Article

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Resilience and Sustainable Development: Building Adaptive Capacity in a World of Transformations

Emerging recognition of two fundamental errors underpinning past polices for natural resource issues heralds awareness of the need for a worldwide fundamental change in thinking and in practice of environmental management. The first error has been an implicit assumption that ecosystem responses to human use are linear, predictable and controllable. The second has been an assumption that human and natural systems can be treated independently. However, evidence that has been accumulating in diverse regions all over the world suggests that natural and social systems behave in nonlinear ways, exhibit marked thresholds in their dynamics, and that social-ecological systems act as strongly coupled, complex and evolving integrated systems. This article is a summary of a report prepared on behalf of the Environmental Advisory Council to the Swedish Government, as input to the process of the World Summit on Sustainable Development (WSSD) in Johannesburg, South Africa in 26 August 4 September 2002. We use the concept of resilience—the capacity to buffer change, learn and develop—as a framework for understanding how to sustain and enhance adaptive capacity in a complex world of rapid transformations. Two useful tools for resilience-building in social-ecological systems are structured scenarios and active adaptive management. These tools require and facilitate a social context with flexible and open institutions and multi-level governance systems that allow for learning and increase adaptive capacity without foreclosing future development options.

The goal of sustainable development is to create and maintain prosperous social, economic, and ecological systems. These systems are intimately linked: humanity depends on services of ecosystems for its wealth and security. Moreover, humans can transform ecosystems into more or less desirable conditions. Humanity receives many ecosystem services, such as clean water and air, food production, fuel, and others. Yet human action can render ecosystems unable to provide these services, with consequences for human livelihoods, vulnerability, and security. Such negative shifts represent loss of resilience.

New insights have been gained during the last 10 years about the essential role of resilience for a prosperous development of society (1). A growing number of case studies have revealed the tight connection between resilience, diversity and sustainability of social-ecological systems (2, 3). This article is a summary of a major report prepared on behalf of the Environmental Advisory Council to the Swedish Government, as input to the process of the World Summit on Sustainable Development (WSSD) in Johannesburg, South Africa in August 2002 (4). In the report, we provide an up-to-date synthesis of case studies and recent insights, in the context of emerging theories of complex systems characterized by uncertainty and surprise (5–7).

Lakes can exist with clear water providing many ecosystem services, or turbid water with toxic algae blooms. Either state can be resilient dependent upon management. Photos: S. Carpenter.

Resilience, for social-ecological systems, is related to (*i*) the magnitude of shock that the system can absorb and remain within a given state; (*ii*) the degree to which the system is capable of self-organization; and (*iii*) the degree to which the system can build capacity for learning and adaptation. Management can destroy or build resilience, depending on how the social-ecological system organizes itself in response to management actions (8, 9).

More resilient social-ecological systems are able to absorb larger shocks without changing in fundamental ways. When massive transformation is inevitable, resilient systems contain the components needed for renewal and reorganization. In other words, they can cope, adapt, or reorganize without sacrificing the provision of ecosystem services. Resilience is often associated with diversity—of species, of human opportunity, and of economic options—that maintains and encourages both adaptation and learning. In general, resilience derives from things that can be restored only slowly, such as reservoirs of soil nutrients, heterogeneity of ecosystems on a landscape, or variety of genotypes and species.

Social-ecological systems are constantly changing. Usually one assumes that ecosystems respond to gradual change in a smooth way, but sometimes there are drastic shifts (photos). Regime shifts are known for many ecosystems and these shifts can be difficult, expensive, or sometimes impossible to reverse (10) (Table 1). Although we understand ecological regime shifts retrospectively, it is difficult to predict them in advance. Measurements or predictions of thresholds typically have low precision, and often ecological thresholds move over time. It is difficult to design assessment programs that learn as fast as thresholds change.

One approach to the ongoing change of social-ecological systems has been the attempt to control or canalize change. Paradoxically, management that uses rigid control mechanisms to harden the condition of social-ecological systems can erode resilience and promote collapse. There are many examples of management that suppressed natural disturbance regimes or altered slowly-changing ecological variables, leading to disastrous changes in soils, waters, landscape configurations or biodiversity that did not appear until long after the ecosystems were first managed (11). Similarly, governance can disrupt social memory or remove mechanisms for creative, adaptive response by people, in ways that lead to breakdown of social-ecological systems (12, 13).

