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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.

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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

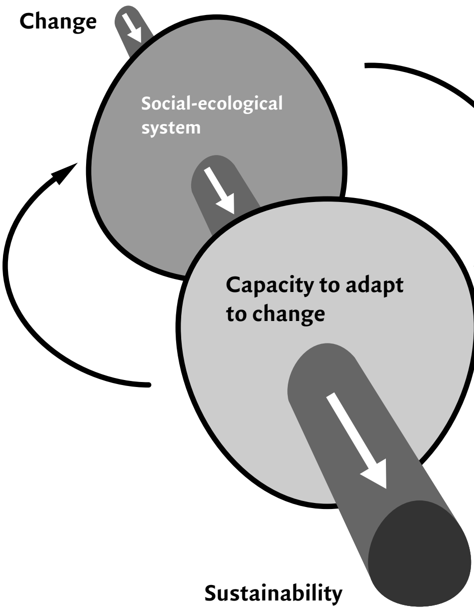

Figure 1.1 The focus on adaptive capacity for sustainability. Sustainability is viewed as a process, rather than an end-product, a dynamic process that requires adaptive capacity in resilient social–ecological systems to deal with change.

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