METHOD FACTSHEET

State and Transition Models

Introduction

State-and-transition models (STMs) are conceptual models of ecosystem dynamics after disturbances based on alternate state theory (Kachergis et al. 2011). In contrast to succession theory, which predicts that ecosystems recover from disturbances and return to a reference (undisturbed) state, alternate state theory maintains that disturbances may trigger a regime shift in critical processes (e.g. population recruitment, nutrient cycling) (Westoby et al. 1989) that will maintain the ecosystem in a state that differs from the reference state. The new state has different structural properties (e.g. functional diversity, species composition and dominance) from the reference state. The disturbances that trigger these changes are natural factors (e.g. droughts, windfalls, fire), management (e.g. clear-cutting, grazing by domestic animals), and the interactions among them; and the shifts in ecosystem condition that they trigger are irreversible in the absence of specific interventions. STMs acknowledge non-linear responses of ecosystem properties to human interventions; alternate states represent abrupt changes in ecological properties.

Given the magnitude of human disturbances on ecosystems (http://www.anthropocene.info/en/anthropocene) and how these are linked to ecosystem condition, a model of ecosystem responses to these factors can be very useful to guide the management of ecosystems and of the goods and services that they provide. STMs are used in this context: they have been increasingly adopted to represent ecosystem changes that result from management in interaction with natural biotic and abiotic drivers (see recommended reading). In OpenNESS, we use the framework as a tool to operationalise, gain a common understanding of, and communicate the importance of ecological functions and processes that underpin the provision of ES in a particular ecosystem.

STMs combine the representation of alternate states and the factors that drive the transitions among states with tables of qualitative descriptions of the states. The benefits of STMs are that they are diagrammatic, low cost, flexible and suit participatory modelling (Nicholson & Flores 2011). Participatory modelling can bring together diverse knowledge holders, build shared understanding about complex systems and create useful models to understand the system of interest (Knapp et al. 2011). When implemented as Bayesian Belief Networks, they can be a powerful tool to communicate uncertainty about state categorisation and of the factors that trigger transitions between states.

Keywords

Ecological function; Ecosystem condition; Ecosystem dynamics; Ecosystem management; Thresholds; Non-linear response; Sustainability.

Why would I chose this approach?

STMs provide the opportunity to represent ecosystems and the provision of ES as process-based and dynamic models, making explicit the critical ecological functions underpinning the provision of ES, and the drivers that affect them. Hence, they complement frequently used models of ES provision that are based on spreadsheet/GIS approaches of spatial indicators (i.e. scoring of land cover/land use typologies and landscape elements: see OPENNESS factsheets on Simple and Advanced Matrix approaches), by offering a mechanistic model of ecosystem condition as a function of ecosystem management. However, STMs can be spatially-explicit (Bestelmeyer et al. 2009) and can be used for land and territorial planning, through mapping of ecosystem states.

Scale of the model

The ecosystems that are modelled with STMs occur under specific physical conditions (i.e. a forest under certain soil and climate characteristics). Alternate states are the result of management (i.e. grazing, wood extraction, tree species planted), of natural factors (droughts, floods, wind) and of their interactions. Hence, STMs are suitable to model ES at the local scale (e.g. farm level) and at regional scales, covering areas with the same soil and climatic conditions. For example, one of the STM applications in OpenNESS modelled the Nothofagus antarctica (Ñire) forest occurring in northern Patagonia.

STMs are also applicable to other systems that present threshold responses. In particular, the diagrammatic visualisation in STMs helps to further the understanding of land managers and supports their participation in the development of the model (Nicholson & Flores 2011).

Decision objectives

STMs are models of ecosystem dynamics, and therefore appropriate to model the consequences of management decisions and other actions on ecosystem condition and on the level of ES provision. By modelling the biophysical components of the cascade model, STMs are suitable for operationalising the ‘cascade model cycle’, making explicit the consequences of decisions about ES delivery on the capacity to sustain multiple ES provision. STMs can be used in the context of adaptive management (Rumpff et al. 2011), to maintain the provision of ES within sustainable ranges (avoiding degradation thresholds), and to evaluate the consequences of actions (management and policy) on multiple ES, including the analysis of trade-offs among ES and cost-benefit analysis. In OpenNESS we explicitly use STMs to address decision-making questions related to forest and freshwater system dynamics and the impacts of these decisions on levels of ES provision.

What are the main advantages of the approach?

