NAVIGATING SOCIAL–ECOLOGICAL SYSTEMS

Building Resilience for Complexity and Change

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Introduction

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1.1 Building capacity to adapt to change: the context

A common perspective until recently was that our problem-solving abilities have been improving over the years. In the area of resource and environmental management, for example, there was a great deal of faith in our growing scientific understanding of ecosystems, our bag of increasingly sophisticated tools and technologies, and the application of market mechanisms to problems such as air pollution control and fishery management through individually allocated quotas. However, the experience over the last few decades does not support such optimism (e.g., Clark and Munn, 1986; Ludwig, Hilborn, and Walters, 1993; Gunderson, Holling, and Light, 1995). Many of our resource and environmental problems are proving resistant to solutions. A gap has developed between environmental problems and our lagging ability to solve them. This is coming at a time when the Earth has become an increasingly human-dominated system. Many of the changes in the biosphere, including the modification of landscapes, loss of biodiversity and, according to some, climate change, are driven by human activities. Furthermore, changes are occurring at an increasingly faster rate than previously experienced in human history.

There is an emerging consensus regarding the need to look for broader approaches and solutions, not only with resource and environmental issues but along a wide front of societal problems. A survey of senior American Association for the Advancement of Science (AAAS) scientists revealed an intriguing insight. When asked about the most urgent challenges facing science and society, scientists identified many items, but a common thread was that each issue 'seemed to have radically outgrown its previously accepted conceptual framing' (Jasanoff *et al.*, 1997). For each of the issues identified, there were new theories and explanations appearing on the horizon, many calling for more creative forms of collaboration between scientists and society, involving a broader range of disciplines and skills needed for the process.

Broader public participation was also important. Scientific solutions were being undertaken with greater attention to their social context, and the interaction between science and society was increasingly seen as important (Jasanoff *et al.*, 1997). The kind of research that is needed may be 'created through processes of co-production in which scholars and stakeholders interact to define important questions, relevant evidence, and convincing forms of argument' (Kates *et al.*, 2001).

There is also an emerging consensus on the nature of the problem. Many of our resource and environmental problems are seen as *complex systems* problems (Levin, 1999a). Natural systems and social systems are complex systems in themselves; furthermore, many of our resource and environmental problems involve the additional complexity of interactions between natural and social systems (Norgaard, 1994; Berkes and Folke, 1998). Such complexity creates a huge challenge for disciplinary approaches. 'Phenomena whose causes are multiple, diverse and dispersed cannot be understood, let alone managed or controlled, through scientific activity organized on traditional disciplinary lines' (Jasanoff *et al.*, 1997). Complex systems thinking is therefore used to bridge social and biophysical sciences to understand, for example, climate, history and human action (McIntosh, Tainter, and McIntosh, 2000). It is at the basis of many of the new integrative approaches, such as sustainability science (Box 1.1) and ecological economics (Costanza *et al.*, 1993; Arrow *et al.*, 1995). It has led to the recognition that much of conventional thinking in resource and environmental management may be contributing to problems, rather than to solutions (Holling and Meffe, 1996).

In this volume, our ultimate objective is to contribute to efforts towards *sustainability*, that is, the use of environment and resources to meet the needs of the present without compromising the ability of future generations to meet their own needs. We consider sustainability as a process, rather than an end product, a dynamic process that requires adaptive capacity for societies to deal with change. Rather than assuming stability and explaining change, as often done, one needs to assume change and explain stability (van der Leeuw, 2000). For our purposes, sustainability implies maintaining the capacity of ecological systems to support social and economic systems. Sustaining this capacity requires analysis and understanding of feedbacks and, more generally, the dynamics of the interrelations between ecological systems and social systems.

Social systems that are of primary concern for this volume include those dealing with governance, as in property rights and access to resources. Also of key importance are different systems of knowledge pertinent to the dynamics

Box 1.1 Sustainability science

By structure, method, and content, sustainability science must differ fundamentally from most science as we know it. Familiar approaches to developing and testing hypotheses are inadequate because of nonlinearity, complexity, and long time lags between actions and consequences. Additional complications arise from the recognition that humans cannot stand outside the nature–society system. The common sequential analytical phases of scientific inquiry such as conceptualizing the problem, collecting data, developing theories, and applying the results will become parallel functions of social learning, which incorporate the elements of action, adaptive management, and policy as experiment. Sustainability science will therefore need to employ new methodologies that generate the semi-quantitative models of qualitative data, build upon lessons of case studies, and extract inverse approaches that work backwards from undesirable consequences to identify pathways that can avoid such outcomes. Scientists and practitioners will need to work together with the public at large to produce trustworthy knowledge and judgement that is scientifically sound and rooted in social understanding.

Source: http://sustsci.harvard.edu/keydocs/friibergh.htm

of environment and resource use, and world views and ethics concerning human–nature relationships. *Ecological systems* (ecosystems) refer to self-regulating communities of organisms interacting with one another and with their environment. When we wish to emphasize the integrated concept of humans-in-nature, we use the terms *social–ecological systems* and *social–ecological linkages*, consistent with our earlier work (Berkes and Folke, 1998). We hold the view that social and ecological systems are in fact linked, and that the delineation between social and natural systems is artificial and arbitrary. The specific objectives of the volume are to investigate:

- how human societies deal with change in social–ecological systems, and
- how capacity can be built to adapt to change and, in turn, to shape change for sustainability.

