Resilience and Biosphere Reserves

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Abstract

The need to understand complex systems phenomena has influenced the development of theory about sustainability and resilience in coupled systems of humans and nature. This paper summarizes the main features of ongoing research by groups of scientists and resource managers to understanding interacting adaptive cycles operating at different scales within different kinds of social-ecosystems. Emphasis is placed on enhancing the resilience of these coupled systems to reduce the likelihood of their sudden reconfiguration into domains of stability that are undesirable in the view of resource users and managers. Biosphere reserves have long acknowledged the need to think in terms of coupled social-ecosystems. Their commitment to promoting sustainability in the context of complex systems dynamics makes them ideal test sites for this kind of collaborative research. A theoretical framework for resilience analysis that can be used for cross case-study situations is described. An approach for applying it for the area of the Southwest Nova Biosphere Reserve is sketched.

Le besoin de comprendre les phénomènes des systèmes complexes a influencé le développement de la théorie au sujet de la durabilité et de la résilience dans les systèmes couplés des humains et de la nature. On résume dans cet article les caractéristiques principales de la recherche progressive effectuée par des groupes de scientifiques et des gestionnaires de ressources pour comprendre les cycles adaptatifs interdépendants agissant à des échelles différentes au sein de différents types d'écosystèmes sociaux. On met l'accent sur l'amélioration de la résilience de ces systèmes couplés pour réduire la probabilité d'une reconfiguration dans des domaines de stabilité qui ne sont pas souhaitables du point du vue des utilisateurs et des gestionnaires de ressources. Les réserves de biosphère ont depuis longtemps reconnu le besoin de penser en termes d'écosystèmes sociaux couplés. Leur engagement à promouvoir la durabilité dans un contexte de dynamique des système complexes en font des sites d'essai idéals pour ce type de recherche collaborative. On décrit un cadre de travail théorique pour l'analyse de la résilience qui peut être utilisé dans des situations d'études de cas croisées. On ébauche une approche pour l'appliquer au secteur de la réserve de la biosphère de Southwest Nova.

Keywords
Biosphere reserves, resilience, complex systems, Nova Scotia

> *We live in a rapidly changing world, and ... in a changing world, one must expect and learn to manage uncertainty (Bellwood, Hughes, Folke and Nystrom 2004).*

Introduction

The concept of the biosphere reserve emerged over 30 years ago from UNESCO as a means of combining goals of conservation of biodiversity across landscapes that were becoming increasingly dominated by human use. Batisse (2001) recalls that biosphere reserves were intended for "reinforcing the conservation of biological diversity, including genetic resources, through a world system of protected areas" and further noted that their implementation "stressed the need to ensure harmonious coexistence of rural populations with the ecosystems from which they derive their subsistence and income." At the time there were numerous systems of national parks and protected areas in existence but the biosphere reserve was novel in that the concept incorporated the idea that humans should be an integrated part of a protected area framework. It was in this unique way that the biosphere reserve concept married the goals of protected areas with the needs of human societies in working landscapes. It is interesting that a key element that distinguishes biosphere reserves from other protected areas – the idea of coupling social and ecological systems – was a tangible policy initiative that pre-dated many important theoretical insights into coupled systems of humans and nature that have developed over the past decades.

Today there exists a wide diversity of approaches to the implementation and management of biosphere reserves – a likely consequence from a rich history of implementation of the idea in many different systems by many different cultures. Many are expected to serve as models of landscape management, sustainable development and as devices for ensuring conservation of regional-scale biological processes (e.g. UNESCO 2002). Given the advances in theoretical concepts in the past two decades – coupled with the relatively long history of in-the-field implementation of the biosphere reserve concept – it is likely worth exploring how the current conceptual framework of the biosphere reserve might be enhanced by more directly considering some of that theory. In return, given the on-the-ground lessons that could be gleaned from the diversity of biosphere reserves around the world, it is worth considering how biosphere reserves might act as a useful international template on which to further enhance the development of theory.

So what theory is relevant? In the past decade, considerable attention has been paid to theories of sustainable development in coupled systems of humans and nature. Here I will focus on ideas about resilience in social-ecological systems (Gunderson and Holling 2002). These ideas demand careful consideration because they shift the focus of land management from a 'command and control' approach – maintaining a system within strictly controlled bounds – to an approach that attempts to enhance the system so that it is less likely to rapidly change into some undesirable configuration. Interestingly, the ideas about resilience in ecological systems were first proposed by Holling in the early 1970s at about the same time as the first biosphere reserves were established (Holling 1973). In the intervening 30 years both the empirical development of the biosphere reserve concept and the theoretical development of resilience have been richly enhanced.

