Applying resilience thinking

Seven principles for building resilience in social-ecological systems

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Introduction

Over the past decades, few concepts have gained such prominence as resilience, the capacity of a system to deal with change and continue to develop. There has been an explosion of research into ways to promote or undermine the resilience of various systems, be it a landscape, a coastal area or a city. However, the multitude of suggested factors that enhance resilience has led to a somewhat dispersed and fragmented understanding of what is critical for building resilience and how an understanding of these factors can be applied.

A resilience approach to sustainability focuses on how to build capacity to deal with unexpected change. This approach moves beyond viewing people as external drivers of ecosystem dynamics and rather looks at how we are part of and interact with the biosphere – the sphere of air, water and land that surrounds the planet and in which all life is found. One of the main ways in which people depend on and interact with the biosphere is through their use of different ecosystem services, such as the water we use for cooking and drinking, the crops we grow to nourish ourselves, regulation of the climate and our spiritual or cultural connections to ecosystems. People also change the biosphere in a myriad ways through activities such as agriculture, and building roads and cities. A resilience thinking approach tries to investigate how these interacting systems of people and nature – or social-ecological systems – can best be managed to ensure a sustainable and resilient supply of the essential ecosystem services on which humanity depends.

This publication is a popular summary of the book "Principles for Building Resilience: Sustaining Ecosystem Services in Social-Ecological Systems", published by Cambridge University Press (2014). This book, in turn, expands on the comprehensive review "Towards principles for enhancing the resilience of ecosystem services" published in the journal Annual Reviews of Environment and Resources (2012). Both these publications reviewed and assessed the different social and ecological factors that have been proposed to enhance resilience of social-ecological systems and the ecosystem services they produce. They present a set of seven principles that are considered crucial for building resilience in social-ecological systems and discuss how these principles can be practically applied. The seven principles are 1) maintain diversity and redundancy, 2) manage connectivity, 3) manage slow variables and feedbacks, 4) foster complex adaptive systems thinking, 5) encourage learning, 6) broaden participation, and 7) promote polycentric governance systems.

In the following pages, each principle is presented along with an example of how it has been applied. Of course, there are no panaceas for building resilience. Indeed, all the principles presented here require a nuanced understanding of how, where and when to apply them, and how the different principles interact and depend on one another. Before applying any of the principles, it is essential to consider what you want to build resilience of, and to what (e.g. fires, floods, urbanization). Simply enhancing the resilience of the existing ecosystem services in a landscape can entrench and exacerbate inequalities, such as where poor urban communities suffer the effects of flooding caused by agriculture or forestry activities on privately owned land upstream. Important trade-offs exist between different ecosystem services (e.g. crop production and biodiversity), and it is not possible to enhance the resilience of all ecosystem services simultaneously. With these caveats in mind, the seven principles provide guidance on key opportunities for intervening in and "working with" social-ecological systems to ensure that they remain resilient and able to provide the ecosystem services needed to sustain and support the well-being of people in a rapidly changing and increasingly crowded world.

Principle one

Maintain diversity and redundancy

In a social-ecological system, components such as species, landscape types, knowledge systems, actors, cultural groups or institutions all provide different options for responding to change and dealing with uncertainty and surprise.

Small-scale farmers often plant several different food crops so that failure of any one crop will not have catastrophic impacts on food provision. Similarly, natural resource harvesting systems, which target a number of different species, are more resilient than systems which target single species. Evidence from several other fields of study suggests that systems with many different components are generally more resilient than systems with few components. Functional redundancy, or the presence of multiple components that can perform the same function, can provide 'insurance' within a system by allowing some components to compensate for the loss or failure of others. In short, redundancy is embodied in the saying "don't put all your eggs in one basket".

Redundancy is even more valuable if the components providing it also react differently to change and disturbance. This is what we call response diversity (differences in the size or scale of the components performing a particular function give them different strengths and weaknesses, so that a particular disturbance is unlikely to present the same risk to all components at once). For example, seed dispersal in Ugandan forests is performed by a range of different-sized mammals, from mice to chimpanzees. While the small mammals are negatively affected by local disturbances, the larger, more mobile species are not and can therefore maintain their function as seed dispersers.

Within a governance system, a variety of organisational forms such as government departments, NGOs and community groups can overlap in function and provide a diversity of responses, because organisations with different sizes, cultures, funding mechanisms and internal structures are likely to respond differently to economic and political changes. Diverse groups of actors with different roles are critical in the resilience of social-ecological systems, as they provide overlapping functions with different strengths. In a well-connected community, where functions overlap and redundancy is present, creativity and adaptability can flourish.

A diversity of users and managers can also safeguard the sustainable use of a resource. For example, within fishing communities, people of different ages, genders and financial means may favour different fishing methods and types of gear. This diversity enhances the ability of the whole community to detect and understand ecological changes because each user has a perspective on a different part of the system.

