go about doing my work.

Role clarity subscale from COpenhagen PsychoSOcial Questionnaire (COPSOQ; Kristensen, Hannerz, Hogh, & Borg, 2005)

It measures the degree to which employees feel recognised for their work.

The response options are: To a very large extent; To a large extent; Somewhat; To a small extent; To a very small extent

1. Does your work have clear objectives?
2. Do you know exactly which areas are your responsibility?
3. Do you know exactly what is expected of you at work?

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Quantitative demands subscale from COpenhagen PsychoSOcial Questionnaire (COPSOQ; Kristensen, Hannerz, Hogh, & Borg, 2005)

It measures the degree to which employees feel recognised for their work.

The response options are: Always; Often; Sometimes; Seldom; Never/hardly ever.
The items marked with R are reverse-scored.

1. Is your workload unevenly distributed so it piles up?
2. How often do you not have time to complete all your work tasks?
3. Do you get behind with your work?
4. Do you have enough time for your work tasks? (R)

Work pace subscale from COpenhagen PsychoSOcial Questionnaire (COPSOQ; Kristensen, Hannerz, Hogh, & Borg, 2005)

It measures employees' perceptions related to their workload, referring to the quantity of tasks as well as the pace in which they must perform them.

For the first item, the response options are: Always; Often; Sometimes; Seldom; Never/hardly ever.
For the items 2 and 3, the response options are: To a very large extent; To a large extent; Somewhat; To a small extent; To a very small extent

1. Do you have to work very fast?
2. Do you work at a high pace throughout the day?
3. Is it necessary to keep working at a high pace?

All instruments have summative items, meaning that higher scores indicate higher job autonomy, higher clarity on roles and higher overload (demands and work pace). Higher autonomy, higher role clarity and reduced overload reflect a good management of employees' workload.

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PARTICIPATORY PLANNING AND GOVERNANCE INDICATORS - FEATURE

CONNECTING NATURE

Engagement

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Description

Work engagement is defined as a positive, fulfilling, work-related state of mind that is characterized by vigor, dedication, and absorption (Schaufeli et al., 2002). In other words, work engagement represents how employees feel energized and motivated about their work. Vigor is characterized by high levels of energy and mental resilience while working. Dedication refers to being strongly involved in one's work and experiencing a sense of significance, enthusiasm, and challenge. Absorption is characterized by being fully concentrated and happily engrossed in one's work, whereby time passes quickly and one has difficulties with detaching oneself from work (Schaufeli & Bakker, 2004).

Methodology

Quantitative Procedure: Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)
Selective Tool 1: Work engagement scale from The Job Demands-Resources Questionnaire (Bakker & Demerouti, 2014)

Selective Tool 2: Utrecht Work Engagement Scale Short Version; 3 items assessing vigor, dedication, and absorption (Schaufeli, Shimazu, Hakanen, Salanova, & De Witte, 2019).

Level of expertise

. Quantitative data collection requires no expertise
. Qualitative data collection requires medium level expertise in social science research

Data collection

Required data

. Essential: questionnaire scores
. Desirable: qualitative data on organizational processes

Data input type

Quantitative and qualitative, if participatory data collection methods, and/or participatory action research are opted for

Data collection frequency

Aligned with NBS implementation and timing of targeted objectives

Participatory process

Participatory methods (e.g., participatory data collection methods, and/or participatory action research) may be applied to collect data on nature-based solutions organizational processes

Connection with SDGs

Goal 9
Goal 11
Goal 16
Goal 17

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Extended description

Work engagement is a positive, fulfilling, work-related state of mind (Bakker & Demerouti, 2008), comprised of (1) vigor, characterized by "high levels of energy and mental resilience while working, the willingness to invest effort in one's work, and persistence even in the face of difficulties"; (2) dedication, characterized by "feelings of a sense of significance, enthusiasm, inspiration, pride, and challenge"; and (3) absorption, characterized by "being fully concentrated and deeply engrossed in one's work, whereby time passes quickly and one has difficulties with detaching oneself" (Schaufeli et al., 2002). Engaged employees are highly active, enthusiastic about their work and often fully immersed in their work and do not feel how time gets by - a motivational experience that brings out the best in people. Motivation stemming from the individual's engagement in the task was shown to be more efficient for employees' innovative work than motivation stemming from factors outside the task (i.e., rewards or compensation) (Hammond et al., 2011). Engaged employees have high energy and self-efficacy, and they are more creative, more productive, and more willing to go the extra mile (Bakker & Xanthopoulou, 2013; Bakker & Demerouti, 2008). There are at least four reasons why engaged workers perform better than non-engaged workers: engaged employees often experience positive emotions (such as happiness, joy, and enthusiasm) experience better health, create their own job and personal resources, and transfer their engagement to others (Bakker & Demerouti, 2008).

