CHAPTER 14

Building resilience and adaptive capacity in social-ecological systems

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14.1 Introduction

A weekly magazine on business development issued an analysis of Madonna, the pop star, and raised the question "How come Madonna has been at the very top in pop music for more than 20 years, in a sector characterized by so much rapid change?" A few decades ago successful companies developed their brand around stability and security. To stay in business this is no longer sufficient, according to the magazine. You must add change, renewal and variation as well. However, change, renewal and variation by themselves will seldom lead to success and survival. To be effective a context of experience, history, remembrance, and trust to act within is required. Changing, renewing and diversifying within such a foundation of stability and maintaining high quality have been the recipe for success and survival of Madonna, and rock stars like Neil Young and U2. It requires an active adaptation to change, not only responding to change but also creating and shaping it. In the same spirit, Sven-Göran Ericsson, coach of several soccer teams in Europe, claimed that it is the wrong strategy not to change a winning team. A winning team will always need a certain amount, but not too much, of renewal to be sustained as a winning team. Sustaining a winning team requires a context for renewal, or 'framed creativity', borrowing from the language of the advertiser.

These metaphors get to the very core of resilience, the concept in focus of this volume in relation to the dynamics of complex and coupled social-ecological systems. Resilience, the capacity to lead a continued existence by incorporating change (Holling, 1986), stresses the importance of assuming change and explaining stability, instead of assuming stability and explaining change (van der Leeuw, 2000). The latter perspective has dominated 20th century resource and environmental science and management (Gunderson, Holling and Light, 1995; Berkes and Folke, 1998), and has been successful in producing stability and security of resource flows in the short term. However, doing so has simplified ecosystems and reduced functional diversity (Holling and Meffe, 1996), and eroded resilience (Gunderson and Pritchard, 2002). Strategies for controlling environmental variability and natural disturbance becomes key in such systems, since fluctuations impose problems to meet predicted production goals. Thus, managers seek to command and control these processes in an attempt to stabilize ecosystem outputs (Carpenter and Gunderson, 2001). Short-term success of increasing yield in homogenized environments contributes to creating mental models of human development as being superior and largely independent of nature's services. According to this thinking, nature can indeed be conquered, controlled and ruled. Short-term success makes navigating nature's dynamics a non-issue and as a consequence knowledge, incentives and institutions for monitoring and responding to environmental feedback erode (Holling, Berkes and Folke, 1998). The belief system of humanity as superior to and independent of nature is reinforced.

The separation of social systems and natural systems is more of a recent mental artefact than an observation of the real world (Nelson and Serafin, 1992; Davidson-Hunt and Berkes [chapter 3]). The Earth has for long been transformed by human action (Turner, Clark and Kates, 1990). Throughout history humanity has shaped nature and nature has shaped the development of human society (Tainter, 1988; Grimm *et al.*, 2000). In that sense there are neither natural or pristine systems nor social systems without nature. Instead humanity and nature have been co-evolving in a dynamic fashion (Norgaard, 1994; Berkes and Folke, 1998). In the present era of the human dominated biosphere, co-evolution now takes place also at the planetary level and at a much more rapid and unpredictable pace than previously in human history.

Facing complex co-evolving systems for sustainability requires ability to cope with, adapt to and shape change without losing options for future adaptability. The irony is that the mental model of optimal management of systems assumed to be stable and predictable has in many respects reduced options and removed the capacity of life-support systems to buffer change (Jackson *et al*., 2001). The insurance for dealing with the unexpected has been driven down by suppressing disturbance and reducing the diversity of the environment.

Actions towards sustainability will require understanding and appreciation of the dynamics of complex life-support ecosystems - a new level of ecological literacy - and not just among scientists, but the general public at large. A fundamental challenge in this context is to build knowledge and incentives into institutions and organisations for managing the capacity of local, regional and global ecosystems to sustain societal development (Ostrom *et al*., 1999; Scoones, 1999) in the context of uncertainty, surprise and vulnerability (Kates and Clark, 1996; Gunderson and Holling, 2001).

The focus of the volume is the study of the adaptability of social-ecological systems to meet change and novel challenges in navigating ecosystem dynamics without compromising long-term sustainability. Throughout this volume we argue that resilience is a key property of sustainability; that loss of resilience lead to reduced capacity to deal with change. Ecological resilience has been defined as the magnitude of disturbance that can be experienced before a system moves into a different state and different set of controls (Holling, 1973). Social resilience has been defined as the ability of human communities to withstand external shocks to their social infrastructure, such as environmental variability or social, economic and political upheaval (Adger, 2000). Systems may be ecological resilient but socially undesirable or they may be socially resilient but degrade their environment. Here, we are concerned with the combined systems of humans and nature, with emphasis on social-ecological resilience. We are concerned with management that secures the capacity of ecosystems to sustain societal development and progress with essential ecosystem services. Successful ecosystem management for social-ecological sustainability requires institutional capacity to respond to environmental feedback; to learn and store understanding, and be prepared and adaptive to allow for change. The challenge is to anticipate change and shape it for sustainability in a manner that does not lead to loss of future options. It involves enhancing the capacity for self-organization.

In this chapter we explore the above hypotheses and present some tentative conclusions on the dynamics of linked social-ecological systems for resource and ecosystem management, drawing on the chapters of the volume. We are interested in periods of change and how people and nature relate to and organize around change. Are there elements that sustain social-ecological systems in a world that is constantly changing? In that sense, we are focusing on periods of change caused by disturbance, surprise or crisis, followed by periods of renewal and reorganization (referred to in the Introduction as “the backloop”). Such periods of change are the most neglected and the least understood in conventional resource management.

In discussing resilience-building for adaptive capacity, the synthesis identifies and expands on four critical factors highlighted in many of the chapters, factors that interact across temporal and spatial scales and that seem to be required for dealing with nature's dynamics in social-ecological systems:

- learning to live with change and uncertainty;
- nurturing diversity for reorganization and renewal;
- combining different types of knowledge for learning; and
- creating opportunity for self-organization towards social-ecological sustainability.

The way that we address these factors in relation to building resilience for adaptive capacity is presented in Table 14.1. The first part emphasizes the necessity of accepting change and living with uncertainty and surprise, and provides examples of strategies of social-ecological management for taking advantage of change and crisis and turning it into opportunity for development. The second part illuminates the importance of nurturing diversity for resilience, recognizing that diversity is more than insurance to uncertainty and surprise. It also provides the bundle of components, and their history, that makes development and innovation following disturbance and crisis possible, components that are embedded in the social-ecological memory. The third part addresses the significance of peoples' knowledge, experience and understanding about the dynamics of complex ecosystems, their inclusion in management institutions, and their complementarity to conventional management. The forth part brings these issues together in the context of self-organization, scale, governance and external drivers, stressing the significance of the dynamic interplay between diversity and disturbance. Both diversity and disturbance are parts of sustainable development and resilience and their interaction needs to be explicitly accounted for in an increasingly globalized and human dominated biosphere.

Table 14.1. Building resilience and adaptive capacity in social-ecological systems

Learning to live with change and uncertainty
- Evoking disturbance
- Learning from crises
- Expecting the unexpected

Nurturing diversity for reorganization and renewal
- Nurturing ecological memory
- Sustaining social memory
- Enhancing social-ecological memory

Combining different types of knowledge for learning
- Combining experiential and experimental knowledge
- Expanding from knowledge of structure to knowledge of function
- Building process knowledge into institutions
- Fostering complementarity of different knowledge systems

Creating opportunity for self-organization
- Recognizing the interplay between diversity and disturbance
- Dealing with cross-scale dynamics
- Matching scales of ecosystems and governance
- Accounting for external drivers

14.2 Learning to live with change and uncertainty

Change and crisis are parts of the dynamic development of complex co-evolving social-ecological systems (Gunderson [chapter 2]). It is impossible to lock a system in a steady state for eternity, or to manage it for stability and security in a command-and-control fashion. Policies aimed at removing change and variation will instead cause an accumulation of such disturbance and cause a more widespread crisis. For example, suppression of forest fires locally will cause an accumulation of fuel on the forest floor as well as of tree biomass. When a fire event finally occurs, it will be hot and intensive, burning deeper into the soil and affecting seed viability, microorganisms, organic content and nutrients. An ecosystem that can withstand a small, low-intensity fire may be severely affected by a large, hot fire that can change soil conditions, water-holding capacity, and destroy old, seed-bearing trees important for reorganization.