Investment in diversity and redundancy can enhance the resilience of people's livelihoods because it enables people to adjust in response to changes in the market or the environment. For example, a substantial number of farmers in the drier parts of South Africa and Namibia have shifted from cattle ranching to wildlife ecotourism in response to a growing market preference for cultural ecosystem services. Farmers are more easily able to make this switch if the natural biodiversity on their farms is relatively intact.

How can we maintain diversity and redundancy?

Management can and should recognize and incorporate the value of diversity and redundancy in the management of social-ecological systems in order to build resilience. This can be achieved by paying attention to the following aspects:

Conserve and value redundancy. Redundancy is seldom explicitly conserved or managed, but is just as important as diversity in providing resilience. Particular focus should be paid to important functions or services with low redundancy, such as those controlled by key species or actors. In some cases it may be possible to increase the redundancy associated with these functions.

Maintain ecological diversity. Biodiversity is essential for ecosystem services such as pollination, pest control, nutrient cycling and waste assimilation. In addition, natural biodiversity can improve the resilience of these services by providing a reservoir of redundancy and response diversity and by reducing the dependence of agricultural systems on external inputs of fodder, fertilizers and pesticides. Strategies for maintaining or enhancing ecological diversity include maintaining structural complexity in landscapes, establishing buffers around sensitive areas, creating corridors for connectivity and controlling overabundant invasive species. In an urban context, 'green infrastructure' in the form of vegetated open space networks can be a more resilient way of providing ecosystem services such as storm water management, compared to 'grey infrastructure' such as concrete pipes.

Build diversity and redundancy into governance systems. Organisations need to recognise and better incorporate the value of diverse sources of knowledge. Provided this is balanced against costs and the risk of conflicting agendas, a diversity of perspectives can improve problem solving and support both learning and innovation. This can allow for quicker recovery after a disturbance.

Focus less on maximum efficiency, even if it costs more. Conventional economic thinking promotes maximum efficiency, while resilience thinking encourages policies that can better cope with ecological, market or conflict-related shocks. Alternative development programmes can be guided by principles of disparity and response diversity. For example, in farming communities livelihood options that are dissimilar to farming, such as a tourism-related activities rather than alternative types of farming, will provide greater response diversity and thus resilience to shocks. Specific incentives can be created to encourage such diversification at the individual farmer level.

Key message

Systems with many different components (e.g species, actors or sources of knowledge) are generally more resilient than systems with few components. Redundancy provides 'insurance' within a system by allowing some components to compensate for the loss or failure of others. Redundancy is even more valuable if the components providing the redundancy also react differently to change and disturbance (response diversity).

PHOTO T. DAW

Case study

Livelihood diversity and redundancy in coastal communities in East Africa

Along the coast of East Africa, households often engage in small-scale fisheries as part of a diverse livelihood portfolio which might include working in tourism, agriculture or casual labour. While households may maximise their total income by specialising in a single livelihood activity, households who have a portfolio of options tend to be more resilient, particularly if different livelihood activities are not affected by the same disturbances (i.e. the different activities provide response diversity and redundancy in terms of livelihood options). For example, in households with diverse livelihood portfolios, fishing activities can continue when the tourism sector suffers low numbers of tourists due to global perceptions of security. This provides some resilience in the face of impacts on any particular livelihood source. A diversity of livelihoods also provides more flexibility in the face of declines in livelihoods such as fishing. It has been shown in Kenya, Tanzania, the Seychelles, Mauritius and Madagascar that coastal fishers are more likely to leave a fishery in response to declining catches if they come from households with more diverse livelihood portfolios. Not only does such livelihood flexibility increase the resilience of individual households, it also reduces the pressure on the parts of the system producing a particular ecosystem service, such as a fishery, thereby enhancing resilience.

Principle two

Manage connectivity

Connectivity can be both a good and a bad thing. High levels of connectivity can facilitate recovery after a disturbance but highly connected systems can also spread disturbances faster.

Connectivity refers to the structure and strength with which resources, species or actors disperse, migrate or interact across patches, habitats or social domains in a social-ecological system. Consider, for example, patches of forests connected in a landscape: the forest landscape is the system, the forest patches are parts of the system. How they are linked together determines how easy it is for an organism to move from one patch to another. In every system, connectivity refers to the nature and strength of the interactions between the various components. From a social network perspective, people are individual actors within a system embedded in a web of connections.

Connectivity can influence the resilience of ecosystem services in a range of ways. It may safeguard ecosystem services against a disturbance either by facilitating recovery or preventing a disturbance from spreading. The effect on recovery is demonstrated in coral reefs. Closely situated reef habitats with no physical barriers enhance recolonisation of species that may have been lost after disturbances such as storms. The basic mechanism is that connections to areas that serve as refuges can accelerate the restoration of disturbed areas, thus ensuring the maintenance of functions needed to sustain the reef and their associated ecosystem services.