The intent in this paper is to briefly outline central aspects of resilience theory and to consider application in the context of a specific Canadian biosphere reserve – the Southwest Nova Biosphere Reserve. While applications of this theory are few, the ideas presented here point to potential benefits. In conclusion, I draw attention to the suitability of such application to biosphere reserves and the potential for biosphere reserves to act as a testing ground for the theory.

Resilience theory and 'panarchy'

Theories of resilience in social-ecological systems are based in the area of complex system science. Complex systems exhibit both self-organizing and emergent properties. That is, the vast array of interconnections among components of the systems tend to mediate change – at least in the short term – and those interactions produce behavior in the system that is not obvious (or predictable) when one looks only at the component parts.

Non-linearity and multiple stable states

Another key aspect of complex systems is that they are non-linear – there exist a number of possible configurations where the system can be stable – that is, configurations to which the system tends to return after being disturbed. Given the right conditions, however, these 'domains of stability' can shift – sometimes dramatically. One only has to consider fisheries such as the cod fishery of Newfoundland for an illustration. Once the dominant species in the North Atlantic Ocean, cod are now virtually absent - despite ten years of restricted fishing. The system was pushed from a stable configuration with large numbers of fish to one with many fewer fish, with no signs of recovery (Hutchings 2000).

The existence of these multiple domains of stability within complex systems also means that the systems are unpredictable. Unpredictability leads to systems with the capability for behavior that can surprise us. And surprise and uncertainty are the very things that land managers and more traditional resource-based biologists abhor. How do you manage a system that can – and will – surprise you? The answer to that question lies in attempting to shift how we view the systems that we manage. That is where concepts of resilience come in to play.

Resilience and adaptive cycles

Resilience is defined as the amount of disturbance a system can absorb before it is shifted into another state that has different controlling processes and key variables. Gunderson and Holling (2000) synthesize several years work by a group of economists, social scientists and ecologists who have collectively explored the nature of coupled systems of humans and nature – referred to as social-ecological systems. They propose a metaphor for social-ecological systems that they term 'Panarchy' (Holling and Gunderson 2002). With the Panarchy metaphor, they argue that systems also consist of a set of interacting cycles – termed adaptive cycles – each phase of which can be broadly thought to exist in one of four key states at any given time: exploitation (r), conservation (K), release (Ω) and re-organization (α). The familiar r and K states form part of the so-called 'forward loop' – they are linked as systems move from being young, with considerable potential for growth, to being more stable, with more built capital and considerably higher degrees of connectedness among their components.

These states are familiar because they are the ones that we frequently observe in nature. Examples include systems such as young and old forests. Young forests tend to have rapid rates of plant growth; intense competition for light, space and nutrients; and rapid absorption and cycling of nutrients – all characteristics of the exploitation (r) stage. In older forests, mature trees have 'locked up' those same components, hence, existing in the conservation (K) stage. Mature forests are stable configurations of states – many can remain as mature forests for long periods of time, and can face considerable external disturbance and remain as forests. However, eventually, the accumulated capital – such as leaf litter and biomass stored within trees – coupled with some set of external conditions – such as, dry summers or lightening – can produce conditions, perhaps fire or an insect outbreak that can rapidly shift a forest into an alternate configuration. This is the short, but critical 'release' stage. It is short, because it usually occurs over short time scales, and critical because it is within this stage that accumulated capital is released into the system, and in which the future re-organization of the system begins. It is this latter component that is termed the 'back loop' (Gunderson and Holling 2002).

Some systems are observed to move directly through these four states in succession, while others will shift between states in various ways. Furthermore, sets of adaptive cycles interact with one-another across temporal and spatial scales – in particular, longer-term, or broader-scale cycles can sometime constrain behavior of cycles at shorter or finer scales, and cycles at finer scales can 'provoke' the behavior of cycles above them. The cycles themselves may behave in a somewhat autonomous manner, but since we know that these cross-scale interactions occur we should also know that we need to pay attention to them (Walker et al. 2002).