Figure 1.1 sketches the scope of the inquiry. We consider change and the impact of change as universal givens. The social–ecological system is impacted by change and deals with it as a function of its capacity to adapt to change and shape it. We look for effective ways of analyzing the phenomenon

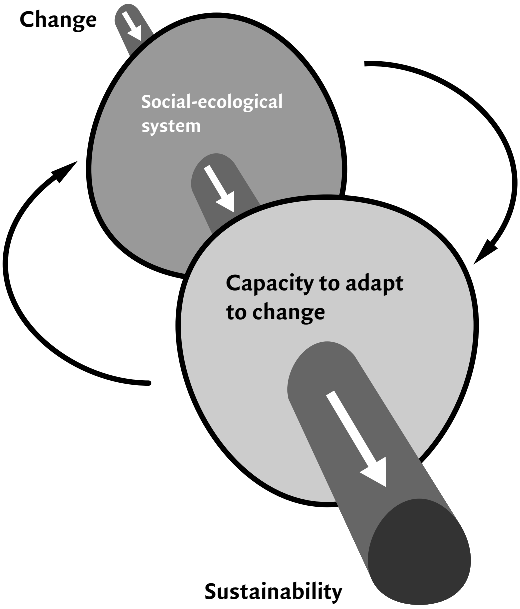

Figure 1.1 The focus on adaptive capacity for sustainability. Sustainability is viewed as a process, rather than an end-product, a dynamic process that requires adaptive capacity in resilient social–ecological systems to deal with change.

of change and how to respond to change in a manner that does not lead to loss of future options. We seek to analyze social–ecological system adaptability to meet novel challenges without compromising sustainability. The approach used in the volume is novel in that we are not focusing merely on environmental change or on social change but rather on social–ecological system change.

This chapter starts with the investigation of some of the implications of complexity in natural systems and in resource and environmental management systems. This is followed by a section that provides an overview of several integrative fields, such as common property and ecological economics that deal with integrated social–ecological systems and provide the starting point for many of the chapters in this volume. We then turn to explaining the rationale of the resilience approach. The systems we deal with are complex, but, as C.S. Holling points out, not *infinitely* complex. In seeking to integrate the two streams of thought, ecological system complexity and social system complexity, we use the idea of *resilience* as our organizing concept and scoping device. Thus, we deal with the issue of change and adaptation through the lens of resilience, which is the subject of the fourth section of this chapter.

1.2 Complex systems: ecology and resource management

A major change in the science of the last few decades has been the recognition that nature is seldom linear and predictable. Processes in ecology, economics and many other areas are dominated by nonlinear phenomena and an essential quality of uncertainty. These observations have led to the notion of *complexity*, developed through the work of many people and groups, notably the Santa Fe Institute (2002). Earlier challenges to the idea of linear causality and reductionistic science go back to general systems theory developed in the 1930s and 1940s (von Bertalanffy, 1968). General systems theory is concerned with the exploration of *wholes* and *wholeness*. It emphasizes connectedness, context and feedback, a key concept that refers to the result of any behavior that may reinforce (positive feedback) or modify (negative feedback) subsequent behavior. It argues that the understanding of the essential properties of the parts of a system comes from an understanding of not only these components but of their interrelations as well. Understanding comes from the examination of how the parts operate together, and not from the examination of the parts themselves in isolation.

With the science of complexity (Costanza *et al.*, 1993; Kauffman, 1993; Holland, 1995; Levin, 1999a), a new understanding of systems is emerging to augment general systems theory. A complex system can be distinguished from one that is simple – one that can be adequately captured using a single perspective and a standard analytical model, as in Newtonian mechanics and gas laws. By contrast, a complex system often has a number of attributes not observed in simple systems, including nonlinearity, uncertainty, emergence, scale, and self-organization.

Nonlinearity is related to inherent uncertainty. Mathematical solutions to nonlinear equations do not give simple numerical answers but instead produce a large collection of values for the variables that satisfy an equation. The solutions produce not one simple equilibrium but many equilibria, sometimes referred to as stable states or stability domains, each of which may have their own threshold effects (Scheffer *et al.*, 2001). Complex systems organize around one of several possible equilibrium states or attractors. When conditions change, the system's feedback loops tend to maintain its current state – up to a point. At a certain level of change in conditions (threshold), the system can change very rapidly and even catastrophically (called a flip). Just when such a flip may occur, and the state into which the system will change, are rarely predictable. If so, Holling (1986) pointed out, phenomena such as climate change would hardly be expected to proceed smoothly and predictably, and he drew attention to a system's resilience as a critical factor in environmental management. Resilience may be considered an emergent property of a system, one that cannot be predicted or understood simply by examining the system's parts. Resilience absorbs change and provides the capacity to adapt to change, as defined later and as illustrated in several chapters of this volume.

Scale is important in dealing with complex systems. A complex system is one in which many subsystems can be discerned. Many complex systems are hierarchic – each subsystem is nested in a larger subsystem, and so on (Allen and Starr, 1982). For example, a small watershed may be considered an ecosystem, but it is part of a larger watershed that can also be considered an ecosystem and a larger one that encompasses all the smaller watersheds. Similarly, institutions may be considered hierarchically, as a nested set of systems from the local level, through regional and national, to the international. Phenomena at each level of the scale tend to have their own emergent properties, and different levels may be coupled through feedback relationships (Gunderson and Holling, 2002). Therefore, complex systems should be analyzed or managed simultaneously at different scales. Consider, for example, biodiversity conservation. Problems and solutions of conservation at the genetic level are considerably different from those at the species level or the landscape level. Different groups of conservationists focus on different levels; they may use different research approaches and may recommend different policies. Biodiversity can be considered at different levels of the scale. However, because there are strong feedbacks among the genetic, species, and landscape levels, there is coupling between different levels, and the system should be analyzed simultaneously across scale.