Perhaps the most positive effect of landscape connectivity is that it can contribute to the maintenance of biodiversity. This is because among well-connected habitat patches local species extinctions may be compensated by the inflow of species from the surroundings. Reduced connectivity caused by anthropogenic fragmentation, like road or dams, has a negative effect on population viability, particularly among large mammal populations. The Yellowstone-to-Yukon (y2y.net) project in North America is an example of conservation planning that reconnects large habitat patches by re-establishing wildlife corridors. Through a variety of collaborative initiatives with diverse stakeholder groups, Y2Y's primary objective is to connect eight priority areas that function as either core wildlife habitat or key corridors in an area spanning 1.3 million square kilometres.

However, too much connectivity can also be a problem. Limited connectivity can sometimes boost the resilience of an ecosystem service by acting as a barrier to the spread of disturbances such as a forest fire. On the other hand, an overly connected system may reduce the probability of population survival when all populations are affected by the same disturbance, for instance a fire or disease.

In human social networks, connectivity can build resilience of ecosystem services through enhanced and improved governance opportunities. High levels of connectivity between different social groups can increase information sharing and help build trust and reciprocity. Certain actors can serve as connectors to other actors and bring in outside perspectives and new ideas to local issues.However, just as high landscape connectivity can increase the risk for simultaneous exposure to a disturbance, well-connected actors with similar types of knowledge, and preferences for immediate gains over long-term resilience, can lead to negative outcomes. Studies show that when homogenisation of norms occurs, the explorative ability of social actors drops, leading to a situation where the network members all think in the same way and may believe they are doing well while they are actually heading towards unsustainable pathways.

How can we manage connectivity?

As with all principles, putting them into practice is inevitably context dependent. To operationalise connectivity is an ambitious endeavour, but a few guidelines include:

Map connectivity. In order to understand the effect of connectivity on the resilience of an ecosystem service, the first step is to identify the relevant parts, their scale, their interactions and strength of connections. Once this is done, visualisation and network analysis tools can help reveal the structure of the network.

Identify important elements and interactions. To guide possible interventions and optimise connectivity, it is important to identify central nodes or isolated patches in the system. This helps to identify vulnerable and resilient parts of the system.

Restore connectivity. This involves the conservation, creation or elimination of nodes. One example is the Monteregie Connection project in southern Quebec, Canada. Here, forests and people are connected to make the landscape and its ecosystem services more resilient to environmental change.

Optimise current connectivity patterns. In some cases, it may be useful to reduce or structurally change the connectivity of a system (e.g. by making it more modular) to increase the resilience of a system. For instance, the loss of electricity across the eastern USA and Canada in 2003, which affected some 50 million people, is an example of a network where local failures in a highly connected system eventually led to a total, systemic collapse.

Key message

Connectivity can both enhance and reduce the resilience of social-ecological systems and the ecosystem services they produce. Well-connected systems can overcome and recover from disturbances more quickly, but overly connected systems may lead to the rapid spread of disturbances across the entire system so that all components of the system are impacted.

PHOTO P. LANGLOIS

Case study

The provision of ecosystem services across a multifunctional landscape in Quebec, Canada

The Montérégie, located in southwestern Quebec is a patchwork of agricultural fields, forests, and villages near the major city of Montréal. The area supports numerous recreational and livelihood activities including hiking, hunting, maple syrup production, and farming. Across this multifunctional landscape, researchers identified six well-defined bundles of ecosystem services that are clustered in specific areas of the landscape and map onto well-known social-ecological subsystems. For example, a "village" bundle characterized by high values for forest recreation, carbon sequestration, soil phosphorus, soil organic matter, water quality, and deer hunting and with lower values for tourism, nature appreciation, pork production and crops, corresponded to places on the landscape that contained vibrant village communities. The other bundles, mapped at a municipal level, were identified as cropland, crops and pork, tourism, exurban, and cottages. The presence of bundles that exist repeatedly across the landscape supports the idea that there is a relationship between structural elements of the landscape, such as connectivity, and the provision of ecosystem services. While much remains to be understood regarding the direct effects of landscape connectivity on the provision of ecosystem services, recent research in the Montérégie demonstrates that forest fragments affect ecosystem service provision in surrounding agricultural fields, such that managing habitat fragmentation can help to increase the quantity and resilience of services.

Principle three

Manage slow variables and feedbacks

Social-ecological systems can often be “configured” in several different ways. In other words, there are many ways in which all the variables in a system can be connected and interact with one another, and these different configurations provide different ecosystem services.

Imagine an ecosystem such as a freshwater lake that provides you with readily accessible drinking water. The quality of this water is linked to slowly changing variables such as the phosphorus concentration in the sediment, which is in turn linked to fertiliser runoff into the lake. In the social domain, legal systems, values and traditions can also be important slow variables. They can affect existing ecosystem services, for instance, through agricultural practices, such as when and how much fertiliser is used in the fields surrounding a lake.

Feedbacks are the two-way ‘connectors’ between variables that can either reinforce (positive feedback) or dampen (negative feedback) change. An example of reinforcing feedback is introduced grasses in Hawaii that cause fires, which promote further growth of the grasses and curb the growth of native shrub species. More grass leads to more fire which, in turn, leads to more grass. This becomes a loop and self-reinforcing feedback. An example of a dampening feedback is formal or informal sanctioning or punishment that occurs when someone breaks a rule. The appropriate punishment can prevent further misbehaviour and discourage others from misbehaving in future.