Features of Panarchy

The Panarchy metaphor is based on four key features that are depicted in socio-ecological systems (Holling and Gunderson 2002). First, change is episodic. There exist periods of slow accumulation of capital (natural, social and economic) interrupted by periods dominated by the release of that capital and its reorganization into a new configuration. It is argued (Carpenter et al. 2001; Scheffer and Carpenter 2003) that this episodic behavior is a result of components of the system that change rapidly interacting with those moving more slowly. These so-called 'fast' and 'slow' variables are critical to understanding how the system can suddenly shift from one configuration of states to another – a 'regime shift' (Scheffer and Carpenter 2003). A superb example is found in the examination of Caribbean reefs by Bellwood et al. (2004). In the past decade, Caribbean reefs have been transformed from coral-dominated systems to algal-dominated systems. The critical slow variables were likely a transition from a multi-species herbivorous fish community to a single species of grazing starfish coupled with slowly increasing levels of nutrients into the system. The critical fast variable responsible for the regime shift was disease that struck the starfish community, rapidly removing the remaining algal grazer. Each variable on its own might have changed the system slowly, but the two variables combined caused a regime shift.

The second feature is that patterns and processes occur in a patchy configuration at a variety of temporal and spatial scales. This is critical because it suggests that different components of the system co-exist in different parts of the adaptive cycle and so we can't simply 'add up' phenomena at different scales to arrive at some new predicted state for the future. Interactions between scales that critically structure how the system looks and behaves will always exist.

The third feature is that ecosystems tend to have multiple stable states and it is possible for the systems to shift – either through external or internal forces – between those states. This was noted above with regard to the Newfoundland cod fishery.

Finally, the fourth feature is that management typically implements policies that focus on maintaining some subset of the system in some ideal state for a given sector – this means that management typically ignores the features of ecosystems outlined above. This is observed, for example, when there are fixed rules that are designed to achieve some constant yields from the system, as in traditional fisheries management. Holling and Gunderson (2000) argue, however, that it is these very policies and management interventions that inevitably lead systems to unexpectedly change configuration, when faced with some heretofore minor disturbance. The policies designed to extract resources from the system work in the short term, but cause the system to lose resilience and ultimately shift to some other – usually undesirable – state.

Uncertainty in ecosystems abounds: we can assert that it is more likely than not that a highly connected (K-phase) system will collapse, but under what set of conditions and according to what sort of timing such an event might happen will be unknown. Perhaps it can never be known. The aims of resilience management are to manage the system so that it is better able to withstand external shocks and disturbances and to ensure that the system contains the elements that will allow it to re-organize itself following some large change (Walker et al. 2002). In short, there needs to be a new paradigm for management which focuses on systems that change in space and time. "The key to enhancing system resilience is for individuals, their institutions, and society at large to develop ways to learn from past experiences, and to accept that some uncertainties must inevitably be faced" (Redmond and Kinzig 2003).

What does all of this mean for Biosphere Reserves?

Biosphere reserves are landscapes specifically chosen because they represent coupled systems of humans and nature. They exist in areas where human activities dominate parts of the landscape, but where core reserve areas remain. The latter are both influenced by and influence the neighboring human-dominated landscape. Such coupled socio-ecological systems are complex, because they contain numerous sub-systems that act and interact over different temporal and spatial scales. As a consequence, they exhibit behaviors that are both surprising and unpredictable. These sub-systems are both ecological and social, and need to be viewed together. Importantly, institutional governance structures need also to act and interact appropriately across the multiple domains.

The biosphere reserve concept already acknowledges at least two key components that are necessary to begin managing socio-ecological systems from a resilience perspective. First, there is explicit recognition of the system as a coupled system of humans and nature. Second, there is recognition of the importance of local institutional structures for guidance and management. What may be missing from some – although probably not all – biosphere reserves, are components that seem to be missing from many other institutions that oversee resource management and protection. These missing components have to do with recognition of the system as a dynamic one, with inherent uncertainty and the potential for surprise. To ask why would prompt a hundred different answers from the existing array of reserves. As such, it is probably more useful to ask how such change in focus might be implemented.

Conducting a resilience analysis in a biosphere reserve

Research into how to translate theories of resilience into practical management approaches is at the early stages. Much still needs to be learned. Walker et al. (2002) outline a four step process for conducting such an analysis within a generic social-ecological system. The process is preliminary, and is based on experiences in several regions of the globe, including Sweden, the US and Australia. Furthermore, Walker et al (2002) note that many of the approaches they outline are being tested and implemented by various groups of stakeholders throughout the world. What is novel about the resilience approach is that the ideas are being considered within a common theoretical framework and approach, which can aid in assessing utility and in cross case-study comparisons. It is more likely that progress will be made in the translation of theory to management with such a theoretical framework and operational structure as a basis.