Self-organization is one of the defining properties of complex systems. The basic idea is that open systems will reorganize at critical points of instability. Holling's adaptive renewal cycle, discussed later in the section on resilience, is an illustration of reorganization that takes place within cycles of growth and renewal (Gunderson and Holling, 2002). The self-organization principle, operationalized through feedback mechanisms, applies to many biological systems, social systems and even to mixtures of simple chemicals. High-speed computers and nonlinear mathematical techniques help simulate self-organization by yielding complex results and yet strangely ordered effects. For example, for many complex systems such as genes, Kauffman (1993) argues that spontaneous self-organization is not random but tends to converge towards a relatively small number of patterns or attractors. At each point at which new organization emerges, the system may branch off into one of a number of possible states. The direction of self-organization will depend on such things as the system's history; it is path dependent and difficult to predict.

These characteristics of complex systems have a number of rather fundamental implications for resource and environmental management. In this chapter we deal with three of them: (1) the essential inadequacy of models and perspectives based on linear thinking; (2) the recognition of the significance of qualitative analysis as a complement to quantitative approaches; and (3) the importance of using a multiplicity of perspectives in the analysis and management of complex systems.

The inadequacy of conventional resource management models and output objectives, such as the maximum sustainable yield (MSY) in fisheries, has been discussed for some time. For example, Larkin (1977) pointed out in a seminal paper that MSY assumes away such complexity as food-web relations in trying to predict single species yields. These models often do not work. However, the issue is more than the ecological shortcomings of a few management tools such as MSY. There is a more fundamental problem. The conventional wisdom in much of twentieth-century ecology is based on the idea of single equilibria. Although most ecologists no longer hold the popular idea of a 'balance of nature,' many of them consider population phenomena in the framework of equilibria and consider population numbers, and ecosystem behavior in general, to be predictable, at least in theory. To be sure, very few ecologists would consider predictive models in ecology as easy to achieve. But there is a fundamental difference between the view that quantitative prediction is *difficult* and data intensive ('we need more research') and the view that nature is *not* equilibrium centered and *inherently* unpredictable. For much of ecology and resource management science, complexity is a subversive idea that challenges the basis of population and yield models.

Recognizing the importance of qualitative analysis is one consequence of the recognition of complex system phenomena for natural resource management (Box 1.1). By qualitative analysis we mean the understanding of the system's behavior to help guide management directions. Qualitative analysis follows from the nature of nonlinearity. Because there are many possible mathematical solutions to a nonlinear model and no one 'correct' numerical answer, simple quantitative output solutions are not very helpful (Capra, 1996). This does not imply that quantitative analysis is not useful. Rather, it means that there is an appropriate role for both quantitative and qualitative analyses, which often complement each other.

Some of this qualitative management thinking has been put to work. Managers may specify objectives in the form of management directions and the understanding of key processes for sustainability. For example, Lugo (1995) pointed out that trying to quantify supposedly sustainable levels of yield in tropical forests rarely leads to ecosystem sustainability. If the objective is conservation, a strategy of focusing on resilience, through an understanding of regeneration cycles and ecological *processes* such as plant succession, may be the key to tropical forest sustainability.

In the area of fisheries, some managers are beginning to experiment with the use of reference directions (e.g., increasing the number of sexually mature year-classes in the population or reducing the proportion of immature individuals in the catch) instead of the conventional target reference points (e.g., a catch of 1000 tons of a particular species). Note that using reference directions, rather than targets, still requires quantitative data, but the choice of the management direction itself is a qualitative decision. This alternative approach shifts the focus of management action from the exacting and difficult question ‘where do we want to be?’ to the simpler and more manageable ‘how do we move from here towards the desired direction?’ (Berkes *et al.*, 2001: 131).

The need to use a multiplicity of perspectives follows from complex systems thinking. Because of a multiplicity of scales, there is no one ‘correct’ and all-encompassing perspective on a system. One can choose to study a particular level of biodiversity conservation; but the perspective from that particular level will be different from the perspective from another. In complex systems, time flows in one direction, i.e., time’s arrow is not reversible. Especially with social systems, it is difficult or impossible to understand a system without considering its history, as well as its social and political contexts. For example, each large-scale management system (e.g., Gunderson *et al.*, 1995) or each local-level common property system (e.g., Ostrom, 1990) will have its unique history and context. A complex social–ecological system cannot be captured using a single perspective. It can be best understood by the use of a multiplicity of perspectives.

These considerations provide an insight into the reasons that conventional scientific and technological approaches to resource and ecosystem management are not working well, and in some cases making problems worse. In part, this failure is related to the focus on wrong kinds of sustainability and on narrow types of scientific practice (Holling, Berkes, and Folke, 1998). In part, it is related to the ideology of a strongly positivist resource management science, with its emphasis on centralized institutions and command-and-control resource management. Such management is based on a thinking of linear models and mechanistic views of nature. It aims to reduce natural variation in an effort to make an ecosystem more productive, predictable, economically efficient, and controllable. But the reduction of the range of natural variation is the very process that may lead to a loss of resilience in a system, leaving it more susceptible to resource and environmental crises (Holling and Meffe, 1996).

Taken together, these implications of complex systems thinking suggest the need for a new kind of resource and environmental management science that takes a critical view of the notions of control and prediction. Holling (1986) called it the ‘science of surprise.’ An appropriate metaphor may be the message on the sign that appears on some remote logging roads on Vancouver Island in Canada: ‘Be prepared for the unexpected.’

