Links between Biodiversity and Ecosystem Services

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Introduction and 'State-of-the-art'

The quantitative relationship between biodiversity, ecosystem functioning and ecosystem services is still poorly understood (Balvanera et al., 2014; 2016). In recent years, many publications have appeared on this topic (e.g. Elmqvist et al., 2010; Mace et al., 2012; Cardinale et al., 2012) and many EU-funded projects addressed this issue, BioScore (www.bioscore.eu), RUBICODE www.rubicode.net; see de Bello et al., 2010; Luck et al., 2009), BESAFE (www.besafe-project.eu; see Harrison et al., 2014). Despite all the valuable results, but many questions remain, hence and now OpenNESS (www.openness-project.eu) continues to address this topic. There is also an on-going discussion as to whether biodiversity is (or should be understood as) an ecosystem service (ES) itself (e.g. Mace et al., 2012) or is the underlying concept providing ES. Especially the latter question hints at the important point that the link between biodiversity and ecosystem services is not just a matter of biophysical relations, but also one related to value dimensions and different emphasis of conservation strategies (see Jax and Heink (2015) and below). It is still unclear under what circumstances an emphasis on ecosystem services in planning and decision making is (conceptually and practically) supportive of the protection of biodiversity, or when the two aims might be conflicting. Regarding the operational, or practical, aspects, several studies and meta-analyses have furthered knowledge on the role of biodiversity in ecosystem functioning and the supply of ecosystem services (Balvanera et al., 2006; Luck et al., 2009; Bastian, 2013). However, the complexity of ecosystem functioning still poses uncertainties about the role of individual species and other components of biodiversity in the supply of ecosystem services, specifically when coupled with social-ecological systems.

Two main areas of research have helped contribute to current knowledge on biodiversity– ecosystem service linkages and are addressed here in some detail: (i) trait-based approaches, and (ii) the identification of ecosystem service providers or service providing units. Other conceptual issues are briefly highlighted under the paragraph on "remaining issues" at the end of this short paper.

A common understanding ('language') regarding the main concepts, definitions and methods to be used is essential. Two key concepts are Biodiversity and Ecosystem Services are briefly defined and discussed in Box 1 (see the OpenNESS Glossary for more detail and definitions of other terms http://www.openness-project.eu/library/glossary).

Box: Key Concepts

Biodiversity: Due to the very broad understanding of "biodiversity" by different researchers and other stakeholders, it is difficult to provide a definition that both is precise and at the same time encompasses all the different meanings attributed to it. For the sake of convenience we suggest to use in OpenNESS the definition given by the CBD which is: *"Biological diversity" means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems*. It should be kept in mind, however, that this definition leaves room for many different interpretations as to the adequate measurement variables for biodiversity and its components. Are, e.g. specific species also "biodiversity" or only the diversity of different species, regardless of their species identity? Is "functional diversity" included? Also, especially in a conservation context, often cultural aspects underlie the uses of biodiversity, e.g. when biodiversity is perceived specifically only as "native" biodiversity or "typical biodiversity" to be important, while for other stakeholders specifically "high"

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biodiversity matters (regardless of being native or typical). Here issues of values and related conservation strategies have a major influence on assessing the relevant measures of biodiversity – and in consequence also on their specific relation to ecosystem services (see Jax and Heink (2015) for details). No general definition will be able to capture all these different aspects related to the term "biodiversity". As they may be of importance to specific application fields, however, the scope of these various aspects should nevertheless be an object of conceptual and empirical research in the different context of use.

Ecosystem services: We propose to largely follow the definition given in the TEEB study and define Ecosystem Services as: *the contributions that ecosystems (whether natural or semi-natural) make to human well-being.* Their fundamental characteristic is that they provide the link to underlying ecosystem functions, processes and structures. As with "biodiversity" many different definitions and interpretations exist which are dealt with in more detail in the glossary and other synthesis papers.