Briefly, the four steps outlined by Walker et al. (2002) are:

1. Establish the important and/or valued attributes of the social-ecological system;
2. Determine a range of alternative trajectories for the system;
3. Conduct a quantitative analysis of the system, using models where possible, to reveal the critical variables within the system that most affect its resilience;
4. Evaluate how desired trajectories for the system might be attained through management and policy using input from key stakeholders.

These steps are fundamentally dependent on first identifying the relevant stakeholder groups. Their participation ensures not only that local insight is input into the system, but also that solutions to any problems revealed will have more legitimacy and likelihood of being successfully implemented.

Given that biosphere reserves explicitly attend to social and ecological aspects of the areas they exist within and that they rely on the involvement of local communities, they would be appropriate areas for exploring this management approach. The following example, considers application to a biosphere reserve in Nova Scotia.

Southwestern Nova Biosphere Reserve as an example

The Southwestern Nova Biosphere Reserve (SNBR) was granted biosphere reserve status in 2001 (SNBR 2001). The area consists of five counties – each of which borders the Atlantic Ocean or Bay of Fundy in the Canadian province of Nova Scotia. The numerous local communities consist of thriving lobster and inshore fisheries, inland farming and forestry, and several millennia of Native use and culture. A diversity of cultural heritages co-exists in small towns and villages that are primarily focused on the sea, but inland, forestry and mining activities also surround two large protected areas – the Tobeatic Wilderness and Kejimikujik National Park. The system is truly complex – with a diversity of land-use histories, ecosystem functions and services and a wide range of potential trajectories.

How might a resilience analysis proceed within the SNBR? The actual process would, in part, emerge from consultation with the biosphere reserve committee itself. Here I focus on Walker et al.'s (2002) four steps – in particular the first two – outlining how the process can build upon existing activities within the biosphere reserve, and what might differentiate it from other superficially similar processes.

Initially, the stakeholders in the region need to be identified and brought together in a consultative process. The SNBR has done this through creation of the Southwest Nova Biosphere Reserve Association, and by extending collaboration further, in part, through other organizations and groups that were identified in the preliminary Cooperation Plan (Baxter 2002). The statements about vision, mission, and goals of the Association would be an initial starting point for a resilience analysis. Review of the stakeholders who agree to participate in the analysis would be desirable just to make sure that groups who might not normally participate in such activities, but who could be critical to the success or implementation of any subsequent management, are included.

Establishing socio-ecological system attributes

As noted, the first step of a resilience analysis would be to examine the historical record of social and ecological interactions in sufficient depth so as to identify how the system has transformed itself in the past. Such an analysis serves several purposes. It helps to bound the system in both space and time, and also helps to reveal major events and to identify attributes and cycles such as those described above. Data from historic and present-day monitoring systems will be essential, and it is likely that stakeholder groups – with their existing networks of knowledge – will provide further information. In Southwest Nova, the first step would likely build upon ideas discussed at the science assessment workshop hosted by the NS Centre for Geographic Sciences (e.g. Maher 2001), GIS analyses of regional scale landscape changes in recent decades (e.g. Colville and Rozalska 2003) and reviews of data from the numerous research and monitoring projects, both completed and on-going, throughout the region. These would all be essential components of the resilience analysis, but there is an expectation that additional data needs and sources would be identified as the process of conducting the historical review proceeded.

In addition to bounding the system in space and time, review of the historical record is intended to interpret the occurrence of major events as a function of changes in one or more key state variables. In particular, the record can be used to identify points in time when major thresholds within the system were crossed (Walker and Meyers 2004) and can help to identify which fast and slow variables might have been responsible. Such an analysis should also reveal the current configuration of the system within the adaptive cycle. Alison and Hobbs (2004) present an example of such a historical analysis for the Australian wheat belt. They suggest that two major adaptive cycles have occurred over the past 120 years. The first was characterized by the initial exploitation of the land coupled with the clearing of native vegetation. Collapse was triggered by low commodity prices associated with the Great Depression. The second cycle came with the post second world war boom and was driven in part by cheap fuel, with a collapse following overproduction on world markets. Although the history of events may be well known, it is the identification of major trajectories and thresholds in the system – and the coupling of those events with key fast and slow variables – that forms the novel core of the analysis.

Within SNBR such an analysis might reveal any of a series of important events coupled with the stages of the adaptive cycle. For example, European settlement began transforming salt marshes as early as 1604 and gradual exploitation of the landscape by the original Acadian settlers would have progressed rapidly (r-K; the forward loop) until the mid-1700s when Acadians were forcibly removed from their land (release/reconfiguration; the back loop). The subsequent influx of the new settlers began a second forward loop, with differential exploitation of the land. These changes include logging and gold mining in the 19th century, continued transformation of salt marshes and exploitation of fisheries, hydroelectric power development with water level controls – for example, Lake Rossignol – and improvements in forest management during the 20th century. More recently, the whole region has been subjected to atmospheric deposition of pollutants (including "acid rain") associated with industrial development at the continental scale. This may have contributed to triggering the collapses of local salmon stocks (Watt et al. 2000).