Related to antecedents of this positive, fulfilling state of mind, previous studies have consistently shown that job resources such as social support from colleagues and supervisors, performance feedback, skill variety, autonomy, and learning opportunities are positively associated with work engagement (Bakker and Demerouti, 2007; Schaufeli and Salanova, 2007). Not only job resources are important for employee work engagement, but also personal resources have a direct positive effect on work engagement (Bakker & Demerouti, 2017). For example, Xanthopoulou, Bakker, and Fischbach (2013) showed that self-efficacy related positively to work engagement, particularly when emotional demands and emotional dissonance were high. In addition, they showed that emotional demands and dissonance related negatively to work engagement when self-efficacy was low. Bakker and Sanz- Vergel (2013) showed that weekly self-efficacy and optimism were positively related to flourishing when weekly hindrance job demands were low (vs. high), and that these personal resources were positively related to weekly work engagement when weekly challenge job demands were high (vs. low).

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Extended methodology

Work engagement scale from The Job Demands-Resources Questionnaire (Bakker & Demerouti, 2014)

The following statements concern the way you experience your work and how you feel about it.
Please choose for each statement the answer that is most representative for you.

Scale: 7-point Likert: 0-Never, 1-Almost never, 2-Rarely, 3-Sometimes, 4-Often, 5-Very often, 6-Always

1. At my work, I feel bursting with energy.
2. In my job, I feel strong and vigorous.
3. I am enthusiastic about my job.
4. My job inspires me.
5. When I get up in the morning, I feel like going to work.
6. I feel happy when I am working intensely.
7. I am proud of the work that I do.
8. I am immersed in my work.
9. I get carried away when I am working.

Scoring: Summative scale; once numbers are assigned for all of the items in the scale, just sum all the values to obtain a total scale score.

[Extra-role performance]

7-point Likert Scale.
0-Not at all characteristic, 1-Hardly characteristic, 2-Somewhat characteristic, 3-Fairly characteristic, 4-Rather characteristic, 5-Strongly characteristic, 6-Totally characteristic

1. You help your colleagues with their work when they return from a period of absence.
2. You help colleagues who are labouring under high work pressure or who have other problems.
3. You are prepared to do things that are not really part of your job description, but which are in the interest of your organisation as a whole.

Utrecht Work Engagement Scale Short version (Schaufeli, Shimazu, Hakanen, Salanova, & De Witte, 2019).

Please read carefully each statement and indicate how best it fits you, using the scale below to respond.

Scale: 7-point Likert; 0-Never, 1-Almost never, 2-Rarely, 3-Sometimes, 4-Often, 5-Very often, 6-Always

1. At my work, I feel bursting with energy. (vigor)
2. I am enthusiastic about my job. (dedication)
3. I am immersed in my work. (absorption)

Scoring: Summative scale

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PARTICIPATORY PLANNING AND GOVERNANCE INDICATORS - FEATURE

CONNECTING NATURE

Organizational trust

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Description

McAllister (1995) defines trust as "the extent to which a person is confident in, and willing to act on the basis of, the words, actions and decisions, of another". Mayer, Davis, and Schoorman (1995) define organizational trust as "the willingness of one party to be vulnerable to the actions of another party based on the expectation that the other party will perform a particular action important to the trustor, irrespective of the ability to monitor or control that other party." Trust in organizational setting therefore involves the willingness to be vulnerable and take a risk concerning the possibility that the other party will not live up to the expectations of this benevolent behavior (Shockley-Zalabak, Ellis, & Winograd, 2000; Lamsa & Pucetaite, 2006). "The global evaluation of an organization's trustworthiness as perceived by the employee. Organizational trust is defined as an employee's feeling of confidence that the organization will perform actions that are beneficial, or at least not detrimental, to him or her" (Tan & Tan, 2000, p. 243).

Methodology

Quantitative Procedure: Scale inventory/Questionnaire (survey procedure, paper-and-pencil administration, computer-based administration)
6 selective tools

Level of expertise

. Quantitative data collection requires no expertise
. Qualitative data collection requires medium level expertise in social science research

Data collection

Required data

. Essential: questionnaire scores
. Desirable: qualitative data on organizational processes

Data input type

Quantitative and qualitative, if participatory data collection methods, and/or participatory action research are opted for

Data collection frequency

Aligned with NBS implementation and timing of targeted objectives

Participatory process

Participatory methods (e.g., participatory data collection methods, and/or participatory action research) may be applied to collect data on nature-based solutions organizational processes