Trait-based approaches

Given their effects on underlying ecosystem services, several studies have used information on functional traits to quantify ecosystem service delivery (Kremen, 2005; De Bello et al., 2010; Díaz et al., 2011). These approaches may also aid in the understanding of mechanisms of multi-functionality and trade-offs. Although knowledge on associations and trade-offs between plant traits is well established, the study of the consequences of these on ecosystem functioning and the resulting services is less well developed (Lavorel and Grigulis, 2012). De Bello et al. (2010) suggested that the multiple associations between traits and services across different trophic levels result in what they call *trait-service clusters*. Their review groups well-documented trait-service associations into clusters of ecologically-related services*,* such as clusters of traits of plants and soil organisms associated with nutrient cycling, herbivory, and fodder and fibre production. They propose that this approach will allow for the assessment of combined biotic effects on the simultaneous delivery of multiple services. Trait-service clusters would potentially serve to manage trade-offs of services associated with traits within a trophic level. For example, the same traits in plant communities that improve fodder production are likely to reduce soil carbon sequestration and might impede services associated with aesthetic and cultural values (De Bello et al., 2010). The approach can also be extended to multiple trophic levels (Lavorel and Grigulis, 2012), as well as facilitating the monitoring of clusters of services at different spatial scales. Until recently, most of the trait-based research has focused on plant trait effects on primary production (Lavorel, 2013). There is a need to extend it to a wider range of ecosystems, services and organisms. An initial endeavour to do so by Luck et al. (2012) sought to develop a framework for selecting response and effect traits which link environmental change with ecosystem services that can be applied to vertebrates.

Ecosystem Service Providers and Service Providing Units

Luck et al. (2003) has highlighted that species populations are the fundamental unit in the provision of ecosystem services and stress the need to understand the links between population dynamics and service output. They offer the concept of a Service Providing Unit (SPU) to define a population in terms of the services it generates at a particular scale instead of geographic boundaries or genetic lines. For example, the entire population of a given tree species might provide the global service of carbon sequestration, whilst regional populations of the same tree species might provide a water filtration service that benefits local communities (Luck et al., 2003). Kremen (2005) extended the SPU concept and proposed identifying key Ecosystem Service Providers (ESP) and suggested defining ESPs in terms of their functional traits and how the dynamics of functional groups of species may impact service provision. This was extended by Kremen et al. (2007) into a framework for understanding the impact of broad scale interactions between the distribution of resources, traits and land-use change on service delivery. The SPU and ESP concepts were combined by Luck et al. (2009) into the *SPU-ESP continuum* to show how the service-provider concept can be applied at the population, functional group and community levels. This produced a more nested approach to the understanding of service functions and processes and offered a detailed categorisation of outputs and their relationship to human well-being. By using examples from existing literature, they provided a classification specifying the type of ecosystems concerned, the ecological unit providing the service or SPU, its attributes and a response measure to describe the relationship between the components

of biodiversity and the level of service provision. Kontogianni et al. (2010) used the concept for valuation purposes and Syrbe and Walz (2012) extended the SPU concept to include place-based assessments and structure metrics. They focus on three concepts: Service Providing Areas (SPAs) are the areal basis for service provision; Service Benefiting Areas (SBAs) to determine where the services are needed (complementary to service generating areas); and the connecting space between providing and benefiting areas, or Service Connecting Areas (SCAs). By using landscape metrics as indicators of landscape services, they seek to estimate and evaluate landscape units and indicate spatial trade-offs between services