Similarly, suppression of institutional or organizational change can create gridlock in the capacity to adapt to change, and may lead to erosion of both natural and social capital (Gundersson *et al*., 1995). Trosper (chapter 13) illustrates the suppression of change in the chapter on the US Forest Sector. The response of the Iron Triangle coalition to external disturbance was to try to avoid it by tightening the internal structure. This strategy, successful in the short term, led to a major management crisis later on. The polarization of US forest policy between commodity interest groups and environmental interest groups removes attention from monitoring and managing forest condition and responding to ecosystem dynamics (Trosper [chapter 13]). To avoid social traps (Costanza, 1987) that erode resilience, there have to be knowledge, practices and social mechanisms that recognize that disturbance, surprise and crisis are part of development and progress (Gunderson [chapter 2], Carlsson [chapter 5]; Tengö and Hammer [chapter 6]; Gadgil *et al*. [chapter 8]). These include conflict resolution, negotiation, participation and other mechanisms for collaboration (Ostrom, 1990; Röling and Wagemakers, 1998) with rules aimed at maintaining the process of learning and adaptation in situations facing uncertainty and external change (Low *et al*. [chapter 4]; Seixas and Berkes [chapter 11]; Blann *et al*. [chapter 9]; Colding *et al*. [chapter 7]; Alcorn *et al*. [chapter 12]). It also requires a social network with trust and respect (Kendrick [chapter 10]) and social nestedness for ecosystem management operating at multiple scales (Alcorn *et al*. [chapter 12]; Trosper [chapter 13]; Folke *et al*., 1998; Gibson, Ostrom and Ahn, 2000; Cash and Moser, 2000; Gunderson and Holling, 2001).

14.2.1 Evoking disturbance

Many local communities have recognized the importance of disturbance for securing ecosystem services and have developed management practices that mimic disturbance regimes in nature. There are practices that evoke release in ecosystems by creating small-scale pulse disturbance (Berkes and Folke, 2001). By imitating fine-scale natural perturbations, these practices speed up local renewal cycles in the larger ecosystem and help avoid the accumulation of disturbance - the revolt connection - that moves across scales and further up in the panarchy (Gunderson and Holling, 2001), the nested set of adaptive renewal cycles introduced in the introductory chapter.

Examples include burning of pastures for pest control and pulses of herbivore grazing in a rotational manner as practiced by some African agro-pastoralists (Tengö and Hammer [chapter 6]; Niamir-Fuller, 1998) that contribute to the capacity of the land to function under a wide range of climatic conditions. Fire management has been practiced widely by traditional societies in Australia and North America to open up clearings (meadows and swales), corridors (trails, traplines, ridges, grass fringes of streams and lakes), and windfall areas (Lewis and Ferguson, 1988; Colding *et al*. [chapter 7]). It was not used on a large scale, but rather in a patchy distribution and on targeted species and habitats (Fowler, 2000). Fire management is also practiced in contemporary forest and protected area management.

Patch clearing through swidden-fallow management and associated agroforestry systems among Amazon area tribes in cycles of up to 30-40 years provided a diversity of resources and ecosystem services over the long-term (Denevan *et al*., 1984; Posey, 1985; Irvine, 1989). Small-scale patch management and shifting cultivation in agriculture is a common measure, as illustrated in the chapters Tengö and Hammer and Colding *et al*. The short periods of additional openings of the channel to the Ibiraquera lagoon by local fishers, is another example where resource flows are secured and large-scale crisis at a later stage avoided (Seixas and Berkes [chapter 11]).

Such management practices, embedded in institutions and often initiated by rituals, are frequently guided by stewards and have a cultural and ethical dimension (Kendrick [chapter 10]; Alcorn *et al*. [chapter 12]; Berkes, 1999). For example, Native Americans of the Great Basin of Western North America viewed fire as a part of an ethic of caring for the land and its resources, and fire was considered as beneficial and a cleansing force (Fowler, 2000). The annual ritual of two days of intensive crayfishing (pulse fishing) in August in Sweden builds social capital in the community and supports the development of institutions for management of a common pool resource in a watershed context (Gadgil *et al*. [chapter 8]; Olsson and Folke, 2001).

Building social-ecological resilience also requires evoking change in social structures. In a study of U.S. Fish and Wildlife Service, Jeffrey (2000) highlights the need for organizational change as a component of ecosystem management, and puts forward the role of leadership in actively initiating change within organizations. Blann *et al*., (chapter 9) stress the key role of social networks of 'practitioners' in which support, trust and sharing of lessons learned can facilitate processes of change at multiple scales.

Management that actively behaves like disturbance is one of a sequence of practices, ecological and social, that generates resilience. It appreciates the role of disturbance in development and includes monitoring and ecological understanding of ecosystem condition and dynamics embedded in social institutions. Evoking disturbance is the first sequence of management practices that relate to "the backloop phases" of the heuristic adaptive renewal cycle model (see the left part of Figure 14.1). We assume that such practices among resource users have evolved as a response to crisis.

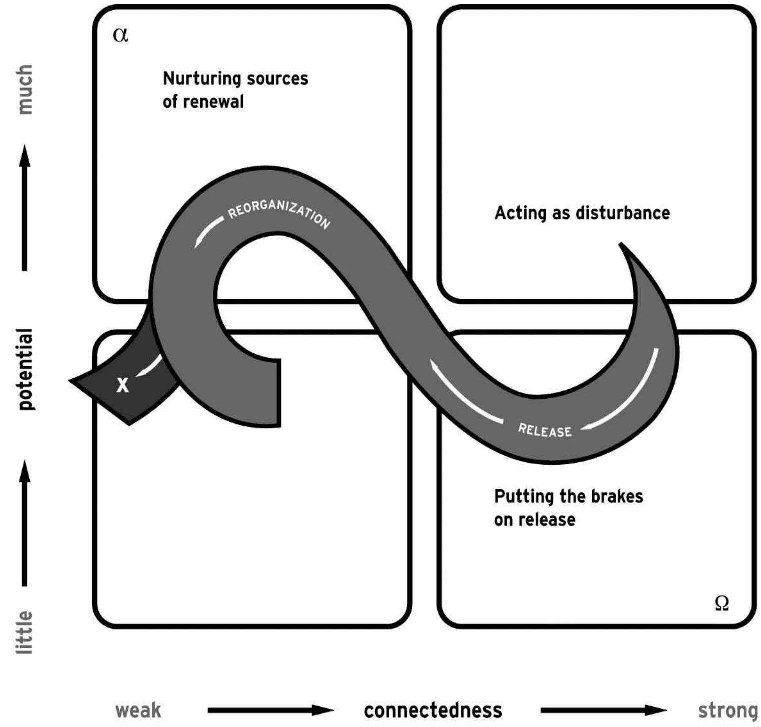

Figure 14.1 Management practices of the Backloop of the Adaptive Renewal Cycle. There are management practices of local communities that 'act like small-scale disturbance' to trigger renewal, 'put the brakes' on release to cope with uncertainty and surprise, and 'nurture diversity' and ecological memory to secure sources of reorganization (modified from Berkes and Folke, 2001).

14.2.2 Learning from crisis

For our purposes, a crisis may be broadly defined as a large perturbation; it may be human-induced (e.g. a resource collapse) or natural (e.g. the effects of a hurricane). Gunderson (chapter 2) states that crises are a special type of surprise. A surprise (a qualitative disagreement between ecosystem behavior and a priori expectations) becomes a crisis when it reveals an unambiguous failure of management actions and policy. Three generic responses are possible when a crisis occurs (Figure 14.2). "No effective response" is one possible management reaction. The reaction aims at getting rid of the disturbance by blocking out change. Institutions and organizations that have a lot of inertia or vested political or economic interests characterize the agents of the reaction (Gunderson, Holling and Light, 1995). Such a response, often based on a presumption of a system near equilibrium, tends to create the conditions for a larger-scale and widespread crisis later on. It creates the revolt connection; trying to preserve the status quo often leads to organizational and political brittleness, as well as to ecological brittleness.

A second possibility is "response without experience," a frequently seen reaction in which the institution (a government agency or a local resource-user institution) responds to a crisis but does not have previously tested policies at its disposal. It may result in new types of arrangements of management institutions and a series of policy responses (broken lines in Figure 14.2), including that of "no effective response". Management recognizes the need to relate to uncertainty and surprise in order to sustain the desirable stability domain, but the response may either increase or decrease resilience. At the same time resilience is needed to allow a margin of failure in management. Alternatively, it can lead to institutional learning or social learning (Lee, 1993). If the crisis is a true surprise or genuine novelty (Gunderson chapter 2), then the institution will have no previous experience with it. Or the crisis may have been predictable but may be of a magnitude that had never been experienced. An example is the cod resource collapse in Newfoundland, which had been predicted by inshore fishers and some field biologists (Finlayson and McCay, 1998). The problem was exacerbated by "an overreliance on the science and culture of quantitative stock assessment" (National Research Council, 1998: 35) by central government agency population modelers who (in retrospect) misused or misjudged their data, and precipitated a stock collapse unprecedented in its magnitude in the North Atlantic.

Would the Newfoundland cod collapse help the management agency "respond with experience" the next time that a similar crisis looms? There is no clear answer to the question because "responding with experience," as we formulate it in Figure 14.2, depends on institutional learning based on previous crises and social-ecological memory. Evoking disturbance practices such as those discussed in the previous section may be a result of institutional learning stored in the memory of local communities (Carlsson [chapter 5]; Tengö and Hammer [chapter 6]; Gadgil *et al*. [chapter 8]; Colding *et al*. [chapter 7]) and may help avoid unwanted qualitative shifts in stability domains of resource systems (Gunderson [chapter 2]; Carpenter, Ludwig and Brock, 1999; Scheffer *et al*., 2001).