- Easy to use: The graphical approach, the independence from any pre-defined functional relationships and the possibility of including different sources of knowledge makes STMs a very flexible and easy to use approach;
- STMs are increasingly being applied as an approach to guide the management of ecosystems and their ES, including to assess the risk of degradation of ecosystem condition; to take proactive measures to avoid degradation; to identify specific intervention strategies and promote desirable transitions based on ecological knowledge; and to set restoration targets (Bestelmeyer et al. 2010);
- In the context of ES assessments and modelling, STMs provide a new way of describing the underlying functions that support ES provision. It is a process-based approach to the management

of ES, in which management interventions are drivers of ecosystem condition and ES provision levels;
- STMs draw on existing data from various sources and are suitable for both participatory knowledge integration and communication;
- States can be mapped, if suitable spatial data are available;
- STMs can be used in scenario analysis and are especially useful to inform adaptive management (Rumpff et al. 2011);
- STMs have an integrative approach of ecosystem functioning in response to management;
- STMs are very suited for implementation as a BBN. In these cases, ecosystem processes and management factors are modelled in a decision-support context, taking into consideration uncertainty (Bashari et al. 2009, Nicholson & Flores 2011).

What are the constraints/limitations of the approach?

- They are specific to an ecological site, so extrapolation to other conditions is limited, but knowledge on similar or comparable sites may be used to complete missing information (Bestelmeyer et al. 2010);
- The identification of thresholds and alternative states is sometimes management driven, with limited correspondence with ecological processes and real ecological thresholds. The thresholds may then be misleading. However, the models must not be understood as static, but rather as representing the best ecological knowledge about a system at a particular time, which should be tested and updated as more knowledge is generated;
- Ecological thresholds can be triggered by interacting drivers at various spatial scales (Peters et al. 2004). These may be difficult to capture without appropriate data and analysis, and/or with other knowledge based on long-term experience (Knapp et al. 2011). Also in this case, STMs must be seen as a representation of the existing knowledge about the system that needs to be open to updates as new knowledge is available;
- The degree of uncertainty about states and thresholds is often not made explicit, although this is very much recommended. Recent implementation of STMs with BBNs provides a promising alternative to overcome this problem;
- STMs may be more demanding than other forms of ES mapping, but the level of demand depends on the ecological knowledge and long-term experience about the case study;
- If implemented as a BBN, the level of model complexity needs to be evaluated prior to building the model (Nicholson & Flores 2011). There are different options to overcome a potential model complexity challenge.

What types of value can the approach help me understand?

STMs are designed for biophysical values. However they may be implemented within a broader approach to consider the socio-cultural or economic implications of a transition within the study area.

How does the approach address uncertainty?

STMs can be implemented as BBNs to explicitly model uncertainty. This refers specifically to the probability of the system being in a particular state as a function of the initial condition and the different levels of the factors (natural and management) that drive change (Rumpff et al. 2011). BBNs provide a powerful combination of predictive, diagnostic and explanatory reasoning (Nicholson & Flores 2011). STMs can be the basis for an ES cascade model if implemented as a BBN. BBN-STMs have been modelled in different ways. For instance, based on participatory modelling, Bashari et al. (2009) characterised the states of a rangeland in Queensland, Australia, derived from grazing pressure, fire and climate.

Nicholson & Flores (2011) provide two different BBN models to represent the STM in Bashari et al. (2009). First, they show the implementation in a variant of Bayesian networks – so-called dynamic Bayesian networks (DBNs) – that allow explicit modelling of changes over time. In a second model, they propose a combination of STMs and DBNs. They compare the different BBN implementations of STMs, with a focus on model complexity analysis. They show that the complexity of each model depends on the inherent structure in the problem being modelled, and conclude that for the models to be tractable, the number of transitions from each state needs to be limited, and only influenced by a small number of causal factors. They recommend an assessment of model complexity prior to any detailed modelling.

How do I apply the approach?

Building of a STM requires the identification of a reference state for a particular ecological site or ecosystem, and of the alternative states that result as a response to human interventions in interaction with the physical environment (climate, soil, nutrient contents, etc.). The reference and alternate states need to be described in terms of a series of state variables that characterise the state's ecological structures and functions (e.g. tree cover, species diversity, species composition, primary productivity, nutrient cycling). Then the drivers, natural factors and management interventions that affect state variables and that trigger change (i.e. transitions between states) have to be identified. A next step is to link the drivers of change with the states (as in Bashari et al. 2009) or with state variables (as in Rumpff et al. 2011) and to produce a catalogue of transitions. The model is revised and refined through literature searches and consultations. If the STM is implemented as a BBN, the conditional probability tables in the model have to be elicited.

In OpenNESS, we aimed to link state variables, a representation of ecosystem condition, with levels of ES provision. In this situation, two further steps are required once the STM is built: (i) to identify the important ES provided by the system, and (ii) to link levels of ES provision to levels in the state variables. In this way, the biophysical structures and functions that support ES provision are made explicit. The steps are summarised below and in figure 1:

- Step 1: Identify reference and alternate system states. This is based on specific structural characteristics, that can be recognised in the field or from data and that derive from use. Information can be derived from historical maps, field experience, scientific data, and/or local knowledge.
- Step 2: Prepare a catalogue of state variables. This step consists of identifying the structural and functional variables that characterise the states. The list is built from literature reviews, data from monitoring programs, and general knowledge about the system.
- Step 3: Build a graphical model of the states and transitions among them, including the levels of the variables associated with the transition. More than one model can be built if there are different beliefs about state transitions and underlying drivers of change.
- Step 4: Prepare a catalogue of factors that determine transitions, and describe them. In Rumpff et al. (2011), for instance, the factors are classified as 'independent environmental variables',

'processes' and (short time scope) 'management actions'. Identify time periods in which responses are expected to manifest.