Typologies of relationships

The EU-funded BESAFE project has built on both the trait-based and ESP/SPU approaches to identify ecosystem service providers and evidence of their key attributes or traits for service delivery for 11 ecosystem services (Harrison et al., 2014). The resulting interconnections between biodiversity and ecosystem services have then been analysed using network analysis to explore the possibility of reducing the complexity by revealing different typologies of relationships. The BESAFE systematic review revealed that species level traits benefit a number of ecosystem services, with species abundance being particularly important for pest regulation, pollination and recreation, and species richness for timber production and freshwater fishing. Functional traits, such as richness and diversity, also displayed a predominantly positive relationship across ecosystem services, most commonly discussed for atmospheric regulation, pest regulation and pollination. Finally, community-level attributes, particularly community and habitat area, were important for improving the services of water quality regulation, water flow regulation, mass flow regulation and landscape aesthetics. The BESAFE systematic review has been extended in the OpenNESS project (EU FP7 OpenNESS Project Deliverable 3.1, Pérez Soba et al., 2015) to cover 13 ecosystem services and a wider range of biotic and abiotic attributes. The findings show that most of the biotic attributes identified in the review have a beneficial impact on ecosystem service delivery. Their contribution is related to three different clusters of attributes. The most commonly identified cluster relates to the *physical amount of vegetation* within an ecosystem, and includes habitat area, vegetation productivity, above- and below-ground biomass, stem density, species size/weight, growth rate, and successional stage. These tend to have beneficial impacts on a particular group of regulating services: atmospheric regulation (carbon storage), water flow regulation (flood protection), mass flow regulation (erosion prevention), water quality regulation (water purification) and air quality regulation. The second cluster focuses on the *presence or abundance of particular species or functional groups*. This is particularly important for the provision of freshwater fishing, timber, species-based recreation, pollination and pest regulation; a number of species-level traits (such as size or predation behaviour) are important for determining which are the most effective contributors to the ecosystem service. A third cluster, though less commonly discussed, comprises *diversity-related indicators*: species richness, species population diversity, functional richness, functional diversity, structural complexity and landscape diversity. Diversity is shown to be important for a wide range of services, including timber production, atmospheric regulation, pest regulation and pollination. Only a few biotic attributes were found to have a negative impact on ecosystem service provision. These were: species mortality rate; the abundance of certain non-native species (e.g. invasive vegetation); the presence of forest plantations which can have a negative impact on freshwater supply; and a limited number of examples where diversity had a negative effect because monocultures were found to provide a better service than polycultures.

Open problems / Issues to be discussed

Further to the issues addressed in OpenNESS (above), some 'open problems' still need further consideration, e.g.:

1. The dependence of ecosystem services on 'biodiversity' (species/ecosystems/genes) is not only a question of biophysical relations (see above) but also, and importantly, of conceptual clarity of the broad concepts of biodiversity and ecosystem services (see box 1). Do our definitions of biodiversity capture the essence of the strategies aiming at biodiversity protection? Is the distinction between 'final and intermediate ES' useful?

2. How can the relationship between biodiversity/ecosystem characteristics and their associated functions and services be quantified? What criteria and indicators are needed? Is it possible/useful to distinguish stock (=state) <-> flow (=performance) indicators? What is the effect of scale?

3. What is the carrying capacity of an ecosystem to provide services? Are there benchmark-values for measuring maximum sustainable use levels? Are there possible critical thresholds?

4. How to deal with 'bundles' of ecosystem services and aggregation of their benefits and values? Is the notion of 'Natural Capital' useful to emphasise the need to look at entire (eco)systems, not single services?

5. There is still a lack of empirical data on the link between biodiversity and ecosystem services, as well as testing of concepts (e.g. SPU) and methods (mapping & modelling) so concerted application in the case studies is essential to operationalise the concepts of ecosystem services and natural capital in practice.

Key messages

Human well-being[2]: The relation between biodiversity and ecosystem services improves our understanding of how biodiversity contributes to human well-being.

Sustainable Ecosystem Management: Information on the relationship between biodiversity and ecosystem services can help to determine carrying capacity and sustainable use levels, which is essential information for sustainable ecosystem management.

Governance: Awareness about the importance of biodiversity for the provision of ecosystem services is crucial for good governance (and vice-versa), and for encouraging integration of biodiversity conservation in sectoral policies.

Competiveness: Collection of new, empirical data and data-storage on the relation between biodiversity and ecosystem services, can help to improve the use of ecosystem services to highlight dependency of markets, and businesses, on biodiversity and make them aware that protecting biodiversity (and its supporting ecosystems) can give a competitive edge for European SMEs and companies as well as regions.

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2   The key messages are referring to the four societal challenges as identified in OpenNESS. There are certainly more societal challenges; the reduced number presented here is due to the four major challenges mentioned in the work programme of FP7 to which OpenNESS responded.

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