Understanding Dynamics of Understanding Dynamics of Understanding Dynamics of Ecosystem-Institution Linkages -Institution Linkages -Institution Linkages for Building ResilienceBuilding ResilienceResilience

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Introduction

Conventional resource management is based on linear models of natural processes, and assumes that there exist simple, quantitative solutions to management problems. Such thinking is rooted in the Newtonian mechanistic view of nature, and is in part related to the limitations of the analytical tools then available. Until high-speed computers came into common use in recent decades, resource managers (as well as other scientists and engineers) had to rely on linear models because they were unable to deal with the mathematics of nonlinear models. Thus, nonlinear models had to be simplified into linear models, and the assumption had to be made that all natural processes could be adequately described by linear equations. In time, many resource managers and scientists apparently came to believe that.

A major change in the science of the last few decades has been the recognition that nature is seldom linear. Processes in ecology, economics and many other areas are dominated by nonlinear phenomena; hence we refer to the science of "complex systems" (Costanza et al. 1993; Arrow et al. 1995). 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, complete with threshold effects and flips, requiring attention to system resilience as a critical factor in the management of ecological and social systems (Holling 1986).

Another consequence of the recognition of complex system phenomena for natural resource management is the increasing emphasis on qualitative analysis as a complement to quantitative analysis. This follows from the nature of nonlinear equations. Since there are many solutions and no one "correct" answer, simple quantitative solutions are not possible. This does not mean, however, that predictions are not feasible. Accurate predictions can still be made – but those should focus more on the qualitative features of a system's behavior, and not so much on the values of the system's variables. As Capra (1996, p. 135) puts it, "the new mathematics thus represents a shift from quantity to quality that is characteristic of systems thinking in general."

During the project that led to the volume, *Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience* (henceforth, the *Linking* volume) (Berkes and Folke 1998), we were conscious of two major considerations. First, we noted that conventional scientific and technological approaches to resource and ecosystem management were not always working, and were in some cases making the problem worse, as previously observed by Holling (1986) and Gunderson et al. (1995). In part, this had to do with the focus on wrong kinds of sustainability and on narrow types of scientific practice (Holling et al. 1998). In part, it was related to the ideology of a strongly positivist resource management science, with its emphasis on centralized institutions and sectoral focus (Berkes and Folke 1998).

Second, we noted there was a widespread search for new approaches, with visions of more environmentally sound and more democratic resource management systems which were self-organizing, adaptive and resilient, and often found on smaller scales. The *Linking* volume revealed a rich set of cases that showed that such alternative resource management was indeed feasible. Further, it revealed that many of these alternative systems were based on local ecological knowledge generated by resource users themselves, and were characterized by decentralized, pluralistic approaches, as had been noted in previous studies of common property institutions (McCay and Acheson 1987; Berkes 1989; Ostrom 1990). Some were based on combinations of local and scientific knowledge (Hanna 1998), and some on historically accumulated and culturally transmitted knowledge, that is, traditional ecological knowledge (Gadgil et al. 1993; Berkes et al. 1995).

At the time we designed the project, *Linking Social and Ecological Systems*, we knew that there already was considerable evidence of cultural capital pertaining to sustainable resource use and the maintenance of resilient ecosystems. However, the evidence was scattered through a broad stream of multidisciplinary literature, and there was a need for systematic treatment. Hence, the major objective of the *Linking* volume was to create a transdisciplinary framework through which we could evaluate examples of socially and culturally evolved management practices based on ecological knowledge and understanding, and the social mechanisms behind them.

Having addressed that objective and having found that it was indeed worthwhile, we now turn to understanding the *dynamics* of ecosystem-institution linkages, with the more explicit objective of examining ways of *building resilience*.

Resilience in this context reflects the capacity of a system to buffer and survive disturbance. Resilience conserves information, knowledge and experience – the ”memory” of the system. Conserving memory is a prerequisite for recovery, and it does also maintain opportunity for innovation and renewal (Gunderson et al. 1997).

Societies may build economic and social resilience in the short term, on the expense of an increasingly degraded natural resource base (Levin et al. 1997). However, since economic and social development ultimately depends on functional diversity and resilience of ecosystem, this is neither a wise nor a sustainable strategy in the long-term.