How can slow variables and feedbacks enhance resilience?

Social-ecological systems are complex adaptive systems, or self-organising systems that can adjust and reorganise in response to disturbance and change, such as floods or the migration of people into urban areas. In most cases, dampening feedback helps to counteract disturbance and change so that the system recovers and keeps working in the same way, producing the same set of ecosystem services.

An example of this is the shift from clear to algae-dominated water in shallow lakes. Clear water shallow lakes usually have many rooted plants growing on the lake floor. These plants absorb phosphorous and nitrogen runoff from agricultural and urban development in the surrounding catchment and help to keep the water clear. In other words, they provide a damping feedback that counteracts the effects of nutrient pollution. However, there is a limit to how much disturbance or change a system can be exposed to before the dampening feedbacks are overwhelmed. If this happens, some feedbacks in the system may be broken, and other, new feedback connections may form. The system may then become configured in a different way, and produce a different set of ecosystem services. In the case of the lake, increasing agriculture in the surrounding area might result in phosphorous and nitrogen levels in the water (slow variable) that eventually exceed the absorptive capacity of the plants. Once this threshold is crossed, excess nutrients in the water lead to growth of free-floating algae. The algae in turn reduce light penetration, gradually leading to the death of the rooted vegetation and the loss of the dampening feedback they provided. Restoring a clear water regime usually requires repeated manual removal of algae, and the reduction of nutrient runoff to a level far lower than what it was before the regime shift occurred. Only then may the rooted plants re-establish themselves and help recreate a clear water regime.

How can we manage slow variables and feedbacks?

The key challenge in managing slow variables and feedback is identifying the key slow variables and feedbacks that maintain the social-ecological regimes which produce desired ecosystem services, and identifying where the critical thresholds lie that can lead to a reconfiguration of the system. Once this is known, even tentatively, the following guidelines can be applied:

Strengthen feedbacks that maintain desirable regimes. For example, hard coral reefs provide ecosystem services such as fisheries and ecotourism, but stresses such as climate change and fishing can cause the system to shift to a regime dominated by seaweed. The resilience of the hard coral regime can be enhanced by promoting the abundance of herbivores, such as parrot fish, that graze on seaweed and thereby provide a dampening feedback. Governance structures that prevent overfishing and protect reef users can also create dampening feedbacks that helps maintain the hard coral regime.

Avoid actions that obscure feedbacks. Certain activities and subsidies can mask or distort dampening feedbacks. Within the fishing industry, most organisations are legally restricted to a defined geographic location. This means that they have an incentive not to overfish, as it would undermine their longer term livelihood options. However, marine 'roving bandits', illegal and unregistered fishing vessels that move around the world and deplete local fisheries, undermine local institutions as they have no incentive to ensure the sustainability of fisheries in particular places. In other words, they sidestep the feedback between fish stocks and fish harvest by continuously moving around the world.

Monitor important slow variables. This is crucial in order to detect slow changes that may cause the system to cross a threshold and reorganise into a different regime. However, financial constraints are causing monitoring programmes all over the world to be cut. Understanding the role of slow variables and feedbacks can help managers recognise that investing in monitoring programmes that focus on the variables that underlie system functioning can be very cost-effective.

Establish governance structures that can respond to monitoring information. Knowledge and monitoring information is not enough to avoid regime shifts that can threaten ecosystem services. Establishing governance structures that can effectively respond to monitoring information is equally critical. One innovative example is the approach applied in the Kruger National Park in South Africa. Their system called "thresholds of potential concern" is based on constantly updated knowledge about key environmental indicators. If monitoring indicates that a critical threshold has been reached or is about to be reached, it triggers a formal meeting where it is required that a decision is taken on whether to take remedial action or adjust the suspected threshold to a new level.

PHOTO R. KAUTSKY/AZOTE

Case study

Avoiding poverty traps in Tanzania

While feedbacks can help keep a system in a desirable regime, they can also lock a system into an undesirable configuration. For instance, in drought-prone areas of Tanzania, population growth has increased the demand for crop production and reduced fallow times. This has led to the depletion of organic matter in the soil and a drop in soil fertility. This, in turn, means that crop harvests are low, and that farmers have little or no surplus to sell, and therefore no money to buy fertilisers to restore or increase soil fertility. The consequence is that they become trapped in a vicious cycle of poverty. In these cases it may be necessary to disrupt or weaken the feedbacks that lock the systems in an undesired configuration. In Tanzania, for instance, rainwater harvesting and conservation tillage can help restore soil fertility and reduce the impacts of drought. This can help increase harvests so that small-holder farmers start accumulating wealth that they can use to buy fertilisers, further improve harvests, and break the poverty trap in which many are stuck.