Connection with SDGs

Goal 9
Goal 11
Goal 16
Goal 17

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Extended description

The importance of trust-based relationships within organizations has been notable for decades (McCauley & Kuhnert, 1992). Since the mid-1990s, the construct of trust has been positioned as the basis for the quality of interpersonal relationships and a source of competitive advantage for organizations (Tan & Lim, 2009). Trust between people and groups within organizations is an important ingredient for being able to achieve long-term stability in the organization and the welfare of its members (Cook & Wall, 1980), as well as an essential element in any positive and productive social process (Zhang, Tsui, Song, Li, & Jia, 2008). Ultimately, the literature has suggested that organizational trust is necessary for the proper operation of organizations (Arrow, 1974; Gulati & Nickerson, 2008). Trust has been identified as a variable affecting organizational learning (Hoe, 2007), and performance (Guinot, Chiva, & Mallén, 2013). Also, trust in organizational setting results in more positive attitudes (Dirks & Ferrin, 2001), organizational commitment and job satisfaction (Nyhan & Marlowe, 1997). Trust between co-workers was also found to be related to perceived organizational support, lower turnover intention, and higher affective commitment (Ferres, Connell, & Travaglione, 2004).
The study of organizational trust and trust in organizations has been acquiring growing importance over the last few years, which is reflected in the recent reviews and compilations published (e.g., Tan & Lim, 2009; Cook & Schilke, 2010; Kramer & Lewicki, 2010), largely owing to the benefits it generates in organizations (Mayer & Gavin, 2005; Hurley, 2006; Kath, Magley, & Marmet, 2010).
Despite the interest in this topic, a review of the management literature on trust reveals that there has been little consensus among scholars to settle on a single working definition of trust (Kramer, 1999; Rousseau, Stikin, Burt, & Carmerer, 1998). While the broad definition is debatable, there does seem to be stronger consensus regarding the conditions for trust. Tzafrir and Dolan (2004) summarized that three conditions might clarify the point of mutuality in trust-based relations: vulnerability (involves the uncertainty of the future and the willingness of the parties to take a risk), previous mutual interactions (which are perceived by the parties as positive and reciprocal), and expectations over time regarding reliable conduct. Lewicki, Tomlinson, and Gillespie's (2006) summary of various models of interpersonal trust concluded that trust from a psychological perspective (Rousseau et al., 1998) is a mental state that implies positive expectations regarding the other party's intentions and behavior.

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In this respect, the act of trusting reflects a willingness to accept vulnerability from the trustor's perspective, and an expectation that the other party, the trustee, will reciprocate trustworthily (Dietz & Den Hartog, 2006).
Rousseau et al. (1998) assert that trust involves individual processes, group dynamics, and organizational or institutional contingencies, simultaneously. Thus, trust may be conceptualized differently depending upon the level at which the data are aggregated (between individuals, groups, systems, organizations, etc.). The literature on trust also emphasizes different foci of trust within different levels of analysis. While Rotter (1971) focuses his definition of trust at the individual level, Mayer, Davis, and Schoorman (1995) establish a dyadic model of organizational trust, and Zucker (1986) focuses on institutional trust. These arguments may be the main reason for Lane's (1998) suggestion that any theory on trust needs to incorporate its 'multidimensional social reality', possibly serving as a bridge between the micro- and macro-levels (Lewis & Weigert, 1985). For this reason, trust is considered a 'mezzo' concept given that it integrates psychological and group dynamic processes at the micro-level and organizational and institutional forms at the macro-level (Rousseau et al., 1998). When employees make judgments regarding the trustworthiness of their organization, these employees are thinking about multiple actors, including their immediate work colleagues (Davis, Schoorman, Mayer, & Tan, 2000); their managers (Creed & Miles, 1996; Mayer & Davis, 1999); groups (Costa, 2003); and the organization as a whole (Shockley-Zalabak, Ellis, & Winograd, 2000).
Thus, organizational trust has been described as a multidimensional variable that can be lateral or vertical and institutional (Costigan, Ilter, & Berman, 1998). Lateral trust refers to the trust that can exist between coworkers, peers or equals sharing a similar employment position, whereas vertical trust refers to trust between workers and their immediate superiors, their subordinates, top management, or organizations as a whole (McCauley & Kuhnert, 1992). There are other kinds of trust in organizations, aside from organizational trust, such as inter-organizational trust (Bachmann & Inkpen, 2011).
In sum, trust and justice are important human values in the workplace, and living up to these values has a great impact not only on the recruitment and the wellbeing of the employees but also on the social processes in the workplace (Pejtersen, Kristensen, Borg, & Bjorner, 2010).

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Extended methodology

COpenhagen PsychoSOcial Questionnaire (COPSOQ; Pejtersen, Kristensen, Borg, & Bjorner, 2010)

The next questions are not about your own job but about the workplace as a whole.