In contrast, management that builds resilience can sustain social-ecological systems in the face of surprise, unpredictability, and complexity. Resilience-building management is flexible and open to learning. It attends to slowly-changing, fundamental variables that create memory, legacy, diversity, and the capacity to innovate in both social and ecological components of the system. It also conserves and nurtures the diverse elements that are necessary to reorganize and adapt to novel, unexpected, and transformative circumstances. Thus, it increases the range of surprises with which a socioeconomic system can cope (14–16).

Building social-ecological resilience requires understanding of ecosystems that incorporates the knowledge of local users (2, 17). Thus, the ecological ignorance of some contemporary societies undermines resilience. The outdated perception of humanity as decoupled from, and in control of, nature is an underlying cause of society's vulnerability (18). Technological developments and economic activities based on this perception fur-

Box 1.

Policy in complex adaptive systems

The earlier world-view of nature and society as systems near equilibrium is being replaced by a dynamic view, which emphasizes complex non-linear relations between entities under continuous change and facing discontinuities and uncertainty from suites of synergistic stresses and shocks. Complex systems are self-organizing. Self-organization creates systems far-from-equilibrium, characterized by multiple possible outcomes of management. The dynamic view of nature and society has major implications for economic valuation and policy. Most approaches to valuation attempt to capture the value of marginal change under assumptions of stability near a local equilibrium. They seldom take into account the inherent complexities and resulting uncertainties associated with ecosystem management and natural capital assets in general. They ignore the slowly-changing probability distributions of critical ecosystem thresholds. Sudden and abrupt change has major implications for policies on production, consumption and international trade. It has also major implications for economic policy, like taxes on resource use or emissions. Because of the complex dynamics, optimal management will be difficult if not impossible to implement. Focusing on economic growth to eradicate poverty, disconnected or decoupled from the complex dynamics of the environmental resource base on which growth depends, or focusing on technical solutions with the purpose to make societal development independent of nature will not lead to sustainable solutions. Instead efforts should be made to create synergies between economic development, technological change and the dynamic capacity of the natural resource base to support social and economic development (4).

Table 1. Examples of documented shifts in states in different kinds of ecosystems.

Ecosystem type	Alternative state 1	Alternative state 2	References
Freshwater Systems	Clear water	Turbid water	Carpenter (22)
	Benthic vegetation	Blue-green algae	Scheffer et al. (10)
	Oligotrophic macrophytes and algae	Cattails and blue green algae	Gunderson (16)
	Game fish abundant	Game fish absent	Post et al. (23)
Marine Systems	Hard coral	Fleshy algae	Nyström et al. (24)
	Kelp forests	Urchin dominance	Estes and Duggins (25)
	Seagrass beds	Algae and muddy water	Gunderson (16)
	Fish stock abundant	Fish stock depleted	Walters and Kitchell (26), Steele (27)
Rangelands	Grass structure	Shrub structure	Walker (28)
Forests	Pest outbreak	No pest	Holling (29)
	Pine trees dominate	Hardwood plants dominate	Peterson (30)
	Birch-spruce succession	Pine dominance	Danell et al. (31)
Arctic systems	Grass dominated	Moss dominated	Zimov et al. (32)

ther contribute to the erosion of resilience (Box 1). It can be counteracted by understanding the complex connections between people and nature, which create opportunity for technological innovations and economic policies aimed at building resilience.

Two useful tools for resilience-building in social-ecological systems are structured scenarios and active adaptive management. People use scenarios to envision alternative futures and the pathways by which they might be reached. By envisioning multiple alternative futures and actions that might attain or avoid particular outcomes, we can identify and choose resilience-building policies (19). Active adaptive management views policy as a set of experiments designed to reveal processes that build or sustain resilience. It requires, and facilitates, a social context with flexible and open institutions and multi-level governance systems that allow for learning and increase adaptive capacity without foreclosing future development options (20, 21) (Box 2).

At least three general policy recommendations can be drawn from the synthesis of resilience in the context of sustainable development. The first level emphasizes the importance of policy that highlights interrelationships between the biosphere and the prosperous development of society. The second stresses the necessity of policy to create space for flexible and innovative collaboration towards sustainability, and the third suggests a few policy directions for how to operationalize sustainability in the context of social-ecological resilience.

i) Although most people appreciate that development is ultimately dependent on the processes of the biosphere, we have tended to take the support capacity of ecosystems for granted. Erosion of nature's support capacity leads to vulnerability. Policy should strengthen the perception of humanity and nature as interdependent and interacting and stimulate development that en-

Mulga woodlands of Australia can exist in a grass-rich state that supports sheep herding, or a shrub-dominated state oF no value for sheep grazing. Either state can be resilient dependent upon management. Photos: D. Tongway.