The chapter on policy transformation in the US forest sector illustrates the inertia and tension of adaptive learning for sustainable forest management at regional and national scales of governance (Trosper [chapter 13]), but the findings of the interviews with resource managers leading diverse groups of constituents through resource management crisis and change in Minnesota move beyond the tension between conserving the old structures and creating new approaches by responding to environmental feedback (Blann *et al*. [chapter 9]). Creating social and institutional space or platforms for dialogue and innovation (Röling and Wagemakers, 1998) following crises is key to stimulate learning and to resolve social uncertainties (Gunderson [chapter 2]). It opens up for double-loop learning, drawing on social-ecological memory and visioning, expanding the temporal frame of reference, and reorganizing conceptual models and paradigms based on a revised understanding of the preconditions generating the crisis (Blann *et al*. [chapter 9]). Hence, institutions seem to emerge as a response to crisis and are reshaped by crisis.

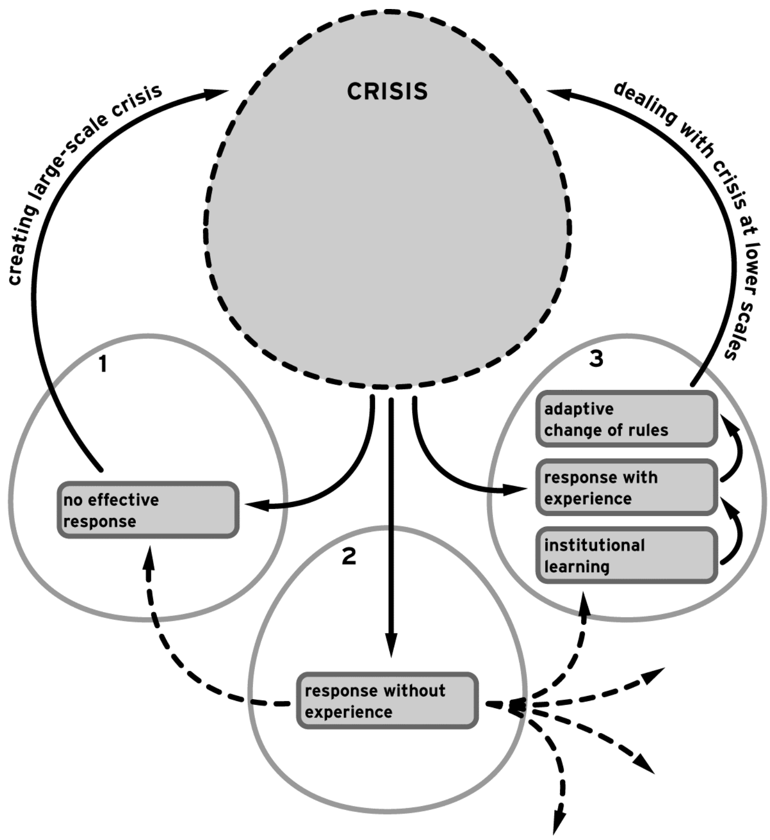

Figure 14.2. Three generic responses to resource and environmental crisis (modified from Berkes and Folke, 2001).

14.2.3 Expecting the unexpected

There are numerous local management practices and associated institutions that avoid large-scale crisis by relating to uncertainty and surprise in order to survive their effects. Such practices "puts the brakes on release" (Berkes and Folke, 2001). Instead of trying to get rid of disturbance, the existence of uncertainty and surprise and their unpredictable nature is an accepted part of development, and management actions evolve to cope with their effects by spreading risks through diversification of both resource use patterns and alternative activities (Davidson-Hunt and Berkes [chapter 3]; Colding *et al*. [chapter 7]). Such responses seem to contribute to social-ecological resilience by aiming at protecting a desirable stability domain in the face of change. Several of these local resource and ecosystem management strategies resemble risk spreading and insurance building within society, similar to portfolio management in financial markets (Costanza *et al*., 2000), and deal with the three types of surprises outlined by Gunderson (chapter 2).

Strategies designed to improve survival when faced with resource uncertainty and surprise, include practices that manage biodiversity through redundancy at several levels, from the species to the landscape level. There are many traditional agricultural groups that conserve low production crop varieties as insurance to climate and pest events that impact high yield crop varieties (Tengö and Hammer [chapter 6]). Such ecological strategies include investment in emergency food crops (Turner, Boelscher Ignace and Ignace, 2000), use of polyculture as a bet-hedging strategy to reduce vulnerability to tropical cyclones, and planting disturbance tolerant crop varieties (Colding *et al*. [chapter 7]). Multiple-disturbance resistant species among the Char dwellers in Bangladesh serve as emergency foods (Colding *et al*. [chapter 7]).

Conserving patches in the landscape to serve as emergency resource supply in the face of change is a common practice. The establishment of range reserves within the annual grazing areas among the African agro-pastoralists is one example (Tengö and Hammer [chapter 6]). These reserves provide an emergency supply of forage, which functions to maintain resilience in the face of disturbance of both the ecosystem and the social system. They serve as "savings banks" when drought challenges the processes and functions of the dryland ecosystem (Niamir-Fuller, 1998). In a similar fashion Swedish forest commons served and still serve as a "savings account" for many local farmers (Carlsson [chapter 5]). These practices deal with ecological uncertainty and surprise and accept disturbance and crisis as a part of reality in managing complex ecosystems and live with it. They reduce the impacts and improve survival during the duration of a disturbance (Figure 14.2). We believe that these practices are the result of a long-term trial - and error process of social - ecological response and adaptation to environmental unpredictability.

In traditional societies and other communities there are an array of social mechanisms, such as systems of flexible user rights and land ownership in combination with coping mechanisms, such as reciprocal gift giving, that help members of these communities survive periods of resource and ecological crises. As suggested by Low *et al*. (chapter 4) diversity and redundancy of institutions and their overlapping functions may play a central role in absorbing disturbance and in spreading risks.

Building social-ecological resilience in the face of uncertainty and surprise is about promoting the capacity to expect the unexpected and absorb it (Kates and Clark, 1996). Accumulating experience through institutional and social learning is important in this context (Lee, 1993; Olsson and Folke, 2001, Berkes and Folke, 2001). If experience embedded in institutions provides a context for the modification of management policy and rules, the institution can act adaptively to deal with the surprise. It can navigate nature's dynamics and do so by diversification and redundancy rather that simplification (Low *et al*. [chapter 4]). Furthermore, surprise and crisis create space for reorganization, and for renewal and novelty (Gunderson [chapter 2]) and provide opportunities for new ways of social and institutional self-organization for resilience (Blann *et al*. [chapter 9]).

However, a dynamic balance is needed between experience and memory, on the one hand, and the amount of renewal and novelty on the other. Creativity needs to be framed. The frame is the history; the accumulated experience and memory of the systems and it involves interactions across spatial and temporal scales (Holling, 2001; Gunderson and Holling, 2001). The dynamic balance between memory and novelty is dealt with in the next section.

14.3 Nurturing diversity for reorganization and renewal

We have emphasized the common response of managing for diversity when faced with disturbance, uncertainty, surprise and crisis. Diversity as part of resilience provides complex social-ecological systems with the ability to persist in the face of change. Managing complex systems implies spreading risks and creating buffers and not putting all eggs in one basket. In addition to the insurance aspect dealt with in the previous section, diversity also plays an important role in the reorganization and renewal process following disturbance. It is in this context that the memory – ecological and social – becomes significant, because it provides a framework of accumulated experience for coping with change. It provides the frame for creativity and adaptive capacity. We start with ecological memory and management practices that nurture this memory. This is followed by an identification of functional aspects of social memory of importance for sustaining adaptive capacity and how the diversity of social and ecological memory relates to social-ecological resilience.

14.3.1 Nurturing ecological memory

Species perform key functions in ecosystems. However, it is not the number of species per se that sustain an ecosystem in a certain stable state or stability domain, but rather the existence of species groupings, or functional groups (e.g. predators, herbivores, pollinators, decomposers, water flow modifiers, nutrient transporters) with different, sometimes overlapping, characteristics or multiple non-identical in-use copies (Low *et al*., chapter 4). Species that may seem redundant and unnecessary for ecosystem functioning during certain stages of ecosystem development may become of critical importance for regenerating and reorganizing the system after disturbance and disruption (Holling *et al*., 1995). Others may not. Seemingly redundant species connect habitats through their overlapping functions within and across scales (Peterson, Allen and Holling, 1998). Overlapping functional diversity increases the variety of possible alternative reorganization patterns and pathways following disturbance and disruption and contributes to ecosystem resilience.

The ecological memory is an important component of overlapping functional diversity. Ecological memory is the composition and distribution of organisms and their interactions in space and time, and includes the life-history experience with environmental fluctuations (Nyström and Folke, 2001). Ecological memory consists of at least three basic and interacting assemblages and their overlapping functional diversity (Figure 14.3a). The first is *biological legacies* or species and patterns that persist within an area affected by disturbance, like a tree surviving a fire or a seed that require burning (Franklin and MacMahon, 2000). The second is *mobile links*, i.e. species of functional groups that migrate between areas (Lundberg and Moberg, **in review**). These links include species that passively spread from one area to another, like larvae through currents or seeds through wind, or actively move between areas, like fish, birds, bats and mammals, and that contribute to reorganization of the area hit by disturbance. The third is the *support areas* for the functional links, i.e. a diversity of habitats in the landscape of which the disturbed area is a part.