Key message

In a rapidly changing world, managing slow variables and feedbacks is often crucial to keep social-ecological systems "configured" and functioning in ways that produce essential ecosystem services. If these systems shift into a different configuration or regime, it can be extremely difficult to reverse.

Principle four

Foster complex adaptive systems thinking

In order for us to continue to benefit from a range of ecosystem services, we need to understand the complex interactions and dynamics that exist between actors and ecosystems in a social-ecological system. Management based on 'complex adaptive systems thinking' that appreciates these interactions and the often complex dynamics they create can enhance the resilience of social-ecological systems.

As the complexities of the world around us become more apparent, our understanding of how to behave in it changes accordingly. Researchers across a wide range of disciplines now debate, embrace and advocate complexity thinking as imperative for understanding and dealing with pressing current social-ecological challenges. Nevertheless, fostering a change in people's frame of reference is much more than just adding to their knowledge base; it implies changing their mindset and behaviour.

A complex adaptive systems (CAS) approach means stepping away from reductionist thinking and accepting that within a social-ecological system, several connections are occurring at the same time on different levels. Furthermore, complexity thinking means accepting unpredictability and uncertainty, and acknowledging a multitude of perspectives.

To understand a social-ecological system we need to understand how actors within the system think, and how their 'mental models' influence the actions that they take. Mental models are cognitive structures upon which reasoning, decision making and behaviour are based. This means gaining insight into how an actor understands a system, how he or she manages it and how he or she reacts to any changes within the system. Today, managers increasingly recognise that there can be no definite formulation or one-size-fits-all solution to a problem. Although there is limited evidence that CAS thinking directly enhances the resilience of a system, there are several examples of how it contributes to it. One example is the Kruger National Park in South Africa. There, management has moved away from strategies to keep ecosystem conditions, such as elephant populations and fire frequencies, at a fixed level and instead allows them to fluctuate between specified boundaries. The use of threshold indicators provides managers with warning signals when a component of the system (e.g. elephant numbers) is approaching a critical point. The overall intention is to reduce human intervention (and investment) and increase the variety of ecosystems and habitat types.

How can we foster CAS thinking?

CAS thinking can be developed, fostered and applied in different ways based on the following guidelines:

Adopt a systems framework. This can help people to organise their thinking and crystallise understanding of interdependencies and relationships between humans and their environment.

Expect and account for change and uncertainty. This can be done by employing a structured process such as scenario planning to explore and evaluate alternative development pathways and assess the intended and unintended consequences of different decisions. Collaborative processes that encourage CAS thinking are more likely to foster resilient systems. A variety of systematic, participatory methods can help engage different groups with different interests and knowledge.

Investigate critical thresholds and non-linearities. When a threshold is crossed there are important implications for management of an SES. It is therefore crucial that management purposefully/deliberately considers system boundaries and thresholds.

Match institutions to social-ecological systems processes. This may imply institutional change or restructuring of responsibilities and expertise to move from traditional resource-by-resource management to more integrated SES management.

Recognise barriers to cognitive change. Those benefiting from existing regimes of a system may resist adopting CAS thinking because they fear it may encourage openness to new and surprising elements that might compromise their position.

Key message

Although CAS thinking does not directly enhance the resilience of a system, acknowledging that social-ecological systems are based on a complex and unpredictable web of connections and interdependencies is the first step towards management actions that can foster resilience.

PHOTO J. SENDZIMIR

Case study

New river management for the Tisza River Basin

The evolution of management paradigms in the Tisza River Basin in Europe is an example of how CAS thinking has supported change in approaches to river management. With a mountainous catchment and broad, flat floodplain, the Tisza is vulnerable to some of the most extreme water level fluctuations in Europe, exacerbated by a system of dykes and drainage canals to support industries and agriculture. Flooding, landscape modification and biodiversity loss reached crisis levels by the late 1990s, prompting a "shadow network" of scientists and local activists to form and engage in dialogues about alternative river management. The network used participatory science to develop a CAS understanding that recognised cross-scale drivers, uncertainty and the importance of incorporating multiple views into river management practices. Using participatory system dynamics modeling tools, the shadow network sought to understand the factors required to transform the historical focus of river management on transporting materials and flood mitigation to maintaining biodiversity and sustainable land management practices. Thus, a participatory forum was key to the development of a shared CAS worldview, and encouraged experimentation in water policy. However, despite the shadow network's adoption of a CAS approach, only an ephemeral shift in policy has occurred, emphasising the barriers to the application of CAS thinking when policy implementation stalls. Therefore, while a CAS approach has helped to build shared understanding and create social capital, it is yet to lead to management changes in the Tisza River system.

Principle five

Encourage learning

Knowledge of a system is always partial and incomplete and social-ecological systems are no exceptions. Efforts to enhance the resilience of social-ecological systems must therefore be supported by continuous learning and experimentation.

Resilience is all about dealing with change, and adaptating and transforming in response to change. Because social-ecological systems are always in development there is a constant need to revise existing knowledge to enable adaptation to change and approaches to management. Adaptive management, adaptive co-management and adaptive governance all focus on learning as an integral part of decision making, and base their strategies on the fact that knowledge is incomplete and that uncertainty, change and surprise play an important part in managing social-ecological systems.

