The importance of ecosystem resilience and phase shifts for biodiversity management

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Introduction

There exists growing evidence that human actions are influencing the planet's biosphere on an unprecedented scale, eroding many of the ecosystem services that human well-being depends on (MA, 2005). This has led to an increasing convergence of natural resource management and biodiversity conservation with new approaches focusing on the functioning of whole ecosystems rather than single species. Understanding ecosystem dynamics in the face of change is crucial to securing vital ecosystem services in the future. In this context, the need for ecosystem resilience has been emphasized to prevent potential phase shifts of ecosystems. This entails important implications for biodiversity management. In this essay I will explore the concepts of phase shifts and ecosystem resilience in order to then examine how they, firstly, affect biodiversity management practices and, secondly, influence the role of biodiversity management in the wider field of human interactions with nature.

Phase shifts in ecosystems

Ecosystems can be described as complex adaptive systems with inherent non-linearity and path dependency (Levin, 1998). It follows that they do not necessarily respond smoothly to gradual changes in slow variables, which are often caused by humans. Instead they can switch rapidly into a new regime when a threshold is passed, a process termed as phase or regime shift (Scheffer and Carpenter, 2003). The regime of an ecosystem is characterised by its structure, feedbacks, and function and different regimes can show a considerable difference in the ecosystem services they supply (Folke et al., 2004). This makes certain regimes of an ecosystem more valuable to humans than others, and regime shifts can come with considerable costs. Additionally, they are often hard to reverse or even irreversible, especially when the system shows hysteresis. Hysteresis implies that the new regime is stabilised by its own feedbacks and therefore, a reverse change in the slow variable to values before the phase shift does not lead to a shift back to the original regime (Scheffer and Carpenter, 2003). A system showing hysteresis is said to possess alternative stable states. Alternative stable states are extensively described by theory and models and Folke et al. (2004) present a range of case studies in which systems have switched to less desirable states, with some of them suggesting hysteresis, for example the clear and turbid states of a lake. Although these case studies suggest their existence, alternative stable states are hard to prove. For example Dudgeon et al. (2010) question the existence of alternative stable states in coral reefs, one of the most cited examples. These disagreements could arise from differing points of view regarding the nature of alternative stable states (Beisner et al., 2003). Neither a single stable state, nor alternative stable states are easy to prove. Therefore Scheffer and Carpenter (2003) question whether a single stable state should be the default assumption, since it could lead to costly management mistakes.

Ecosystem resilience

Ecosystem resilience is inextricably linked to regime shifts and has been defined as 'the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks' (Walker et al., 2004:2); in other words, the capacity to remain in the same regime after disturbance. It should not be confused with 'engineering resilience', which is described by the system's return time to a local equilibrium after disturbance (Peterson, Allen and Holling, 1998: 10). Ecosystem resilience is a dynamic property of the system that changes through time. Human actions often lead to a slow erosion of resilience, which goes unnoticed until a disturbance that could have been absorbed previously leads to a shift into a new regime. All the examples of regime shifts given by Folke et al. (2004) have been precipitated by human-induced erosion of resilience, for example by increased nutrient input into lakes, overfishing in coral reefs or change in disturbance regimes. Disturbances and change on different scales are important properties of many ecosystems, which are sometimes described in the idea of the adaptive cycle (Gunderson, 2000). Managing a system for least disturbance and maximum stability, assuming a single equilibrium, can erode resilience and makes the system more vulnerable to catastrophic shifts. Holling (1996:330) describes this as the 'pathology of natural resource management'. As disturbance and change is inevitable, maintaining or increasing resilience is crucial to avoid undesirable regime shifts in ecosystems.

Implications for biodiversity management practices

Static reserves and protected areas constitute the mainstay of traditional biodiversity management. This approach is likely to be insufficient, considering the importance of ecosystem resilience in an increasingly human-dominated environment (Bengtsson et al., 2003). On-going research has highlighted two key aspects which are crucial in management for resilience; firstly a focus on species that are key to ecosystem function and secondly, the consideration of cross-scale interactions (Hughes, 2005).

To maintain structure and functions of a regime it is important to understand the relationship between biodiversity and ecosystem function. For this purpose species that share common functional properties are often grouped together in 'functional groups' (Nyström et al., 2008:799). Conservation of these functional groups is crucial because the loss or addition of a group leads to greater vulnerability to change (Folke et al., 2004). For example, the Jamaican coral reefs experienced a phase shift after the functional group of grazers was first substantially diminished by fishing and then completely lost when sea urchins were reduced by disease (Hughes, 1994).