Each of these assemblages consists of several functional groups, interacting with overlapping functions as a dynamic ecological community and linked with hydrological, biogeochemical and other abiotic flows. The vulnerability of functional groups seems to be related to redundancy of species within each group and suggests that ecosystems have lower resilience to disturbance when functional groups have low diversity (Nyström, Folke and Moberg, 2000). The presence and dynamics of this network of interacting species with overlapping functions is the result of previous experience and accumulated information in the life history of species to environmental change (Bengtsson *et al*., **in review**). The memory connects a system's present to its past and to its neighbors. The rates of reorganization and the level of similarity between the old and the new ecosystem are a function of the extent and availability of ecological memory in the landscape or the seascape. This does not imply tightly connected systems, but systems with redundant and loosely connected subsystems, which allow persistence in the face of change (Low *et al*. [chapter 4]).

As illustrated in several chapters of the volume, there are many ecological practices in both traditional and contemporary societies supporting ecological memory and biological diversity, thereby contributing to the regeneration and renewal of disturbed ecosystems (see also Figure

14.2). Obvious ones include the protection of species, including keystone species, as well as a ban on harvesting during certain stages in their life cycle, and the setting aside of reserves, protected areas and other socially fenced areas (e.g., sacred groves, spirit sanctuaries, and buffer zones).

To be effective, these habitats need a social context. Contemporary society tends to create reserves for conservation of biodiversity per se. It is only recently that such reserves are being implemented to enhance production in surrounding areas (Allison, Lubchenco and Carr, 1998) and there are still many problems with monitoring, enforcement and sanctioning of reserves and protected areas. Protected areas common in indigenous cultures include sacred grooves and other forms of taboo systems (Ramakrishnan, Saxena and Chandrashekara, 1998; Colding and Folke, 2001). There are communities that provide temporal and spatial refugia to a number of ecologically viable species involved in the generation of ecosystem services. These species may hide, forage, and reproduce in the vicinity of the local ecosystems belonging to these communities. Protection of species, especially keystone ones, is important for communities prone to large-scale and frequent natural disturbances (Colding *et al*. [chapter 7]). Smaller terrestrial and aquatic ecosystems, such as forest patches, coastal reefs and river stretches, may receive protection from habitat taboos that conserve ecological services on which the local community depends (Chernella, 1987; Gadgil, 1987; Ruddle, 1988; Ramakrishnan, Saxena and Chandrashekara, 1998).

Protection of species and habitats help nurture ecological memory through diversity and supports the reorganization phase of ecosystem development. Other measures include management practices during ecological succession that make use of and support biological diversity in the production of food, timber and other ecological services (Tengö and Hammer [chapter 6]). They play a significant role in building resilient landscapes for adaptive capacity (Gadgil, Berkes and Folke, 1993; Berkes, Folke and Gadgil, 1995). The biological diversity such practices support helps sustaining redundancy within and between functional groups of species and provides ecological memory for reorganization in a patch or an area following disturbance (Figure 14.3a).

Such management in the context of landscape dynamics, with patchy mosaic of ecosystems in different development stages, is in stark contrast to land use transformations aiming at optimal production and control of commodities over vast areas (Bengtsson *et al*., **in review**). In homogenized and intensively managed landscapes the ecological memory is degraded, more distant and reduced, leading to much longer time periods for reorganization. One may speculate that simplified landscapes, with low levels of ecological memory and homogeneous spatial patterns, will be more prone to opportunistic invasive organisms and may more easily shift between stability domains. Such systems will most likely be subject to higher variability and lower predictability concerning their capacity to sustain a flow of ecosystem services. Homogenization leads to ecosystems that are more susceptible to disturbance and consequent regime shifts (Gunderson and Pritchard, **2002**; Scheffer *et al*., 2001). Due to reduced ecological memory, simplified landscapes will most likely require management interventions to secure ecosystem services and avoid shifts into undesirable stability domains. As human actions continue to remove or degrade ecological memory that provides redundancy, there comes a time when the buffering capacity is lost, and management is confronted with a surprise often leading to a crisis (Low *et al*. [chapter 4]). As stated by Gunderson (chapter 2) ecological memory and its functional diversity maintains the capacity for renewal in a dynamic environment by providing a buffer that protects the system from the failure of management actions that are based upon incomplete understanding, and thereby allows managers to learn and actively adapt their resource management policies.

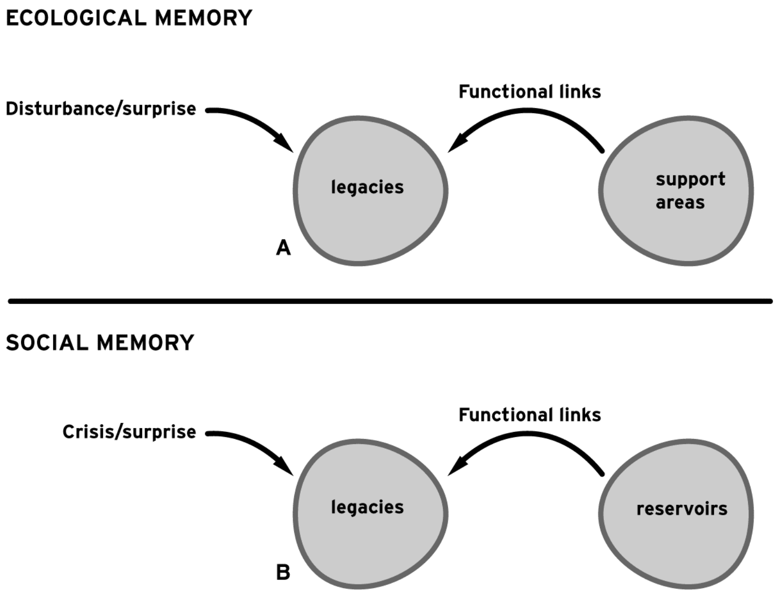

Figure 14.3. Components of memory for adaptive capacity in ecological and social systems. The *ecological memory* a) consists of a diversity of species within and between functional groups (e.g. photosynthesizers, pollinators, seed dispersers, grazers, predators, decomposers, nutrient transporters, water flow modifiers) of biological legacies in the area subject to disturbance, of mobile species in functional groups that link the disturbed area to other areas and of support areas that provide habitat for the functional groups of mobile links.
The *social memory* b) consists of a diversity of individuals, institutions, organizations and other actors with different and overlapping roles within and between critical groups (e.g. knowledge carriers and retainers, interpreters and sense makers, stewards and leaders, networkers and facilitators, visionaries and inspirers, innovators and experimenters, entrepreneurs and implementers, followers and reinforces; see Table 14.2) of survivors on the arena subject to crisis, of functional links that enter from outside to take advantage of the space created by the crisis and the reservoirs of practices, knowledge, institutions, cultural values and world views on which they draw. The combination of such sources of ecological and social resilience and their overlapping functions and redundancy provides potential for reorganization, novelty and adaptive capacity in the face of disturbance and crisis. Functional social-ecological diversity is a key ingredient of adaptive capacity and a key characteristic of resilience.

14.3.2 Sustaining social memory

Through institutional and social learning (Lee, 1993), resource users develop a collective memory of experiences with resource and ecosystem management. This memory provides context for social responses to ecosystem change, increases the likelihood of flexible and adaptive responses, and seems to be particularly important during periods of crisis, renewal and reorganization. It draws on experience but allows for novelty and innovation within the framework of accumulated experience. The institutional memory is an accumulation of a diversity of experiences concerning management practices and rules-in-use at the level of institutions as opposed to individual resource user. Institutional memory provides the foundation for modification of rules, and typically refers to decadal time scales, as opposed to months or a year.

Institutional memory is a subset of social memory that bridges the deepest values and symbolic truths of a society and the social or ecological environment on which members of that society have to act. Social memory is the arena in which captured experience with change and successful adaptations, embedded in a deeper level of values is actualized through community debate and decision-making processes into appropriate strategies for dealing with ongoing change (McIntosh, 2000). It is a part of the cultural capital of human society (Berkes and Folke, 1992). Social memory embeds long-term historical and cultural observations (McIntosh, Tainter and McIntosh, 2000) of which cultural diversity (Gadgil, 1987) and a diversity of worldviews (Kendrick [chapter 10]) linked to cultural evolution (Boyd and Richerson, 1985) may play an essential role in nurturing resilience for adaptive capacity.

In Figure 14.3b we initiate the identification of key aspects of social memory, in parallel to ecological memory (Figure 14.3a). The social memory consists of a diversity of individuals, institutions, organizations and other players with different but overlapping roles within and between critical functional groups. Some suggested 'functional groups' of social memory are listed and exemplified in Table 14.2 and Box 14.1.