In adaptive management, articulating, testing and evaluating alternative hypotheses of how the system works are crucial tasks. Adaptive management is therefore all about learning by doing through testing out alternative management approaches.

Adaptive co-management also focuses on learning by doing but has a more explicit emphasis on knowledge sharing between different actors, often from communities and policy-making. Adaptive governance focuses on boosting learning through knowledge sharing across scales in order to bridge various organisations and institutions. This cross-scale focus on learning is pursued in order to develop new social norms and cooperation.

Although specialist agencies and scientists often carry out monitoring and experimentation, and thus learn during the process, there is a growing recognition of the importance of broader participation in order to stimulate learning among different groups in society. More collaborative processes can also help make values about different ecosystem services more explicit. One of the most well-known examples of this is the Kristiandstad Vattenrike, a wetland area in the southern part of Sweden. Growing developmental pressures led to increasing degradation of what was considered a vast area of water logged swamps with low value. However, thanks to a broad and collaborative process including local inhabitants and politicians, the perception of the wetlands changed and it is now considered to be a highly valued area for a range of purposes, including recreation.

Similarly, in the Australian Great Barrier Reef, a change of perceptions among politicians and the public, from considering the reef as pristine to acknowledging it as severely threatened, paved the way for stronger protection of the reef and its associated ecosystem services. Both of these shifts in perceptions occurred through processes of collaborative learning.

How can we encourage learning?

There are overlapping guidelines on how to foster learning for resilient outcomes. The most important ones include:

- Support long-term monitoring of key social and ecological components
- Provide opportunities for interaction that enable extended engagement between participants
- Engage a variety of participants
- Establish a suitable social context for the sharing of knowledge
- Ensure sufficient resources to enable learning processes to take place
- Enable people to network and create communities of practice

The design of the learning process is crucial. That is why it is essential to keep in mind conditions and obstacles that can render learning ineffective. Maladaptive or dysfunctional learning can lead to strategies and behaviours that threaten the function of entire social-ecological systems. For example, the systematic anti-environmental campaigning outlined in Naomi Oreskes and Erik Conway's book Merchants of Doubt (2011) set out to deliberately undermine environmental science by emphasizing uncertainty and manufacturing 'debate'. Power dynamics can also influence how learning takes place. There are numerous examples of scientific knowledge being prioritized for learning and management above other knowledge systems, particularly ignoring traditional or local knowledge. An iconic example was the collapse of the Canadian cod fishery, where local fishers raised serious concerns about cod stocks but these concerns were ignored.

PHOTO J. O'BRIEN/COMPASSLIVE

Case study

Social learning for fire management in south-eastern US

The south-eastern United States was once covered by a longleaf pine savanna, but forestry, agriculture and the suppression of fire means that this fire dependent ecosystem now covers just a few percent of its former range. Fire management is the key to maintaining this ecosystem, which is habitat for many endangered species and provides many ecosystem services. An adaptive management partnership between the Nature Conservancy and Eglin Air Force base (which contains the largest remaining area of longleaf pine savanna), used a participatory modeling approach to develop an integrated model of long term forest dynamics, and evaluate alternative fire management strategies. Over five years, this process led to a new understanding of historical and current fire dynamics. Some key findings were that forest areas need to be burned more frequently, that policies to protect old trees were doing more harm than good, and that policies that work with fire and vegetation feedbacks could greatly improve the efficiency of prescribed fire. The creation of clearly understandable simple models of fire vegetation dynamics, and possible future pathways, enabled this understanding to be translated into new policies and practices. This resulted in the development of new ecosystem management policies and decision support tools to manage fire as well as maintain and enhance the longleaf pine savanna.

Key message

Learning and experimentation through adaptive and collaborative management is an important mechanism for building resilience in social-ecological systems. It ensures that different types and sources of knowledge are valued and considered when developing solutions, and leads to greater willingness to experiment and take risks.

Principle six

Broaden participation

Participation through active engagement of all relevant stakeholders is considered fundamental to building social-ecological resilience. It helps build the trust and relationships needed to improve legitimacy of knowledge and authority during decision making processes.

Involving a diversity of stakeholders in the management of social-ecological systems can help build resilience by improving legitimacy, expanding the depth and diversity of knowledge, and helping detect and interpret perturbations. Participation can range from simply informing stakeholders to a complete devolution of power. It may occur in various—or all—stages of a management process, although diverse participation can be particularly useful in the startup phase. This is because early participation means knowledge of user groups can be incorporated in defining management priorities and needs.

There are a range of advantages to a broad and well-functioning participation. An informed and well-functioning group have the potential to build trust and a shared understanding – both fundamental ingredients for collective action. An example is found in Australia where an extensive public participation and consultancy process was initiated to raise awareness about threats to the Great Barrier Reef. Through greater awareness of the threats facing the Great Barrier Reef, the public participation process was able to raise public support for improved conservation plans.