The lesson from complex systems thinking is that management processes can be improved by making them adaptable and flexible, able to deal with uncertainty and surprise, and by building capacity to adapt to change. Holling (1978) recognized early on that complex adaptive systems required adaptive management. *Adaptive management* emphasizes learning-by-doing, and takes the view that resource management polices can be treated as ‘experiments’ from which managers can learn (Walters, 1986; Gunderson, 1999). Organizations and institutions can ‘learn’ as individuals do, and hence adaptive management is based on social and institutional learning. Adaptive management differs from the conventional practice of resource management by emphasizing the importance of *feedbacks* from the environment in shaping policy, followed by further systematic experimentation to shape subsequent policy, and so on. Thus, the process is iterative, based on feedback learning. It is co-evolutionary, involving two-way feedback between management policy and the state of the resource (Norgaard, 1994), and leading to self-organization through mutual feedback and entrainment (Colding and Folke, 1997).

1.3 Integrative approaches to social–ecological systems: an overview

Many of the principles of complex systems apply to both natural systems and social systems. Some of these principles or ideas, for example the importance of context and history in understanding a system, probably make more intuitive sense to social scientists than to natural scientists. Our effort in this volume is to seek principles and ideas which make sense to both natural scientists and social scientists and which can be mobilized towards our objective of examining how human societies deal with change in social–ecological systems, and how they can build capacity to adapt to change.

Until recent decades, the point of contact between social sciences and natural sciences was very limited in dealing with social–ecological systems. Just as mainstream ecology had tried to exclude humans from the study of ecology, many social science disciplines had ignored environment altogether and limited their scope to humans. The unity of biosphere and humanity had been sacrificed to a dichotomy of nature and culture. There were exceptions, of course, and some scholars were working to bridge the nature–culture divide (e.g., Bateson, 1979); we deal with some of them in Chapter 3. But, by and large, models of human societies in many social science disciplines did not include the natural environment. This changed in the 1970s and the 1980s with the rise of several subfields allied with the social sciences but explicitly including the environment in the framing of the issues. Six of these integrative areas are directly relevant to the perspectives of this volume: environmental ethics, political ecology, environmental history, ecological economics, common property, and traditional ecological knowledge. We describe each briefly here because many of the chapters in this volume borrow from the approaches and terminology of these fields.

Environmental ethics arose from the need to develop a philosophy of relations between humans and their environment, because conventional ethics only applied to relations among people. A number of schools of environmental ethics have emerged, including the ecosophy of Naess (1989). Particularly relevant to this volume, a discussion has developed on the subject of worldviews, pointing out that there is a wide diversity of spiritual and ethical traditions in the world that helps offer alternatives to the current views of the place of humans in the ecosystem (Callicott, 1994). Culturally different attitudes towards the environment have implications for the management of the environment, even though there is no clear correspondence between ethical traditions and their actual performance (Berkes, 2001). Some of the literature on environmental ethics emphasized belief systems (religion in the broad sense) as encoding wise environmental management. For example, Anderson (1996: 166) argued that ‘all traditional societies that have succeeded in managing resources well, over time, have done it in part through religious or ritual representation of resource management.’

Political ecology grew out of the field of political economy, but it is different from political economy that tends to reduce everything to social constructions, disregarding ecological relations. ‘Political ecology expands ecological concerns to respond to the inclusion of cultural and political activity within an analysis of ecosystems that are significantly but not always entirely socially constructed’ (Greenberg and Park, 1994). The analysis of political ecology often starts by focusing on political–economic divisions among the actors. These may be divisions between local and international interests, between North and South; they may involve power relations based on differences of class, ethnicity, and gender (Blaikie and Jeanrenaud, 1996). The political ecology perspective compels the analyst to consider that there exist different actors who define knowledge, ecological relations, and resources in different ways and at different geographic scales. Actors will bring different cultural perspectives and experience, and may use different definitions in pursuit of their own political agendas (Blaikie, 1985; Blaikie and Jeanrenaud, 1996). With its explicit attention to the multiplicity of perspectives and to scale issues, political ecology fits well with systems thinking.

The rich accumulation of material documenting relationships between societies and their environment (Turner *et al.*, 1990) has given rise to a discipline identified as environmental history (Worster, 1988) or historical ecology (Balee, 1998). Investigating the root causes of environmental problems, environmental historians discussed, among others things, how ecological relations became more destructive as they became more distant, especially after the great transformation following the Industrial Revolution (Worster, 1988). They not only interpreted ancient landscapes but also analyzed the *dynamics* of these landscapes, making ecological sense of resource use practices, and their change that *resulted* in these landscapes. For example, Cronon (1983) studied the colonization of New England states, and found that the early European–Indian relationship could be characterized in terms of two competing economies. The Indian economy treated the environment as a portfolio of resources and services that supported livelihoods, whereas that of the colonists turned the environment into commodities, sequentially depleting one resource after another. Similarly, the push for valuable timber production under colonialism in India resulted in the commodification of resources serving diverse livelihood needs, and the depletion of certain species (Gadgil and Guha, 1992).

Ecological economics examines the link between ecology and economics. Taking issue with conventional economics that often downplays the role of the environment, and conventional ecology that ignores humans, ecological economics tries to bridge the two disciplines to promote an integrated view of economics within the ecosystem (Costanza, 1991). Among the defining characteristics of ecological economics are: the view of the economic system as a subset of the ecological system; a primary interest in natural capital; a greater concern with a wider range of values; and longer time horizons than those normally considered by economists. Ecological economics has helped reconceptualize systems problems such as conservation by shifting attention from the elements of the system to the structures and processes that perpetuate that system (Costanza, Norton, and Haskell, 1992). For example, biodiversity can be seen as providing ecosystem insurance, and redundancy as a mechanism to provide adaptive capacity in an ecosystem characterized by hierarchical organization, scale effects, and multiple equilibria (Barbier, Burgess, and Folke, 1994; Perrings *et al.*, 1995).