'Redundancy' and 'response diversity' have been identified as important characteristics of functional groups that ensure the stability of the function in the face of change or disturbance. Functional redundancy refers to the 'functional complementarity among species' (Nyström et al., 2008:799), the extent to which species can replace each other in one functional group. High functional redundancy can therefore provide insurance when species are lost. However, this insurance can be void if all species respond similarly to a certain change. This would constitute a low 'response diversity,' which is defined as 'the diversity of responses to environmental change among species that contribute to the same ecosystem function' (Elmqvist et al., 2003:488). For example, with up to 200 species, the functional group of fish predators in a typical central Indo-Pacific reef system has a high functional redundancy. However, due to equal vulnerability to fishing, overfishing has led to significant alterations in the food web (Bellwood et al., 2004). Genetic and population diversity can make important contributions to response diversity (Folke et al., 2004) as well as the operation of species of the same function across different spatial and temporal scales. For example, grazers on coral reefs operate on scales ranging from decimetres in the case of sea urchins, and up to hundreds of kilometres in the case of green turtles (Elmqvist et al., 2003). Since disturbances usually occur within a certain scale the operation across different scales ensures the continuation of the function. Peterson, Allen and Holling (1998) propose that strong competitive interactions within the same function and scale encourage functional diversity within scale and distribution of function across scales.

Cross-scale dynamics of ecosystems are generally regarded as crucial influences on ecosystem resilience. Both Nyström and Folke (2001) and Bengtsson et al. (2003) stress the importance of ecological memory for ecosystem resilience, because it determines the ecosystem's trajectory of reorganisation after disturbance. The sources of renewal are partially supplied from within the system in the form of biological or structural legacies and partly from support areas outside the system, with mobile link species serving as important connections (Nyström and Folke, 2001). By supplying sources of renewal, the landscape surrounding the system is therefore an important factor in ecosystem resilience. Nyström and Folke (2001: 410) use the term 'spatial resilience' to describe the 'dynamic capacity of a reef matrix to avoid thresholds at a regional scale'. Natural landscapes often consist of patches in different stages of the renewal cycle, providing habitat for early successional species as well as mature areas that ensure a trajectory of renewal in the same regime by supplying the right sources. Landscapes dominated by humans, however, are increasingly homogenised. Terrestrial or marine reserves are often implemented to supply sources of renewal and therefore resilience to the surrounding landscape. As Bengtsson et al. (2003) point out, however, most reserves do not match the temporal or spatial scale of their ecosystem dynamics or disturbance regimes. Isolated from these dynamics, they are themselves increasingly vulnerable to phase shifts if sources of renewal cannot be supplied from the intensively managed surroundings. On the one hand, connectivity to the wider landscape therefore seems to be crucial for resilience. On the other hand, it can also have negative consequences, for example by promoting the flow of pathogens or pollution. In the case of highly interconnected coral reefs, Hughes et al. (2005:382) remark that 'if too many patches of habitat degrade, the remaining healthy ones can catastrophically collapse, once a critical threshold is passed.' Using models, van Nes and Scheffer (2005) found that less connection between patches led to independent phase shifts in response to change and therefore a smooth change of the whole system. Change in highly connected patches, however, was better absorbed at first but was followed, due to a domino effect, by a catastrophic shift of the whole system.

It follows that biodiversity conservation and ecosystem resilience cannot be ensured when the system is managed in isolation using static, small-scale reserves. It has to be managed as part of the wider landscape, because 'multi-scale dynamics requires multi-scale management' (Hughes et al. 2005:383). Biodiversity management needs to be process-orientated, with a focus on functional groups instead of single species. As part of the solution, Bengtsson et al.

(2003:394) propose a number of dynamic reserves in addition to traditional static reserves, which would be temporarily limited and managed on a landscape level to 'maintain enough diversity within and among functional groups to secure buffering capacity and sustainable use of natural resources'.

Implications for the wider role of biodiversity

The increasing recognition of the importance of ecosystem functions and resilience also has a significant impact on the role of biodiversity management in the wider context of human interactions with nature. By linking biodiversity directly to the supply of ecosystem services, the resilience approach significantly boosts the importance of biodiversity. It strongly suggests that biodiversity management should become a central aspect in all human influenced landscapes and not only in reserves tucked to the peripheries. This 'mainstream' biodiversity management differs from traditional approaches because the focus is not on the intrinsic value of species and the irreversibility of extinction, but solely on the species' value for human use. From this perspective some species are more valuable than others and some species might 'fall through the cracks' (Fischer, Lindenmayer and Manning, 2006:84). For example conservation has traditionally focused on biodiversity 'hot spots', because more species can be conserved for a smaller cost. Bellwood et al. (2004:831), however, propose that 'cool spots' of low species diversity and lower redundancy and response diversity might be more important because they are more vulnerable.

Conclusion

The consideration of phase shifts and ecosystem resilience is of considerable importance for biodiversity management. It underlines the importance of maintaining key ecosystem functions across multiple scales and attributes biodiversity management an essential role in securing the supply of vital ecosystem services, shifting the focus from system efficiency to persistence in the face of change. In doing so, however, it challenges many deep entrenched ideas and faces a number of significant barriers. More research is needed to put the concepts derived from observations and models on a scientifically convincing basis and to develop techniques for more rigorous measurement of resilience that make the concept more applicable in practice (Nyström et al., 2008) However, to create truly resilient ecosystems, new management techniques, such as adaptive management, new institutions, and a better understanding of the interactions of social and ecological systems are needed. The extension of the resilience concept to social-ecological systems provides a powerful tool to 'foster communication across disciplines and between science and practice' (Brand and Jax, 2007:10) and provides hope for the pressing challenges mankind is facing.

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