When there is a crisis, space is created for renewal, reorganization and novelty. The crises may be external markets and tourism pressure (Seixas and Berkes [chapter 11]), floods and flood management or changes in property rights (Colding *et al*. [chapter 7]), acidification (Gadgil *et al*. [chapter 8]), resource failures like the caribou crisis (Kendrick [chapter 10]), rigid, conventional paradigms of resource management (Blann *et al*. [chapter 9]), new legislation (Trosper [chapter 13]) or governmental policies that do not take into account local contexts or traditional societies (Alcorn *et al*. [chapter 12]).

Groups such as the ones identified in Table 14.2 play a part a) among the survivors on the arena subject to crisis, b) among the functional links that enter from outside to take advantage of the space created by the crisis and c) among the reservoirs of practices, knowledge, institutions, cultural values and world views supporting the functional links (Figure 14.3b). In real life, some of these functions are combined. For example, among the Cree of James Bay, elders combine the functions of knowledge carriers, sense makers and stewards (Berkes, 1998). We hypothesize that the combination of functional groups related to social memory, their diversity, overlapping functions, and their redundancy provides resilience for reorganization, novelty, and thereby enhances adaptive capacity in the face of disturbance and crisis.

Table 14.2 Functional groups of social memory

Knowledge carriers and retainers
Interpreters and sense makers
Networkers and facilitaters
Stewards and leaders
Visionaries and inspirers
Innovators and experimenters
Followers and reinforcers

But their combination may also cause barriers, collision and erosion of memory, as may be the case when different cultural value systems, worldviews and discrepancies in conceptualization are brought together and interact (chapters by Tengö and Hammer, Kendrick), or when the cultural dynamics created by the policies of those in power during earlier periods may inhibit development of the ability to respond to disturbance and surprise through building resilience (Trosper [chapter 13]; Gunderson, Holling and Light, 1995). In this sense, the underlying worldview of resource management imposes a grid on social memory for managing ecosystem dynamics.

Box 14.1 Functional groups for social memory

A number of distinct, but often overlapping, roles exist regarding social memory in social-ecological systems. Note that we are not trying to characterize all social roles in society, but merely the functional roles by which resource users develop and retain a collective memory of resource and ecosystem management. Based on the chapters of the volume we identify seven such roles: Knowledge carriers and retainers; interpreters and sense makers; networkers and facilitaters; stewards and leaders; visionaries and inspirers; innovators and experimenters; followers and reinforcers

Knowledge carriers and retainers of memory include the such as wise men of the traditional society in Tanzania, who have regular meetings regarding such things as the status of the land, issues on drought, diseases and land fertility (chapter by Tengö and Hammer). Other examples include the institution in Samoa that sustains the practical knowledge of polyculture as a resilience strategy in the face of large unpredictable disturbances (chapter by Colding *et al.*), and the sense of place project of cultural revival and rememberance in the Sonora watershed (chapter by Davidson-Hunt and Berkes).

Interpreters and sense makers include the biology teacher in the local community in Sweden who continuously processes ecological information into practical knowledge and makes it accessible for decision-making (chapter by Gadgil *et al.*), and the fishers who monitor pulses of fish migrations in the Brasilian lagoon fishery (chapter by Seixas and Berkes).

Networkers and facilitators include the resource managers of Minnesota leading diverse groups of constituents through crises and change (chapter by Blann *et al.*). Other examples include the networkers and organizers in Peoples' Biodiversity Registers in India (chapter by Gadgil *et al.*), organizers of forest commoners in Sweden (chapter by Carlsson), the second Committee of Scientists in the US Forestry sector in the attempt to facilitate the ecosystem approach in forestry (chapter by Trosper), and Dayak educational program organizers who bring together elders and adults to help preserve the memory of useful species, ritual protections, and sacred areas (chapter by Alcorn *et al.*).

Stewards and leaders include those in the tiny Inuit community in eastern Hudson Bay who organized a major aboriginal peoples' assessment of regional environmental change; and the two stewards that triggered the evolution of the local Swedish fishing association for watershed management (chapter by Gadgil *et al.*).

Visionaries and inspirers who initiate and create incentives for renewal and reorganization following crisis in resource management are illustrated in the Minnesota chapter (Blann *et al.*), and in the aboriginal forest management case in British Columbia (Pinkerton, 1998).

Innovators and experimenters, such as those in the caribou co-management case, bring together social memories of different cultures for mutual learning and novelty, a process that requires respect and trust building (chapter by Kendrick).

Entrepreneurs and implementers often take innovations and apply them, as in the indigenous social network in Indonesia that developed and implemented a new social structure to respond to crisis from external drivers (chapter by Alcorn *et al.*).

Followers and reinforcers are those people and groups, the willing participants who make a project work, such as those in the local fishing association in Sweden initiated by two key stewards, and the participants of the Peoples' Biodiversity Registers (chapter by Gadgil *et al.*).

14.3.3 Enhancing social-ecological memory

Sustaining ecosystem capacity that fosters ecological memory requires continual social and institutional adjustments to environmental dynamics and ecological feedback. The experience, of the role of disturbance, uncertainty and surprise, and the need to nurture biodiversity and conserve ecological memory for maintaining adaptive capacity, must be stored in the social memory of resource users and managers and be expressed in management practices that build resilience. For example, elders with extensive ecological knowledge (Berkes, 1999) and other similar "stewards of wildlife habitats" (Nabhan, 1997) are carriers of social memory of resource and ecosystem dynamics, with observations that often include understanding of long-term and large-scale changes (Berkes and Folke, 2001; Davidson-Hunt and Berkes [chapter 3]). Rituals in both traditional and contemporary society play a role in transforming social memory into practical resource and ecosystem management (Alcorn and Toledo, 1998, Gadgil *et al*. [chapter 8]). Local monitoring can provide a more effective response to signals of change in ecosystem dynamics than does monitoring by centralized agencies (Carlsson [chapter 5]). Key individuals that act as visionary leaders create incentives for cross-scale institutional and organizational collaboration and contribute to sustaining and building institutional and social memory for ecosystem management (Pinkerton, 1998; Blann *et al*. [chapter 9], Olsson and Folke, 2001).

Enhancing social-ecological memory also involves sharing experiences of crisis at wider levels of society. This is the case in West and East Kalimantan where the LBBT provides legal training and facilitates local communities to share experiences from confronting logging and plantation companies. It also involves nurturing the opportunity for self-organization in the institutional or political space created by crisis. For example, the great fires of Indonesia in 1997 opened up new opportunities for negotiations among NGOs and the political elite (Alcorn *et al*. [chapter 12]).

Institutional and social memory for resilience should not be uniform and static, but diverse and dynamic. We propose that systems with uniform and static memory, with limited carriers of memory, or few structures for storing and developing memory, are more vulnerable to change and surprise. They have lower adaptive capacity. In this sense, redundancy among individuals and institutional and social redundancy may serve functions similar to overlapping functions of ecological redundancy for reorganization and renewal after disturbance (Peterson, Allen and Holling, 1998), recognizing that redundancy implies similar but not identical functional roles. Low *et al*., (chapter 4) suggest that policies and institutions that recognize, and respond to, the inherent redundancy of ecosystems are much less likely to be surprised by cumulative erosive actions or loss of ecological resilience. They propose that institutions organized in ways that parallel the structure of ecosystems are more likely to receive accurate and timely information about the state and dynamics of the systems and be able to respond in constructive ways. The existence of seemingly redundant local institutional variations may imply that institutional responses can be more potent and rapid than otherwise, and that local variations may be able to meet unforeseen contingencies.

In a metaphorical sense, such characteristics of social memory may be compared with the proposed role of the diversity of species with and between functional groups in ecosystem reorganization (Walker, 1992; Peterson, Allen and Holling, 1998; Nyström, Folke and Moberg, 2000; Low *et al*., chapter 4). For example, the system may do well with only one steward under periods of slow and stable development, but when faced with change, other stewards may be needed to buffer surprise and crisis, renew and innovate, and reorganize. Similarly, seemingly redundant rules may be waiting in the wings to secure the ability of ecosystem management to respond to uncertainty and surprise (Low *et al*. [chapter 4]). Without diversity and redundancy in functional groups the resource management system may be fragile and vulnerable to disturbance and crisis, as illustrated by the bifurcation policies in crayfish management in Sweden, balancing on the edge of shifting into another stability domain of management (Gadgil *et al*. [chapter 8]). Such sliding may lock the system in a certain development trajectory, with an irreversible loss of adaptive capacity.

There has to be a potential for combining and recombining social memory, adding and filtering external influences (chapters by Alcorn *et al*., Seixas and Berkes, Tengö and Hammer), as well as transferring knowledge and experience in space and time (Gadgil *et al*. [chapter 8]) to enhance overlapping functions and redundancy for resilience. Based on the discussion of social-ecological memory in resilience (Figure 14.3), we propose that human actions and innovations framed by a dynamic, diverse and evolving social memory in tune with ecosystem dynamics has the potential to foster adaptive capacity in social-ecological systems. We also argue that social memory needs to encompass ecological knowledge and understanding, including knowledge of local resource users. In the introductory chapter, we stated that such ecological knowledge and understanding is a key link between ecosystem dynamics and its successful management, and that this knowledge could fruitfully be combined with other knowledge systems, the subject of the next section.