Ecological economics makes a distinction between *human-made capital,* generated through economic activity through human ingenuity and technological change, and *natural capital,* consisting of non-renewable resources extracted from ecosystems, renewable resources produced by the processes and functions of ecosystems, and ecological services sustained by the workings of ecosystems (Jansson *et al.*, 1994). To these, a third kind of capital may be added: c*ultural capital* refers to the factors that provide human societies with the means and adaptations to deal with the natural environment and to actively modify it. Ecological knowledge and institutions, important for the arguments in this volume, are considered to be a part of this cultural capital (Berkes and Folke, 1994).

The field of common property examines the linkages between resource management and social organization, analyzing how institutions and property-rights systems deal with the dilemma of the 'tragedy of the commons' (McCay and Acheson, 1987; Berkes, 1989; Bromley, 1992; Ostrom *et al.*, 1999). The emphasis is on *institutions*, defined as 'humanly devised constraints that structure human interaction . . . made up of formal constraints (rules, laws, constitutions), informal constraints (norms of behavior, conventions and self-imposed codes of conduct), and their enforcement characteristics' (North, 1994). Institutions are the set of rules actually used or the working rules or rules-in-use (Ostrom, 1992). However, they are also socially constructed, with normative and cognitive dimensions (Jentoft, McCay, and Wilson, 1998), particularly relevant to this volume in dealing with the nature and legitimacy of different kinds of knowledge.

Institutions of key importance are those that deal with property rights and common-property resources. *Property* refers to the rights and obligations of individuals or groups to use the resource base (Bromley, 1991; Hanna, Folke, and Mäler, 1996). It is a bundle of entitlements defining owner's rights, duties, and responsibilities for the use of the resource, or a claim to a benefit or income stream (Bromley, 1992). *Common-property (common-pool) resources* are defined as a class of resources for which exclusion is difficult and joint use involves subtractability (Berkes, 1989; Feeny *et al.*, 1990).

Local, indigenous or traditional knowledge refers to ecological understanding built, not by experts, but by people who live and use the resources of a place (Warren, Slikkerveer, and Brokensha, 1995). *Local knowledge* may be used as a generic term referring to knowledge generated through observations of the local environment in any society, and may be a mix of practical and scientific knowledge (Olsson and Folke, 2001). *Indigenous knowledge* (IK) is used to mean local knowledge held by indigenous peoples, or local knowledge unique to a given culture or society (Warren *et al.*, 1995). In this volume, we use *traditional ecological knowledge* (TEK) more specifically to refer to 'a cumulative body of knowledge, practice and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment' (Berkes, 1999: 8). The word *traditional* signifies historical and cultural continuity, but at the same time we recognize that societies are in a dynamic process of change, constantly redefining what is considered 'traditional.'

TEK started attracting attention through the documentation of a tremendously rich body of environmental knowledge among a diversity of groups outside the mainstream Western world (Johannes, 1981; Colding and Folke, 1997; Berkes *et al.*, 1998, Berkes, Colding, and Folke, 2000; Folke and Colding, 2001). The relationship between TEK and science is controversial, but these two kinds of knowledge should not be thought of as opposites. Rather, it is more useful to emphasize the potential complementarities of the two (e.g., Berkes, 1999; Riedlinger and Berkes, 2001). We deal with local/traditional knowledge for diversity and conceptual pluralism to expand the range of information and approaches for improving resource management.

Each of the six areas summarized here is a ‘bridge’ spanning different combinations of natural science and social science thinking. Environmental ethics, political ecology, and environmental history help emphasize that all of the examples in this volume have a cultural, historical, political, and ethical context, as seen in several of the chapters. Various chapters build on and contribute to the literature of ecological economics, common property and TEK. The search for resource management alternatives often includes the ecological economics notions of economic systems-within-ecosystems, natural capital, and intergenerational equity. The questions of the control of property rights, the nature of institutions, and their cross-scale interactions are key considerations in many of the chapters. Complexity draws attention to the fact that local and traditional knowledge and management systems should be seen as *adaptive responses* in a place-based context and a rich source of lessons for social–ecological adaptations.

1.4 Social–ecological resilience

Holling (1973) introduced the resilience concept into the ecological literature as a way to understand nonlinear dynamics, such as the processes by which ecosystems maintain themselves in the face of perturbations and change (Gunderson, 2000). As defined by the Resilience Alliance (2002), and as used in this volume, it has three defining characteristics:

- the amount of change the system can undergo and still retain the same controls on function and structure, or still be in the same state, within the same domain of attraction;
- the degree to which the system is capable of self-organization; and
- the ability to build and increase the capacity for learning and adaptation.

To illustrate the first characteristic, consider the case of insectivorous birds and insect outbreaks in the boreal forests of Canada (Holling, 1988). The assemblage of migratory insectivorous bird populations is one of the controlling factors of forest renewal produced by budworm population cycles. The existence of these birds contributes to the resilience of the boreal forest. Mathematical simulations based on long-term studies indicate that the total bird population would have to be reduced by about 75 percent before the system might flip out of the current domain of attraction and into a different one (Holling, 1988).