If a variety of people participate, from a diversity of backgrounds and perspectives, it can uncover perspectives that may not be acquired through more traditional scientific processes. Participation can also help strengthen the link between information gathering and decision-making. For example, in the Philippines, participatory monitoring of protected reef areas improved transparency of decisions which, in turn, enhanced relationships between project stakeholders. It also improved the comprehension and validity of the information and how it was used in decision making by local people.

Participation, however, is no panacea. If not undertaken thoughtfully, it may enhance the influence of some stakeholders at the expense of others by increasing their power or influence within the system, resulting in competition and even conflict. Furthermore, weak forms of co-management, where participation inlcudes little authority but much responsibility for local resource users, may degrade the resilience of social-ecological systems and the ecosystem services they produce. In Chilean fisheries, for example, formalized co-management institutions undermined previously strong local resource management institutions. Although the co-management institutions aimed to improve the government fisheries' protection goals, instead they added a layer of bureaucracy between resource users and the resource. This weakened local capacity to respond quickly to changes in the resource base.

How can we broaden participation?

Creating a good participation process is highly context specific, and determining who to involve and the most appropriate tools and methods to use are challenging. Common pitfalls found in operationalizing participatory processes include underestimating the financial, time and human resources needed to carry out successful participation, insufficient training in communication and facilitation skills, lack of clarity on the roles or rules of participation, and stakeholders becoming involved too late in the process to have meaningful impact.

There are several overlapping guidelines that can contribute to a more effective participation:

- Clarify your goals and expectations of the participation process
- Get the right people involved
- Find inspired and motivated leaders that can mobilize the group
- Provide capacity building
- Deal with power issues and potential conflicts
- Secure sufficient resources to enable effective participation

PHOTO WOLCOTT HENRY 2005/MARINE PHOTOBANK)

Case study

A vulnerability assessment in remote communities of Kahua in the Solomon Islands

The ecologically diverse and remote region of Kahua in the Solomon Islands includes a population of 4500 people in 40 communities which have limited transport, communications and other services. The communities depend on subsistence agriculture comprised of root crops, fishing and forest resources. A local grassroots structure, the Kahua Association, established precedents for community participation, learning and action. The project included a three tiered approach to participation with each tier co-designed by the research team together with the Kahua Association based on the type and involvement of participants. All project phases planned to facilitate and embed co-learning with the project participants and ultimately the community. This was achieved by involving the association members as research partners in the design, co-ownership, implementation and use of the research and its outputs. It involved training of local people to undertake social and environmental investigations; encouraging individuals to reflect on their own perspectives, experience and behaviours; and open and timely sharing of research findings within the community. Outcomes of the process included widespread community participation, data collection and presentations. It also fostered a culture of reflection and learning, fundamental elements for building resilience.

Key message

Broad and well-functioning participation can build trust, create a shared understanding and uncover perspectives that may not be acquired through more traditional scientific processes.

Principle seven

Promote polycentric governance

Polycentricity, a governance system in which multiple governing bodies interact to make and enforce rules within a specific policy arena or location, is considered to be one of the best ways to achieve collective action in the face of disturbance and change.

Although there are many ways in which collective action can be achieved, polycentricity is considered unique. Classic studies on the sustainable governance of social-ecological systems highlight the importance of so-called "nested institutions" (the norms and rules governing human interactions). These are institutions connected through a set of rules that interact across hierarchies and structures so that problems can be addressed swiftly by the right people at the right time. Nested institutions enable the creation of social engagement rules and collective action that can "fit" the problem they are meant to address.

In contrast to more monocentric strategies, polycentric governance is considered to enhance the resilience of ecosystem services in six ways, which coincide elegantly with other principles in this publication: it provides opportunities for learning and experimentation; it enables broader levels of participation; it improves connectivity; it creates modularity; it improves potential for response diversity, and builds redundancy that can minimize and correct errors in governance.

Another reason why polycentric governance is better suited for the governance of social-ecological systems and ecosystem services is because traditional and local knowledge stands a much better chance of being considered. This, in turn, improves sharing of knowledge and learning across cultures and scales. This is particularly evident in local and regional water governance, as in watershed management groups in South Africa or the management of large-scale irrigation systems in the Philippines, where polycentric approaches have facilitated participation by a broad range of actors and incorporation of local, traditional and scientific knowledge.

Nevertheless, the appeal of using polycentric thinking is hampered by the lack of clear principles for how to operationalize it. There are several examples of various attempts at cross-scale collaboration but very few analyses assessing their impact on governance. Polycentric governance also raises three challenges, which could weaken rather than strengthen the resilience of ecosystem services. The first is the need to balance redundancy and experimentation with the costs of involving members of multiple governance bodies and interests. For instance, South Africa's National Water Act advocates integrated water resource management and is working toward an improved institutional fit, but it also acknowledges the realistic need to balance breadth with costs. A second challenge is that of negotiating trade-offs between various users of ecosystem services. These trade-offs often lead to the third challenge, which is not only about dealing with resolving political conflict and the potentially skewed benefits of common resources, but also so-called "scale-shopping", where groups dissatisfied with politics at one scale simply approach a more favourable political venue in which to frame their interests.