Box 2.

Adaptive management in the Everglades and the Grand Canyon

The Everglades of Florida and the Grand Canyon ecosystem are complex social-ecological systems, where unwanted ecosystem state shifts (eutrophication, species endangerment, loss of habitat and biodiversity) have resulted from large-scale water-management projects. In both cases, the restoration of resilience has been a social objective, involving millions to billions of dollars. Uncertainty has been confronted in both areas through the articulation of a set of competing hypotheses about what led to the loss of resilience, and what is needed to restore those lost ecosystem functions and services. Those hypotheses are tested through a structured set of management actions designed to sort among the alternative explanations and a comprehensive monitoring plan established through decades of research. The slowly-changing variables—nutrients in sediments, and decadal hydrologic cycles—are the critical objects of monitoring, as they are the key indicators of ecosystem resilience. In larger, more complex systems than the Everglades and Grand Canyon, structured management experiments may be impossible, yet it is still necessary for people to assess the fundamental variables and branch points that lead to alternative futures. In these situations, scenario exercises are a useful mechanism for building understanding and flexibility toward adaptive change.

The Everglades and the Grand Canyon diverge with respect to their ability to cultivate institutional learning. The Everglades process has been trapped by special interest groups (agriculture and environmentalists) who seek to avoid learning, thus undermining the possibilities for enhancing resilience. The Grand Canyon group, on the other hand, has developed an 'Adaptive Management Work Group' which uses planned management actions and subsequent monitoring data to test hypotheses, and build understanding of ecosystem dynamics. Such understanding is one necessary ingredient of adaptive capacity. Working with open institutions is essential for dealing with multiple objectives, uncertainty and the possibility of surprising outcomes. Such emergent governance that creates new institutional platforms for adaptive management is evolving in many places. For example, adaptive co-management systems, i.e. flexible community-based systems of resource management tailored to specific situations and supported by and working in collaboration with concerned governmental agencies, educational institutions and where appropriate NGOs, take place, for example, in the context of the Biodiversity Register program in India and through the involvement of several local steward associations in the management of semi-urban and urban landscapes in Sweden. Adaptive co-management draws on accumulated social-ecological experience and is informed by both practice and theory. It relies on the participation of a diverse set of interest groups operating at different scales, from local users, to municipalities, to regional and national organizations, and occasionally also international networks and bodies (16).

hances resilience in social-ecological systems, recognizing the existence of ecological thresholds, uncertainty and surprise.

ii) Policy should create arenas for flexible collaboration and management of social-ecological systems, with open institutions that allow for learning and build adaptive capacity. Policy frameworks with clear directions for action towards building adaptive capacity and thus social-ecological sustainability are required in this context (the EU watershed management directive is one example). They create action platforms for adaptive management processes and flexible multi-level governance that can learn, generate knowledge and cope with change. Such systems generate a diversity of management options for respond to uncertainty and surprise.

iii) Policy should develop indicators of gradual change and early warning signals of loss of ecosystem resilience and possible threshold effects. Policy should encourage monitoring of key ecosystem variables and aim to manage diversity for insurance to cope with uncertainty. Policy should stimulate ecosystem friendly technology and the use of economic incentives to enhance resilience and adaptive capacity. For example, the development of monocultures should be avoided. Policy should provide incentives that encourage learning and build ecological knowledge into institutional structures in multi-level governance. Policy should invite participation by resources users and other interest groups and their ecological knowledge. Structured scenarios and active adaptive management processes should be implemented.

Managing for resilience enhances the likelihood of sustaining development in a changing world where surprise is likely. Resilience-building increases the capacity of a social-ecological system to cope with surprise. A changing, uncertain world in transformation demands action to build the resilience of the social-ecological systems which embrace all of humanity.

The need to account for resilience in a world of transformations is a perspective that should become embedded in strategies and policy of the World Summit on Sustainable Development and recognized in the next phases for implementation of Agenda 21.

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33. We acknowledge support from the McDonnell Foundation to the Resilience Alliance and are grateful to Elena Bennett, Siv Näslund, Olof Olsson, Kristina Olsson, Thomas Rosswall and colleagues of the Resilience Alliance for valuable comments on the manuscript and inspiration.

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