As the populations of these birds are reduced because of overwintering habitat loss or other factors, the resilience of the boreal forest is also reduced. As a system loses its resilience, it can flip into a different state when subjected to even small perturbations (Levin *et al.*, 1998). Loss of resilience can be modeled or viewed as having a system moved to a new stability domain and being captured by a different attractor. Examples include the transformation of productive grasslands in subtropical Africa into thorny shrublands as a consequence of poor cattle management practices (Perrings and Walker, 1995). It is important to note that the actual point of change cannot easily be predicted. There are threshold effects; the changes are relatively sudden – not necessarily gradual or smooth. Recovery can be costly or nearly impossible (Mäler, 2000), and such flips can be irreversible (Levin, 1999a).

Thus, resilience is concerned with the magnitude of disturbance that can be absorbed or buffered without the system undergoing fundamental changes in its functional characteristics. The issue of disturbance is important. Not only are there natural disturbances, such as forest fires and insect outbreaks, but many human activities, such as resource use and pollution, which also create disturbances. Ecosystem responses to resource use, and the reciprocal response of people to changes in ecosystems, constitute coupled, dynamic systems that exhibit adaptive behavior (Gunderson *et al.*, 1995). This recognition brings into focus the second and third defining characteristics of resilience, those regarding self-organization and learning. It underscores the importance of considering linked social–ecological systems, rather than ecosystems or social systems in isolation (Berkes and Folke, 1998).

Resilience is an important element of how societies adapt to externally imposed change, such as global environmental change. The adaptive capacity of all levels of society is constrained by the resilience of their institutions and the natural systems on which they depend. The greater their resilience, the greater is their ability to absorb shocks and perturbations and adapt to change. Conversely, the less resilient the system, the greater is the vulnerability of institutions and societies to cope and adapt to change (Adger, 2000). Social–ecological resilience is determined in part by the livelihood security of an individual or group. Such security involves, according to Sen (1999), the questions of entitlements and access to resources, the distribution of which is a key element of environmental justice.

The concept of resilience is a promising tool for analyzing adaptive change towards sustainability because it provides a way for analyzing how to maintain stability in the face of change. A resilient social–ecological system, which can buffer a great deal of change or disturbance, is synonymous with ecological, economic, and social sustainability. One with low resilience has limited sustainability; it may not survive for a long time without flipping into another domain of attraction. Here, it should be noted, resilience is not being defined as returning to an equilibrium. This is because we are using a view of ecosystems in which there is no one equilibrium but rather, as a consequence of complexity, multiple states or domains of attraction and multiple equilibria. Thus, ecological stability as a concept is not very useful, and resilience cannot be defined as bouncing back to equilibrium – there is no equilibrium to bounce back to.

In operationalizing this view of resilience, managing for sustainability in socio-economic systems means not pushing the system to its limits but maintaining diversity and variability, leaving some slack and flexibility, and not trying to optimize some parts of the system but maintaining redundancy. It also means learning how to maintain and enhance adaptability, and understanding when and where it is possible to intervene in management. These 'soft' management approaches are necessary because 'hard' management approaches involving quantitative targets for resource production etc. often do not work. Linear models on which 'hard' management depends tend to be incomplete or even misleading in the management of the ecosystems of the world. Equilibrium-based predictive models do not perform well with complex social–ecological systems.

To illustrate policy implications of complexity, Wilson (2000) pointed out with respect to ocean fisheries that the current linear models of resource production (as in single-species management) have to be replaced with a view of ocean ecosystems as multiscale and hierarchical, and the current predominantly top-down institutions with a cross-scale institutional design that matches the hierarchical scale of marine ecosystems. 'These suggested changes in scientific perspective and institutional design will not necessarily solve scientific uncertainties. But they will replace those uncertainties in an institutional context which encourages learning and stewardship' (Wilson, 2000).

Gunderson and Holling (2002) embarked on the volume *Panarchy* with the idea that sustainable futures were inherently unpredictable, rejecting the idea that sustainability can be planned in a rational fashion. In the absence of a linear, mechanical universe that would have permitted simple, rational measures, they argued that the best bet for sustainability involves what we have referred to as the second and third characteristics of resilience – capability for self-organization and capacity for learning and adaptation. Gunderson and Holling provide a synthesis of existing theory for sustainability, complexity, and resilience, and attempt to develop novel extensions of that integration, identifying gaps in knowledge. Several of their conclusions are of significance for the present volume. They find that key unknowns lie in the development of theories to address self-organization at various scales, and to address adaptive change in social–ecological systems.

Another cluster of challenges is in the area of institutions: how do we design institutions and incentive structures that sustain and enhance sources of self-organization and resilience? How can we formulate patterns of emergence of social control mechanisms dealing with environmental problems? How can we create policies to increase the speed of emergence and increase the efficiency of learning? A third cluster of gaps in knowledge concerns the dynamics of disturbance, crisis, response to change, and renewal: how do we facilitate constructive change? Protect and preserve accumulated experience? Build and sustain the capacity of people, economies, and nature for dealing with change?

Gunderson and Holling note that the last decade of the twentieth century saw a cascade of regional and global transformations, biophysical, economic, and political. Such 'gales of change,' they observe, signal periods when the *backloop* of the adaptive renewal cycle dominates, the part of the cycle dealing with disturbance, crisis, response to change, and renewal. To understand the significance of the backloop, we need to review Holling's concept of adaptive renewal cycle.