Scale: To a very large extent = 5; To a large extent = 4; Somewhat = 3; To a small extent = 2; To a very small extent = 1

Mutual trust between employees
Do the employees withhold information from each other? R
Do the employees withhold information from the management? R
Do the employees in general trust each other?

Trust regarding management
Does the management trust the employees to do their work well?
Can you trust the information that comes from the management?
Does the management withhold important information from the employees? R
Are the employees able to express their views and feelings?

Justice
1. Are conflicts resolved in a fair way?
2. Are employees appreciated when they have done a good job?
3. Are all suggestions from employees treated seriously by the management?
4. Is the work distributed fairly?

Trust in Organizations (Tan & Lim, 2009)

This assesses othe level of trust one has in his/her organization.

Scale: 5-point Likert-type scale ranging from 1 (strongly disagree) to 5 (strongly agree) for all items.

1. If I had my way, I wouldn't let the organization have any influence over the issues that are important to me.
2. I would be willing to let the organization have complete control over my future in the organization.
3. I would be comfortable allowing the organization to make decisions that directly impact me, even in my absence.
4. I am willing to rely on the organization to represent my work accurately to others.
5. I am willing to depend on the organization to back me up in difficult situations.

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Trust in management scale (Mayer and Davis, 1999)

Scale: 5-point Likert-type scale ranging from 1 (strongly disagree) to 5 (strongly agree) for all items.

1. If I had my way, I wouldn't let top management have any influence over issues that are important to me.(R)
2. I would be willing to let top management have complete control over my future in this company.
3. I really wish I had a good way to keep an eye on top management. (R)
4. I would be comfortable giving top management a task or problem which was critical to me, even if I could not monitor their actions.

Scoring: summative scale; (R) = Reverse-scored item.

Interpersonal trust at work (Cook & Wall, 1980)

It assesses faith in intensions of co-workers and management, as well as confidence in actions of co-workers and management.

Scale: 7 point Likert scale from 1 (strongly agree) to 7 (strongly disagree)

1. Management at my firm is sincere in its attempts to meet the workers' point of view.
2. Our firm has a poor future unless it can attract better managers.(R)
3. If I got into difficulties at work I know my workmates would try and help me out.
4. Management can be trusted to make sensible decisions for the firm's future.
5. I can trust the people I work with to lend me a hand if I needed it.
6. Management at work seems to do an efficient job.
7. I feel quite confident that the firm will always try to treat me fairly.
8. Most of my workmates can be relied upon to do as they say they will do.
9. I have full confidence in the skills of my workmates.
10. Most of my fellow workers would get on with their work even if supervisors were not around.
11. I can rely on other workers not to make my job more difficult by careless work.
12. Our management would be quite prepared to gain advantage by deceiving the workers. (R)

Scoring: summative; a simple, unweighted sum of the responses to each item in a scale or subscale, the response scale ranges being 1-7; items 2 and 12 are negatively phrased and need to be reverse scored
Faith in intentions of:

Peers - items 3,5,8
Management - items 1 , 7, 12
Confidence in actions of:
Peers - items 9, 10, 11
Management - items 2,4,6

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Organizational trust (Guinot, Chiva, & Mallén, 2013)

It assesses levels of vertical and horizontal trust, as well as general perceived trust in people and organization in general.

Please answer the following questions about your company or organization. To answer, indicate the number corresponding to the answer that best fits your opinion, with 1 being strongly disagree and 5 strongly agree.

Scale: Strongly disagree = 1, Disagree = 2, Neither agree nor disagree = 3, In accordance = 4, Strongly agree = 5.

1. Employees fully trust that this organization will treat them fairly.
2. The level of trust between supervisors and workers in this organization is high.
3. The level of trust between the people of this organization is high.
4. People depend heavily on each other in this organization.

Scoring: summative.

Trust measure items Robinson (1996)

It assesses employees' trust and trust content such as integrity, predictability and benevolence.

Scale: five-point Likert-type scale, ranging from strongly disagree (1) to strongly agree (5).

1. I believe my employer has high integrity (Integrity)
2. I can expect my employer to treat me in a consistent and predictable fashion (Predictability)
3. My employer is not always honest and truthful (Integrity [r/c])
4. In general, I believe my employer's motives and intentions are good (Benevolence)
5. I don't think my employer treats me fairly (Integrity/benevolence [r/c])
6. My employer is open and upfront with me (Integrity)
7. I'm not sure I fully trust my employer. (General [r/c])

Scoring: summative; overall trust can be reflected by the sum of all items responses; scores for trust content (integrity, predictability and benevolence) can be obtained by summing up the respective items scores. Items marked with rare reversed scored.

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INDICATOR REVIEWS