- Step 5: Incorporate transition factors. Link transition factors to changes in states or state variables.
- Step 6: Refine the model iteratively.
- Step 7: Identify important ES provided by the system. Prepare a catalogue of ES and ES benefits.
- Step 8: Incorporate ES and benefits. Link levels of ES provision and benefits to states or state variables.
- Step 9: If implemented as a BBN, establish conditional probability tables.

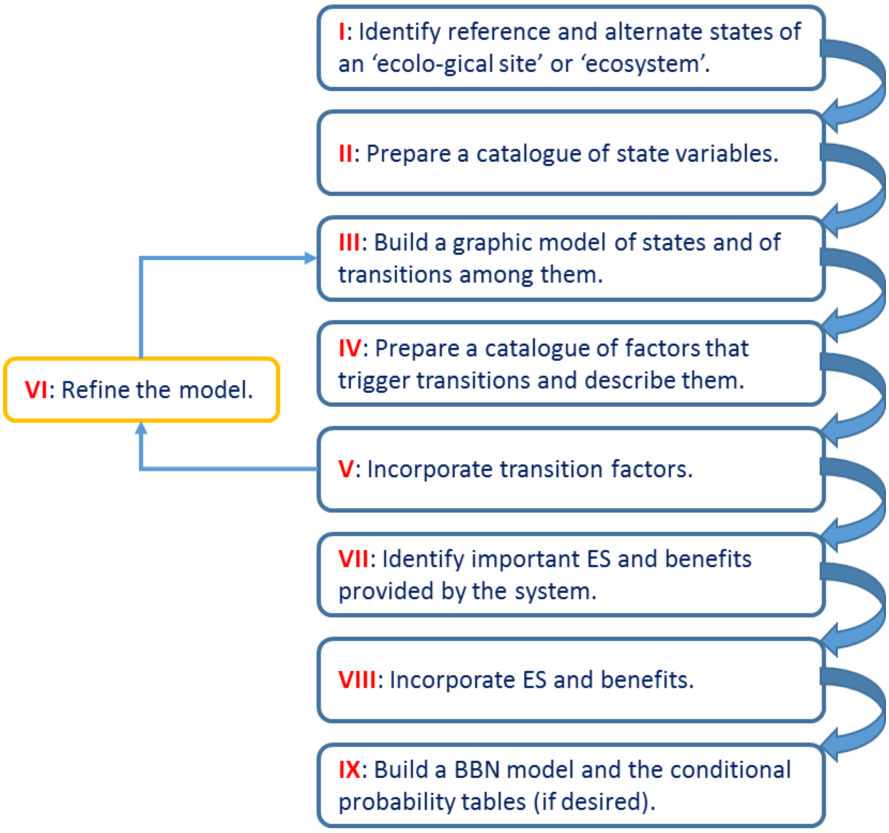

Figure 1. Steps required to build a STM, linked to ES and implemented as a BBN. Based on Rumpff et al. (2011).

Requirements

Data	☑ Data is available ☐ Need to collect some new data ☐ Need to collect lots of new data	STMs are built using different kinds of knowledge sources, i.e. historical maps and remote sensing data, time series/monitoring data, field measurements and ground-truthing, experiments, expert and practitioner's knowledge (Bestelmeyer et al. 2010).
Type of data	☑ Qualitative ☑ Quantitative	Both
Expertise and production of knowledge	☑ Work with researchers within your own field ☐ Work with researchers from other fields	STMs are used to capture all kinds and sources of knowledge that can help understand ecosystem dynamics.

	☑ Work with non-academic stakeholders	
Software	☑ Freely available ☑ Software licence required ☐ Advanced software knowledge required	There is no need for any software to build an STM. But, if implemented as a Bayesian Belief Network (BBN), the model will require the corresponding licence.
Time resources	☑ Short-term (< 1 year) ☐ Medium-term (1-2 years) ☐ Long-term (more than 2 years)	STMs are generally built with the intention of putting together all existing knowledge about a system one is familiar with. In this sense, time resources required can be < 1 year, but this assumes that most of the data and information are assembled in advance. Modelling of ES in STMs (linked to state variables) requires additional data such as primary productivity, tree growth, meat production, recreational value, and information about other cultural services.
Economic resources	☐ < 6 person-months ☑ 6-12 person-months ☐ > 12 person-months	Between 6-12 months depending on the level of information available and the kind of analysis to be performed.
Other requirements	If implemented as a BBN (as has been the case in the OpenNESS studies), it requires knowledge about BBN modelling, software, and licences.	

Where do I go for more information?

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