1.5 Adaptive renewal cycle: emphasis on the backloop

Chapters of the present volume deal with cyclic change as an essential characteristic of all social and ecological systems. Our starting point is the pervasive idea that social systems and ecological systems are dynamic. More specifically, Holling (1986) has argued that ecosystems go through regular cycles of organization, collapse, and renewal. For example, a forest goes through the stages of growth and maturity, followed by a disturbance, such as fire, which releases the nutrients on the way to a new cycle of growth. A business cycle may consist of a company starting up and growing. The company will eventually decline and go out of business, while its parts and the accumulated experience may combine with other sources and reorganize into a new business. Empires start as small states, growing large and eventually collapsing, but giving rise to new nation states and leaving behind organizational legacies in the process. Cyclic change, including birth–death cycles and seasonal cycles, is so ubiquitous in the world that the importance of cycles has been embedded in many traditions of ancient wisdom, including Hinduism and American Indian religions. However, the less wise may see but not recognize the cycle. What may appear as a linear change

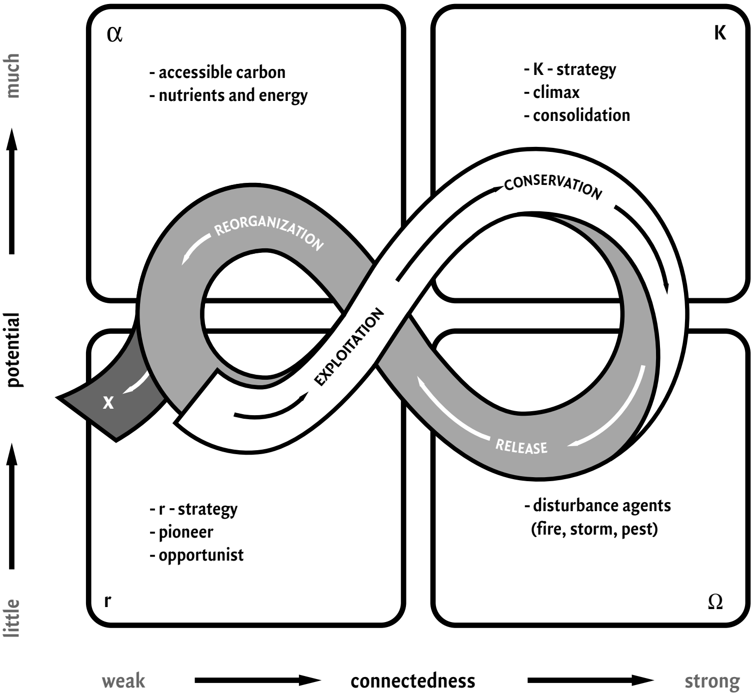

Figure 1.2 The adaptive renewal cycle. A heuristic model of the four system stages and the flow of events among them. The cycle reflects changes in two properties: (1) y-axis: the potential that is inherent in the accumulated resources and structures; (2) x-axis: the degree of connectedness among controlling variables. The exit (marked with an X) from the cycle indicated at the left of the figure suggests, in a stylized way, the stage where the potential can leak away and where a shift is most likely into a less productive and organized system. The shaded part of the cycle is termed the ‘backloop’ (Holling, 1986, 2001) and concerns the release and reorganization phases.

(e.g., growth) at one temporal scale may in fact be part of a cycle when viewed from a higher-order temporal scale.

Holling’s *adaptive renewal cycle* is an attempt to capture some of the commonalities in various kinds of cyclic change (Fig. 1.2). The heuristic model probably does not capture the unique characteristics of different kinds of cycles and the possibilities of divergent responses. But it does provide the insight, for example, that forest succession should be seen, not as a unidirectional process (with climax as endpoint), but as one phase of a cycle in which a forest grows, dies, and is renewed. The cycle in Figure 1.2 consists of four phases: *exploitation*, *conservation*, *release*, and *reorganization*.

In a resilient forest ecosystem, these four stages repeat themselves again and again. The first two phases, exploitation (the establishment of pioneering species) and conservation (the consolidation of nutrients and biomass), lead to a climax, in the terminology of classical ecology. But this climax system *invites* environmental disturbances such as fire, insect pest outbreak or disease, and is more susceptible to these disturbances than non-climax forests. When surprise occurs, the accumulated capital is suddenly released, producing other kinds of opportunity, termed creative destruction. Release, which is a very rapid stage, is followed by reorganization in which, for example, nutrients released from the trees by fire will be fixed in other parts of the ecosystem as the renewal of the forest starts again. It is in the reorganization phase that novelty and innovation may occur (Holling, 1986; Holling *et al*., 1995).

As a complex system, the forest ecosystem is hierarchically scaled. The term *panarchy* is used to capture the dynamics of adaptive cycles that are nested within one another across space and time scales, as shown in Figure 1.3