PHOTO B. ALVARIUS

Case study

Environmental Management in Southern Arizona

In southern Arizona, a number of collaborations on environmental management and the promotion of ecosystem services, when taken together, can be treated as a polycentric system. In Cochise County, over 20 different groups and actors contribute to decision-making processes about pressing environmental challenges in the region. The kinds of collaborations vary from modest information sharing to more closely knit collaborative networks. For instance, both the Northern Jaguar Project and the Chiricahua Firescape planning share information and create informal networks linking the various actors together. The Upper San Pedro Partnership goes further and coordinates monitoring and joint investment. Perhaps the best example of a polycentric system is the Malpai Borderlands (pictured), a tight knit group of trusting relationships built over decades for monitoring rangeland conditions. Together, all these collaborations and networks contribute to a polycentric management approach for dealing with environmental issues.

Key message

Collaboration across institutions and scales improves connectivity and learning across scales and cultures. Well-connected governance structures can swiftly deal with change and disturbance because they are addressed by the right people at the right time.

Glossary

ADAPTIVE MANAGEMENT: Management approach that emphasizes learning and uses structured experimentation in combination with flexibility to foster learning.

ADAPTIVE CO-MANAGEMENT: Explicitly links learning (experiential and experimental) and collaboration to facilitate effective governance.

ADAPTIVE GOVERNANCE: Connects individuals, organizations, agencies, and institutions at multiple organizational levels. Adaptive governance systems often self-organize as social networks with teams and actor groups that form a learning environment to draw on various knowledge systems and experiences to tackle complex environmental issues.

CONNECTIVITY: The way and degree to which resources, species, or social actors disperse, migrate, or interact across ecological and social landscapes.

COMPLEX ADAPTIVE SYSTEM (CAS): A system of interconnected components that has the capacity to adapt and self-organize in response to internal or external disturbance or change.

CROSS-SCALE: A study or process that addresses multiple spatial and/or temporal scales and focuses explicitly on how they interact.

DIVERSITY: Includes three interrelated aspects: variety (how many different elements), balance (how many of each element), and disparity (how different the elements are from one another).

ECOSYSTEM SERVICES: The benefits that people obtain from ecosystems, including direct products (e.g. water, crops), processes that regulate environmental conditions (e.g. floods, climate), as well as recreational, aesthetic and spiritual benefits.

FEEDBACKS: A mechanism, process, or signal that loops back to influence the SES component emitting the signal or initiating the mechanism or process.

FUNCTIONAL REDUNDANCY: The presence of species or system elements that can functionally compensate for one another.

MENTAL MODELS: Peoples' cognitive representations of external reality.

MULTI-SCALE: A study or process that includes two or more different levels of organization.

NESTED INSTITUTIONS: Sets of rules that are hierarchically nested at several different scales to address problems or challenges confronted at different temporal and spatial scales.

INSTITUTIONS: The norms and rules governing human interactions. These can be formal, such as rules and laws, but also informal, such as norms and conventions of society.

POLYCENTRICITY: A governance system in which there are multiple interacting governing bodies with autonomy to make and enforce rules within a specific policy arena and geography.

RESILIENCE: The capacity of a system – be it a landscape, a coastal area or a city – to deal with change and continue to develop. This means the capacity to withstand shocks and disturbances such as a financial crisis or use such an event to catalyse renewal and innovation.

SCALE: Extent and/or resolution of a process or analysis, or the level of organization of a phenomenon or process, e.g. field, farm, region, country.

SLOW VARIABLES: A variable whose rate of change is slow in relation to the timescales of ecosystem service provision and management, and is therefore often considered constant.

SOCIAL-ECOLOGICAL SYSTEM (SES): A coupled system of humans and nature that constitutes a complex adaptive system with ecological and social components that interact dynamically through various feedbacks.

Useful reading

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Read more about the basics of resilience in our broschure "What is resilience?"

This brochure is based on the book **Principles for Building Resilience: Sustaining Ecosystem Services in Social-Ecological Systems**

This book provides an in-depth review of current knowledge around how resilience can be applied in the management of social-ecological systems and the ecosystem services they provide. It assesses and evaluates the evidence in support of various propositions that have been put forward as underlying principles for building resilience, discusses the practical application of these principles and lays out further research needs. The seven principles include: maintain diversity and redundancy; manage connectivity; manage slow variables and feedbacks; foster complex adaptive systems thinking; encourage learning; broaden participation; and promote polycentric governance. Written for researchers, lecturers, practitioners and graduate students, the book is of interest to all those working at the core of resilience science as well as those working in the broader fields of sustainability science, environmental management and governance.

Read more about the book here: www.cambridge.org/9781107082656

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Stockholm Resilience Centre is an international centre that advances transdisciplinary research for governance of social-ecological systems with a special emphasis on resilience – the ability to deal with change and continue to develop.

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