After identifying the bounds of the system through this retrospective analysis, one of the main outcomes should be that the system's critical fast and slow processes and their associated variables have been identified. In addition, the analysts should have gained some insight into how they interact. It is these interacting variables that typically cause systems to shift from apparently 'stable' states into new domains of attraction. Since the goal of resilience analysis is to identify where such domains might lie, there is a need to discover current attributes of the system that confer resilience, and some of the possible pathways to get to alternative – more desirable – stable states.

Determining alternative trajectories

The second step of analysis is to determine what possible trajectories the system might move along – either by design or default. The range of trajectories should be broad – encompassing a diverse set of possible futures – but the number of possibilities should be limited to 3-5. The range of trajectories that are envisioned for the system can be used to develop scenarios for envisioning the system's future (Peterson et al. 2003). These scenarios should be based on the constraints of the system – for example, they should be realistic and conform to known physical laws – but should also incorporate, to the extent possible, some of the uncertainties and ambiguities within the system. By linking external shocks and disturbances, people's positive and negative visions for the future, and policies that might be imposed on the system, scenarios can be used to help stakeholders determine which critical drivers within the system need to be dealt with in order to achieve desirable futures – or avoid undesirable ones.

Modeling and evaluation

While the third and fourth steps would be dependent on the outcomes of the first two, the third step strives to develop models of systems, or system components, that can be used to explore their behavior and resilience under different kinds of assumptions. Such models are developed using the data on historical change and potential drivers generated in steps 1 and 2. Models can be conceptual or mathematical – and will most likely be both. They should strive for simplicity, while retaining the key components and behavior of the system they represent (Scheffer and Carpenter 2003). Ideally such models couple social and ecological components of the system at multiple spatial scales (e.g. Carpenter and Brock 2004) but the formulation and study of such models is in its infancy. These models, coupled with the visions and scenarios developed by stakeholders, would then be used to explore pathways to alternate configurations of their system.

It needs to be borne in mind that when considering such alternate configurations, some may be more or less desirable than current ones. In fact, either is possible. The goal of management, then, is to either build resilience into the current system (if its configuration is desirable, and stakeholders want to stay within the domain in the face of disturbance) or to direct the system from a currently stable, but undesirable configuration, into one that is more desirable. How to effect such changes is an active area of research (Walker et al. 2002).

My point here is not to provide excessive detail about how to proceed with such an analysis, but to point out that a diverse array of viewpoints and sources is necessary, and the utility comes from identifying those critical points where rapid change has occurred within the system in the past. Knowing those points leads to an increased understanding of the key variables that interact to cause thresholds in the system state. Such a perspective would provide a solid set of guiding principles for biosphere reserve committees, and would feed into models that could be more readily employed for management.

The Future....

Biosphere reserves exist as formal entities throughout the world. They act as a useful conduit that helps link social systems more tightly with protected areas and with the services provided by the ecosystems within which they are co-embedded. Increasingly, parks are considering their protection mandates from the context of a broader ecosystem – most notably by using the Greater Ecosystem concept and developing cooperative endeavours and partnerships beyond their jurisdictional boundaries. Biosphere reserves on the other hand, which already have broader scope, may struggle with means to implement some rather daunting policy and management challenges, which are common to multi-jurisdictional and multi-scale management and planning. Resilience theory and analysis offers a useful framework to bring social and ecosystem concepts together, but critical research that can link together theory and practice is necessary.

Biosphere reserves offer an extremely useful template for such research because they inherently start from the premise that the system of interest is a coupled social-ecological system. Existing stakeholder groups could help bring together the myriad sets of time series of data that already exist in many forms for many areas and aid in identifying which variables should continue to be tracked in time, and which new variables should be followed. Both activities will aid in furthering our ability to identify the presences and causes of thresholds in systems (Scheffer and Carpenter 2003; Walker and Myers 2004). Working with social, economic and ecological modelers, biosphere reserves could also be used as test beds for the development of new models and as templates for experiments to test those models. Finally, the considerable challenges of translating the findings of such analyses into management strategies would be aided considerably by conducting such management experiments in the context of the biosphere reserve.

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