14.4 Combining different types of knowledge for learning

Sustainable use of the capacity of ecosystem to generate services is unlikely without improved understanding of ecosystem dynamics. It has been argued that all forms of relevant information should be mustered to increase knowledge and understanding for improved management of complex ecosystems, including different systems of knowledge and their combination (Berkes and Folke, 1998). Here we address the relationship between experiential and experimental knowledge, the need to expand knowledge from structure to function of nature, the incorporation of knowledge of ecological processes and dynamics into institutions, and the increased potential for learning and building social-ecological resilience by making use of and combining different knowledge systems.

14.4.1 Experiential and experimental ecological knowledge

Only a fraction of the dynamics of ecosystems is likely to have been subject of careful observations within the framework of formal science. A large proportion would be part of the experience of the people living, observing and using the systems in a variety of contexts (chapters by Carlsson, Tengö and Hammer, Seixas and Berkes, Gadgil *et al*., Colding *et al*.). Monitoring change is key to increasing the ability to respond to change and shape institutions and management practices. Resource users' local ecological knowledge incorporates knowledge derived from historical observations of 'natural experiments' and the dynamics of these systems. It is practical and place based. Gadgil *et al*. (chapter 8) argue that such "experiential" knowledge of many local communities and indigenous societies may play an important role in the understanding of the behavior of ecological systems, particularly in situations of crisis and reorganization. Such practical working knowledge may be a valuable complement to scientific "experimental" knowledge in addressing the dynamics of complex adaptive ecosystems and their management (Johannes, 1998; Levin, 1999). In this sense, practice informs theory as much as theory informs practice. The strength of conventional experimental science is in the collection of synchronic (simultaneously observed) data, whereas the strength of many experiential management systems is in diachronic information (long time-series of local observations).

Local knowledge systems are not static but are in continuous development. There are knowledge systems with conceptualisations of the world that are quite different from science-based resource management knowledge (Kendrick [chapter 10]; Berkes 1999). However, actually held ecological knowledge of local communities facing a globalized world, increasingly tends to become a combination of locally generated experiential knowledge and outside knowledge, of which scientific knowledge plays an important role (Olsson and Folke, 2001). Furthermore, local knowledge systems in themselves will not be sufficient for maintaining sustainable resource use, since the world is increasingly human dominated and interconnected across spatial and temporal scales, both ecologically and socially, and interfere with local authority (Alcorn *et al*. [chapter 12]). The important point to make is that an adaptive learning process for managing ecosystems for social-ecological resilience should not dilute, homogenize, or diminish the diversity of experiential knowledge systems for ecosystem management, with lessons for how to respond to change and how to nurture diversity.

14.4.2 Expanding from the knowledge of structure to the knowledge of function

The bulk of ethnobiological knowledge analyzed by scientists concern taxonomic knowledge or knowledge about species or particular resources. In this volume, we have been more concerned with ecological knowledge of ecosystem processes and functions. Several chapters have analyzed the capacity of ecosystems to sustain human well being, including the role of functional biodiversity underlying the generation of particular resources or ecosystem services, as well as the role of society in managing this capacity. By analyzing management practices we have been able to focus on what sometimes is referred to as 'tacit' ecological knowledge and understanding (Polanyi, 1958; Blann *et al*. [chapter 9]) and how it contributes to maintaining stability of human communities in the face of change. We have also illustrated that local knowledge of ecosystem dynamics is not static but in continuous development drawing on social-ecological memory.

14.4.3 Building process knowledge into institutions

Management practices of local resource users and communities do not exist in a vacuum but are framed by a social context. Hence, they tend to be embedded in institutions and other forms of social mechanisms (chapters by Carlsson, Tengö and Hammer, Seixas and Berkes, Gadgil *et al*., Colding *et al*.). Those that work in synergy with ecosystem dynamics are thought to be supported by worldviews and cultural values that do not decouple people from their dependence on natural systems (chapters by Davidson-Hunt and Berkes, Blann *et al*., Kendrick, Alcorn *et al*.).

The importance of coupled social-ecological management of ecosystem dynamics can be exemplified from a study on frontier colonist farmers in the Brazilian Amazon (Muchagata and Brown, 2000). People moving from one area to another rapidly gained detailed knowledge of particular resources, but their knowledge of processes and functions of the underlying ecosystem was very patchy. Humans seem to acquire fairly rapidly the knowledge of biological structures and the taxonomy of resources. But securing the flow of resources requires the capacity of the ecosystem to sustain its processes and functions, the knowledge of which takes a longer time to develop. It requires dwelling for long periods of time in the ecosystem and a sense of place perspective (Davidson-Hunt and Berkes [chapter 3]). Such knowledge acquisition is an ongoing dynamic learning process; perhaps most importantly, it seems to require social networks and an institutional framework to be effective. Thus, it is not effective to separate ecological studies aimed at management from the institutional framework within which management takes place. Understanding ecosystem processes and managing them is a progression of social-ecological co-evolution, and it requires learning and accumulation of ecological knowledge and understanding in the social memory. In this sense a collective learning process that builds knowledge and experience with ecosystem change evolves as a part of the institutional and social memory, and it embeds practices that nurture ecological memory. We propose that over the longer term environmental wisdom evolves as part of such a process.

If this is true, knowledge generation in itself will not be sufficient for building adaptive capacity in social-ecological systems to meet the challenge of navigating nature's dynamics. Learning how to sustain social-ecological systems in a world of continuous change needs an institutional and social context within which to develop and act (Gunderson [chapter 2]; Blann *et al*. [chapter 9]; Kendrick [chapter 10]). The knowledge system itself becomes part of the processes of institutional and social learning and memory to deal with ecosystem dynamics.

14.4.4 Fostering complementarity of different knowledge systems

Local ecological knowledge systems of resource users and local communities can complement conventional resource management in at least three ways. Here we discuss them in relation to the adaptive renewal cycle presented in the introductory chapter.

- Qualitative monitoring and management during the exploitation and conservation phases of the adaptive renewal cycle;
- Building resilience during the release and reorganization phases; and
- Providing long time-series of local observation and institutional memory for understanding ecosystem change.

The exploitation and conservation phases are the two stages that have been the main concern of conventional resource management science, with emphasis on collection of quantitative data. Many locally developed management systems, however, collect and use qualitative information, as the examples in Tengö and Hammer (chapter 6), Gadgil *et al.* (chapter 8), Blann *et al.* (chapter 9) and Colding *et al.* (chapter 7) indicate. The two approaches, and the kind of information they collect, are complementary in that they may be used to add to the strengths of one another.

The release phase of the adaptive renewal cycle seems to be largely ignored by conventional resource management, and the reorganization phase is largely understudied. By contrast, many experiential knowledge based systems seem to accord a great deal of emphasis to these backloop phases, judging by the rich variety of practices that exist in a variety of cultures and geographic areas (Folke *et al*., 1998). Many societies interpret and respond to feedback from complex adaptive ecosystems, and their practices are not only locally adaptive, but generalizable over wide regions (Gadgil *et al*. [chapter 8]; Berkes, 1999). These practices provide insights for contemporary resource management, and complement existing approaches (Berkes, Colding and Folke, 2000). Conventional science does not have a great time depth of environmental data. For example, instrumental data on climate change in the

Canadian Western Artic only dates back from the mid-1950s. Since assessing climate change requires baseline information and a longer time series of observations than is available, a study was initiated in 1998 to tap the knowledge of Inuvialuit hunters and fishers. The results of the project showed the feasibility of using traditional knowledge to complement scientific data in five areas. These are the use of traditional knowledge (i) as local scale expertise; (ii) as a source of climate history and baseline data; (iii) in formulating research questions and hypotheses; (iv) as insights into impacts and adaptation in Arctic communities; and (v) for long term, community-based monitoring (Riedlinger and Berkes, 2001).

Thus, scientific understandings of complex adaptive systems and their change could be enriched by insights from local management systems. Several chapters of the volume support this conclusion. Conceptually, one may think of a sequence of knowledge systems for ecosystem management. In some, knowledge for ecosystem management can be based on either traditional ecological knowledge (e.g. chapters by Alcorn *et al*., Colding *et al*., Tengö and Hammer; Berkes, 1999) or scientific/governmental knowledge (e.g. chapter by Trosper, Gunderson, Holling and Light, 1995). Some aim at bringing insights from traditional ecological knowledge into scientific knowledge and vice versa (e.g. chapters by Gadgil *et al*.). In others it may be hard to separate the content of practical or local ecological knowledge from the influence of scientific knowledge (e.g chapter by Seixas and Berkes; Olsson and Folke, 2001). Furthermore, there may be deliberate attempts to co-manage and combine different knowledge systems. For example, Kendrick (chapter 9) discusses the role of co-managing knowledge among interest groups with different worldviews, characterizing them as mutual learning systems. Blann *et al*. (chapter 10) emphasise the importance of bringing diverse interest groups together in temporary learning systems, or platforms for learning, in the management of complex dynamic ecosystems. Adaptive management (Holling, 1978) is about creating platforms and involving user groups and interest groups for knowledge sharing about complex ecosystem management and for how to relate to uncertainty and surprise. Adaptive co-management explicitly recognizes the necessity of combining adaptive management with institutions across scales. There is appreciation throughout the volume of the tight coupling between knowledge of ecosystem dynamics and of institutions in social-ecological systems. Such coupling is an important characteristic of self-organized complex systems (Levin, 1999); process knowledge is integral to institutions in an ongoing feedback and learning process.