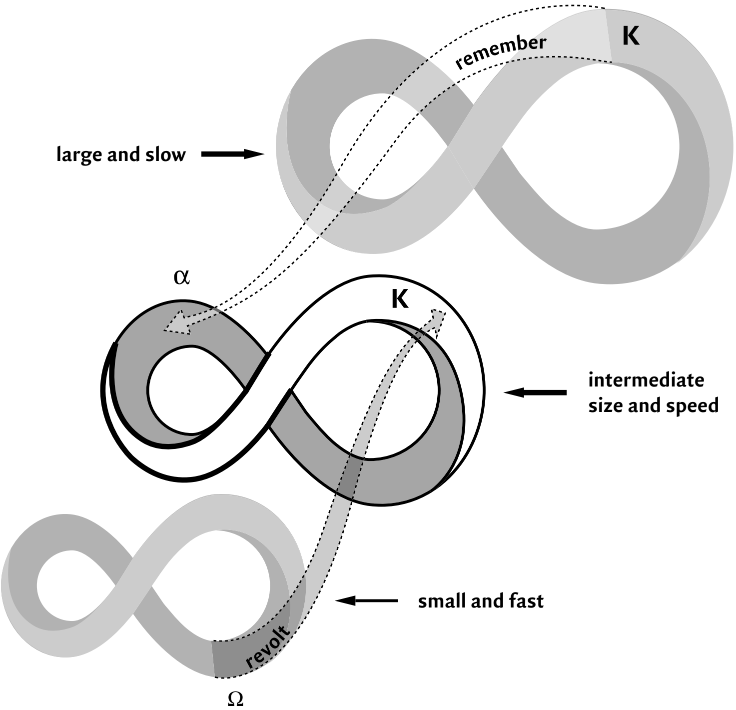

Figure 1.3 Adaptive renewal cycles nested across scales: panarchy. The 'revolt' connection between scales can cause a critical change in one cycle to cascade up to a stage in a larger and slower one. The 'remember' connection facilitates renewal and reorganization by drawing on the memory that has been accumulated and stored in a larger, slower cycle. The 'revolt' and 'remember' connections are exemplified in several of the chapters of the volume and discussed in Chapter 14 in relation to crisis and social–ecological memory. Adapted from Gunderson and Holling (2002).

(Gunderson and Holling, 2002; Holling, 2001). For example, the smallest and the fastest of the three nested ‘reclining figure eights’ may refer to a tree crown, the intermediate one to a forest patch, and the largest and the slowest to a forest stand. Each level may go through its own cycle of growth, maturation, destruction, and renewal. For institutions, those three speeds might consist of operational rules, collective choice rules, and constitutional rules (Ostrom, 1990). For knowledge systems, the corresponding three scales might be local knowledge, management institutions, and worldview (Folke, Berkes, and Colding, 1998a).

There are many possible connections between phases at one level and phases at another level. The two connections in Figure 1.3 labeled ‘revolt’ and ‘remember’ seem to be particularly significant in the context of building resilience. An ecological example of revolt is a small ground fire that spreads to the crown of a tree, then to a patch in the forest, and then to a whole stand of trees. Each step in that cascade of events moves the transformation to a larger and slower level. A societal example may be the transformation of regional organizations by a local activist group.

‘Remember’ is a cross-scale connection important in times of change, renewal, and reorganization. For example, following a fire in a forested ecosystem, the reorganization phase draws upon the seed bank, physical structures, and surviving species that had accumulated during the previous cycle of growth of the forest, plus those from the outside. Thus, renewal and reorganization are framed by the memory of the system. Each level operates at its own pace, protected by slower, larger levels but invigorated by faster, smaller cycles. The panarchy is therefore both creative and conservative (Holling, 2001) through the dynamic balance between change and memory, and between disturbance and diversity. All living systems, ecological as well as social, exhibit properties of the adaptive cycle, and are nested across scales (Gunderson and Holling, 2002). Several of the chapters provide examples, and the point will be developed further in the synthesis chapter.

Many theories on the management of natural resources and ecosystems have focused on the exploitation and conservation phases of the renewal cycle in order to make management more efficient. This emphasis can be seen in resource management, geared for economic production, that commonly seeks to reduce natural variation in target resources because fluctuations impose problems for the industry that depend on those resources (Holling and Meffe, 1996). Controlling variation, as in the form of natural disturbances, is key in many conventional management systems. This control can be achieved in a number of ways, for example by increased financial investments in harvesting technologies and through energy inputs, such as insecticides, pesticides, and irrigation, as in conventional agriculture. The system is assumed to be stable as long as change can be controlled.

Such measures seek to maintain the system in a configuration of ‘optimality,’ in the conservation domain characterized by high levels of stored capital. In the forest case, for example, a great deal of planning goes into shortening the growth and succession stages so that the forest reaches the conservation phase, with a high standing crop or biomass of trees. Using a command-and-control approach, managers then try to keep the forest in that state of optimality. Such management may be effective in the short term, but over time, it may reduce resilience in management systems and in the ecosystem itself by making them more vulnerable to disturbances and surprises that cannot be anticipated in advance (Baskerville, 1995; Holling and Meffe, 1996).

Compared to this single-minded interest in the exploitation and conservation phases of the renewal cycle, conventional resource management has largely ignored the release and reorganization phases (Fig. 1.2). Yet, these two *backloop* phases are just as important as the other two (exploitation and conservation phases) in the overall cycle (Folke *et al.*, 1998a). Furthermore, they are of great interest in their own right for a number of reasons.

Crises have a constructive role to play in resource management by triggering the opportunity for renewal, in systems capable of learning and adapting (Gunderson *et al.*, 1995). In economics, Schumpeter (1950) coined the term *creative destruction* to describe the window of opportunity for novelty and creation that was generated by the failures of existing industrial plants with their old technologies. *Novelty,* or the ability to innovate, is an essential element of adaptability and hence of resilience. Of fundamental importance for self-organization is *memory* – memory that allows a system the ability to reorganize after a disturbance. *Memory* is the accumulated experience and history of the system, and it provides the sources for self-organization and resilience. It has both ecological and social components.

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 includes the species and patterns that persist in a particular area after a disturbance event, together with support areas and the links that connect the disturbed area to the sources of species assemblages that allow reorganization of the system. We return to this concept in more detail in the final chapter.

Social memory refers to the long-term communal understanding of the dynamics of environmental change and the transmission of the pertinent experience, as used, for example, in the context of climate change (McIntosh, 2000: 24). It captures the experience of change and successful adaptations.