14.5 Creating opportunity for self-organization towards social-ecological sustainability

Resilience may be considered a precondition for adaptive capacity, the capacity to respond to and shape change. Adaptive capacity includes learning and changing of resource management rules as experience accumulates and social-ecological memory develops. Adaptation in self-organized systems is related to rules-of-thumb or simplified rules (Holland, 1995). These rules govern how the system adapts in response to past and present conditions. In the self-organized process, patterns of behavior and framework emerge that help facilitate future learning processes (Levin, 1999). However, responding to and shaping change can take different pathways. For example, adaptation may concentrate on reducing the impacts of change, or it may take advantage of new opportunities created by change. Environmentalists and the nature conservation movement have tended to focus on reducing the impacts of change on nature, and preserving nature as it is, while those promoting progress see conservation as a constraint, and tend to focus on the new opportunities that change creates for economic development. A conflict is created, the positions are locked and there is a battle between perspectives and worldviews. The interplay between sustaining and developing is not recognized. In this section we will discuss the significance of the interplay between diversity and disturbance for social-ecological resilience and adaptive capacity, as well as cross-scale issues in coupled social-ecological system, and the relation to external drivers of change that may support or contest resilience.

14.5.1 Recognizing the interplay between diversity and disturbance

Resilience buffers change, thereby contributing to sustaining the system in a desirable stability domain. Memory is key component of resilience. It supplies the experience of previous self-organizations and the ingredients for new self-organization embedded in a historical and evolutionary context. Change, surprise and crisis, here referred to as disturbance, open up space for change. Creation of space allows for opportunity and renewal by recombining memories and by bringing in novelty. Diversity of memories provides the potential for alternative ways to maintain functioning when faced with change. Diversity provides insurance to cope with change. It also provides the potential for reorganizing following change. Hence, there is a dynamic symbiosis between diversity and disturbance that is part of resilience and key to sustainable development. Disturbance can trigger positive change when there is memory, but with lack of memory for resilience a similar disturbance may cause severe consequences. Human actions that alter and accumulate disturbance and reduce memory, seem to generate vulnerable social-ecological systems through loss of resilience; vulnerable in the sense of balancing on the edge to undesirable stability domains.

Hence, there is a dynamic interplay between reducing the impacts of change and at the same time taking advantage of the opportunities created by change. Systems where change is not allowed will almost certainly generate surprise and crisis. Systems that allow too much change and novelty will suffer loss of memory. The interplay between change, capacity to respond to and shape change that allows for renewal is key in self-organization. The dynamic process requires social-ecological memory with functional diversity (including redundancy) for turning disturbance into options for renewal and novelty. In this sense, memory frames creativity. Holling (2001) coined the concept panarchy (a heuristic model of a hierarchy of nested adaptive renewal cycles, see Berkes *et al*. [chapter 1]) to capture the scale dimension of the interplay between diversity and disturbance. Each level in the panarchy operates at its own pace, protected from above by slower, larger levels with spatial and temporal memory, but revitalized from below by faster, smaller cycles of innovation. The whole panarchy therefore both creates and conserves, combining learning and innovation with continuity. Systems can develop, and at the same time be sustained (Gunderson and Holling, 2001), by operating in a context of framed creativity.

The dynamic interplay between disturbance and diversity is stressed in Figure 14.5. Based on the findings of the volume we argue that the interplay of disturbance and functional diversity, as a part of memory, is a prerequisite for building resilience for adaptive capacity in linked social-ecological systems. Creating platforms for conflict resolution and participation by various interest groups for knowledge creation will not be sufficient for sustainability. It requires the context of the interplay between diversity and disturbance in resilience. Ecological knowledge and understanding of this interplay is a necessity as well.

Learning to live with change and uncertainty and nurturing diversity for reorganization and renewal is an ongoing dynamic process of sustaining development. But it requires a fundamental shift in thinking and perspective from assuming that the world is in a steady-state and can be preserved as it is, by focusing on preventing and controlling change, to a recognition of change being the rule rather than the exception, and thereby concentrating on managing the capacity in complex adaptive social-ecological systems to live with change and shape change.

14.5.2 Dealing with cross-scale dynamics

The panarchy metaphor is one way to organize thinking and understanding of the temporal and spatial dimensions of building resilience in social-ecological systems (Gunderson and Holling, 2001). Here we deal with institutional and ecosystem linkages of these dimensions and over a diversity of scales (McIntosh, Tainter and McIntosh, 2000; Costanza *et al*., 2001). Several of the chapters in this volume deal with such cross-scale dynamics.

Gunderson (chapter 2) in his classification of surprises tells that an interaction between key variables operating at distinctly different scale ranges and with different speeds, can cause sudden qualitative shifts in stability domains. Efforts to reduce the risk of unwanted shifts in stability domains should therefore address the gradual changes that affect resilience rather than merely aiming at controlling disturbance. In other words, the challenge is to sustain a large enough stability domain to secure the flow of ecological goods and services, and to sustain enough memory to secure resilience and the adaptive capacity-enhancing interplay between disturbance and diversity.

The resilience of the ecological stability domain often depends on slowly changing variables such as land use, nutrient stocks, soil properties and biomass of long-lived organisms (Gunderson and Pritchard, 2002). These factors may be predicted, monitored and modified. By contrast, stochastic events that can trigger threshold effects and shifts in stability domains (such as hurricanes, droughts or floods) are usually difficult to predict or control. Therefore, building and maintaining resilience of desired ecosystem states may be the most pragmatic and effective way to manage ecosystems in the face of increasingly human driven environmental disturbances across scales from local to global levels.

Human adaptability can be disadvantageous in this context. Loss of resilience it is often masked by support from socioeconomic infrastructures at other scales that make it possible to maintain a business-as-usual strategy in a situation of crisis. A common response to deal with surprises is trying to remove or ignore them. Such responses impede social-ecological learning. Examples include capital markets that provide loans and financial insurance to fishermen and farmers for periods of resource crisis, thereby removing incentives for responding to environmental feedback and avoiding the building of ecological knowledge system into local institutions that may tighten social-ecological feedback loops (Colding *et al*. [chapter 7]). There are local communities aware of the pitfalls of relying on outside inputs and incentives. Alcorn *et al*. (chapter 12) describe how the Dayak have been cautious about maintaining a balance between economic dependence on forest products and products used for subsistence. Dayak associations have become wary of dependence on external donors. While accepting some support, they have built in ways for the movement to be supported by the Dayak themselves, for example through credit unions. Such strategies buffer against economic surprises and create local incentives for developing strategies to cope learn.

Low *et al*. (chapter 3) argue that diversity and redundancy among local level resource management systems enhance performance so long as there are overlapping units of government that can resolve conflicts, aggregate knowledge across scale and insure that when problems occur in smaller units, a larger unit can temporarily step in. This seems to be the case in the lagoon fishery in Brazil (Seixas and Berkes [chapter 11]), where repeated crises, combined with externally driven change led to the involvement of higher level institutions. In the crayfish watershed management system in Sweden (Gadgil *et al.* [chapter 8]), management self-organized ecologically from individual crayfish to the whole watershed and institutionally from a few individuals to a nested set of organizations, facilitated by rules and incentives at the national level.

Low *et al*. (chapter 4) conclude that the presence of larger overlapping jurisdictions is an important complement to the work of parallel smaller-scale units. Ostrom (1998) uses the term polycentric management for management that involves a diversity of local, as well as higher level of governance, and aims at finding the right balance between decentralized and centralized control. Polycentric management allows decisions to be made at different levels in society and increases the possibilities to create feedback loops at various scales. In polycentric systems the skills, networks of human relationships, and mutual trust that are incrementally developed in one setting represent social memory that could be transformed for reorganization in another setting (chapters by Alcorn *et al*., Gadgil *et al*. and Blann *et al*.).

Another such cross-scale transformation in social-ecological systems concerns the evolution of ecological knowledge systems in settings external to the dominating US forestry management paradigm. Trosper (chapter 13) describes how the ecosystem approach, developing over decades in science and policy (Dale *et al*., 2000), was available and activated for implementation in a situation of crisis and restructuring in the US forestry sector. The case illustrates that the process of generating and accumulating knowledge of complex ecosystem management over temporal and spatial scales in one setting, can be made accessible in another setting. In this case, the transfer of knowledge from one panarchy to another required functional groups of leaders and networkers for the activation and creation of social memory in a new setting.

14.5.3 Matching scales of ecosystems and governance

Several chapters in the volume stress the capability of local users and their organizations to constantly reshape and adapt their institutions to ecosystem dynamics (chapters by Carlsson, Tengö and Hammer, Gadgil *et al*., Kendrick, Colding *et al*. and Alcorn *et al*.). Carlsson (chapter 5) concludes from his study of a boreal forest area in Sweden that well-organized groups of local common pool resource users, closely connected to the resource system, are in a better position to adapt to and shape ecosystem change and dynamics than remote levels of governance. Such systems involve social mechanisms to spread risks over time. A diversity of different types of property rights provides opportunities for local users to gain the benefits of each property rights system. As illustrated throughout this volume, insights are available from local management systems, including those with cross-scale interactions, on how to relate to the dynamic interplay between diversity and disturbance, an interplay that seems critical for building resilience.

The learning process is of central importance for social-ecological capacity to build resilience. It is important that learning processes include operational monitoring and evaluation mechanisms in order to generate and refine ecological knowledge and understanding into management institutions. This is the focus of adaptive co-management in which institutional arrangements and ecological knowledge are tested in an ongoing trial-and-error process. Adaptive co-management draws on social-ecological memory and is informed by both practice and theory. It relies on the participation of a diverse set of stakeholders operating at different scales (chapters by Gadgil *et al*., Blann *et al*., Kendrick).

Adaptive co-management requires different management practices than conventional ones (Low *et al*. [chapter 4]; Gunderson and Holling, 2001), practices with the ability to tighten environmental feedback, and building resilience to allowing for disturbance and change (Berkes and Folke, 1998). Adaptive co-management benefits from combining the ecological knowledge of local resource users, scientists, and other interest groups, often with different conceptualizations of the issues and even different worldviews and belief systems, in mutual learning systems (Kendrick [chapter 10]). They should not start from scratch, i.e. trying to be adaptive without experience (Figure 14.2), but draw on and nurture ecological and social memory of the area and region to shape and turn surprise and crisis into renewal and opportunity. That we refer to as the process of framed creativity. Adaptive co-management designs should make use of information technology and create novel platforms for learning how to build resilience under uncertainty in landscapes increasingly transformed by human actions. Such design may be important for reducing ecological illiteracy in urbanized regions and reconnect people whose livelihoods are no longer closely related to the land. Incentives from urban areas need to be created to support local areas that practice resiliency management of the resource base that sustains urban lifestyles, so that people attentive to the land can continue to nurture social-ecological systems (Davidson-Hunt and Berkes [chapter 3]).

Accounting for external drivers

Even if a resource management system is dynamic in its response to ecosystem change and surprise and builds social-ecological resilience, it may be fragile and vulnerable to external social and economic drivers (Dasgupta and Mäler, 1992; Balland and Platteau, 1996). This is exemplified by Seixas and Berkes (chapter 11) where the local system is overwhelmed by shocks derived from the larger scale, in this case related to tourism. In contrast, Alcorn *et al*. (chapter 12) describe how social renewal as a response to crisis can counteract the erosion of social-ecological resilience. In this case, the response by the Dayak of Borneo was to develop a cluster of dynamic associations between local and national levels to influence external social and economic drivers. The response involved diversification across scale with many loosely connected associations with overlapping functions derived from a bottom up perspective.

In Figure 14.4 we referred to such institutional designs as meso-scale membranes. They may be generated from the bottom-up or constructed from above, or a combination thereof. They may function to filter out major external socioeconomic drivers entering from larger scales, such as urbanization, side effects of international trade, new technologies, surprises, disruptive world views, climate change and human health impacts.

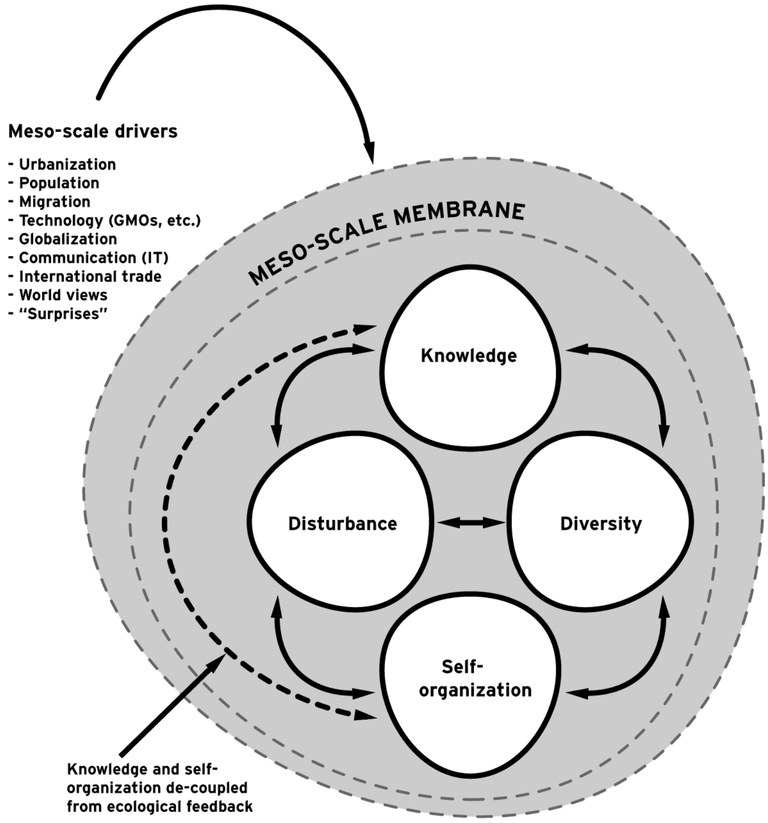

Figure 14.4. The interplay between disturbance and diversity and their relationship to knowledge systems and self-organization as a prerequisite in the building of resilience for adaptive capacity in social-ecological systems. The figure also addresses cross-scale dynamics and the matching to meso-scale drivers of human domination.

Many aspects of globalization tighten intersystem linkages, hierarchies, and interdependencies between local resource users and the wider society. These effects may operate through the market, political control, and social networks, and tend to distance resource users from their dependence on dynamic and complex adaptive life-support ecosystems, disconnect the production from consumption, and disconnect the production of knowledge from its application (Folke *et al*., 1998). There is a risk that the tightening of processes of globalization weakens societal feedback loops to ecosystem dynamics essential for sustaining and building adaptive capacity and for securing the flow of critical ecosystem services for societal development. Therefore, local solutions in an increasingly globalized world cannot work by themselves. New levels of governance are required. Cash and Moser (2000) propose that governance for linking global and local scales should utilize boundary organizations, like the one described in Alcorn *et al*. (chapter 12); utilize scale-dependent comparative advantages, like polycentric management systems; and employ adaptive assessment and management strategies, like the adaptive co-management approach. Such governance should focus on sustaining ecosystem stability domains that generate essential support to society in the face of change.

The paradox is that the processes of economic diversification, liberalization and globalization ultimately depend on nature's subsidies, on diversity and resilience of ecosystems, but tend to create increasingly fragile ecosystems, as witnessed in modern food, fiber and timber production systems. Modern belief systems and associated institutional frameworks often seem to create simplified ecosystems with impoverished diversity, low resilience and reduced capacity to adapt to environmental change. They create their own vulnerability.

The issue of interest for navigating nature's dynamics, according to Trosper (chapter 13), is the ability of surprise and crisis to precipitate responses in socio-cultural systems that move away from destabilizing behavior and polarization, toward collaboration and actions that restore resilience. Given the pace of global change, human welfare is utterly dependent on forward-looking, adaptive, and informed management decisions for building social-ecological resilience for adaptive capacity and sustainability.

14.6 Concluding remarks

Previously in human history there were major events and local changes in the ability of the ecosystem to support social systems, but resilience was so high that in many respects nature could be seen as fairly stable. Change was buffered by resilience. Our view is that the situation is different today due to the human dominance of ecosystems. Widespread human alteration of ecological interactions and biogeochemical processes, from local to global levels, result in modified ecological resilience, increased likelihood of surprises, and unpredictable and enhanced variability in essential resource flows. The situation requires a shift to a view of the world as consisting of complex systems. This implies a shift in management towards those social institutions and organizations that can deal with nature's dynamics in a fashion that builds, not only ecological or social, but social-ecological resilience. Otherwise the development and wellbeing of human societies will become increasingly vulnerable to environmental change.

The chapters of the volume have all dealt with this issue and have addressed management practices and characteristics of social mechanisms that build social-ecological resilience in complex systems. Building resilience includes; 'learning to live with change and uncertainty'; 'nurturing diversity for reorganization and renewal'; 'combining different types of knowledge for learning'; and 'creating opportunity for self-organization' (Table 14.1). These four overall categories, or as we propose – *principles for building resilience* – interact, and are in many ways interdependent. For example, learning for self-organization will not be sufficient by itself. It will not lead to social-ecological resilience. It will require the dynamic interplay between diversity and disturbance, along with recognition of cross-scale dependencies. We suggest that recognition of the four principles and their interactions is a prerequisite for directing society towards sustainability.

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