The challenge is to find ways to match the dynamics of institutions with the dynamics of ecosystems for mutual social-ecological resilience and improved performance (Folke et al. 1997). This is the overall objective of the present project *Understanding Dynamics of Ecosystem-Institution Linkages for Building Resilience.*

The project is a follow-up to the *Linking* volume. The next step is to form transdisciplinary research teams to analyze critical linkages in social-ecological systems, and to generate insights on how to interpret, respond to, and manage feedbacks from complex systems. In continuing to cast our net wide to mobilize a wider range of considerations and sources of information than those used in the conventional practice, our long-term objective is to improve resource management.

We focus on selected cases to learn from a diversity of management systems and their dynamics. In particular, we focus on management systems that have *not* been dominated by conventional resource management and mechanistic, linear thinking and practice, and those that maintain practices for the building of resilience. We address the question, what confers institutional resilience, and how can institutional resilience be combined with ecological resilience for mutual benefit?

Figure 1 defines the area of interest of the project. On the left-hand side is the natural system, which may consist of *nested ecosystems* (e.g., a regional ecosystem containing the drainage basin of a river, which in turn consists of a number of watershed ecosystems and so on). On the right-hand side, is a set of *management practices* in use. These practices are embedded in institutions, and the *institutions* themselves *may be a nested set*.

The linkage between the ecosystem and management practice is provided by *ecological knowledge and understanding*. This linkage is critical. If there is no ecological knowledge and understanding of the dynamics of the resource and the ecosystem in which it operates, the likelihood for sustainable use is severely reduced. Management practices and institutions have to recognize, interpret, and relate to ecosystem dynamics in a fashion that secures the flow of natural resources and ecosystem services (Hanna et al. 1996). This flow forms the biophysical precondition for social and economic development (Odum 1989, Daily 1997, Baskin 1997).

As sketched in Figure 1, the main focus of the project is this *link between ecosystems, management practices and institutions, and their coupled dynamics*. Since the social-ecological system in Figure 1 is an open system, there are a number of influences that impinge on it. These influences include factors such as population growth, technology change, effects of capital markets and trade. Political change occurring outside the study area and the ubiquitous pressures of globalization may also have major influences on the system. Such factors are no doubt important but are not the primary focus of this project.

Here the major objectives are to:

- Identify and investigate management practices of dynamic complex systems, founded on ecological knowledge and understanding
- Investigate how such management practices are embedded in institutions, and identify key elements behind adaptive institutional response to ecosystem change.
- Analyze how the dynamics of 1 and 2 could be linked for building social-ecological resilience.

What we are thinking of more specifically will be discussed in the following.

Social-Ecological Systems and Resilience

Disturbance is endogenous to ecosystem development, a part of the adaptive renewal cycle (Fig. 2). Holling et al. (1998) argue that there are social systems that have developed mechanisms to interpret signals of disturbance and other phenomena of ecosystem change and actively adapt to them. Ecological knowledge is critical in this adaptive process. The generation, accumulation and transfer of ecological knowledge within and between human groups and between generations makes it possible for a society to be alert to changes in resource abundance and ecosystem dynamics. We see traditional ecological knowledge as a dynamic process of continuous and active adaptation to resource and ecosystem change (Berkes and Folke 1998).

The *Linking* volume addressed the question of how adaptiveness and resilience can be built into institutions so that they are capable of responding to the processes that contribute to ecosystem resilience. It explored local and traditional practices of resource use, including combinations of Western and non-Western practices, and the social mechanisms behind these practices. It posed three hypotheses:

- Maintaining resilience may be important for both resources and social institutions, and that the well-being of social and ecological systems is thus closely linked.
- Successful knowledge and resource management systems will allow disturbances to enter at a scale that does not disrupt the structure and functional performance of the ecosystem and the services it provides.
- There are social mechanisms behind management practices based on local ecological knowledge, as evidence of a co-evolutionary relationship between local institutions and the ecosystem in which they are located.

In addressing the first hypothesis, the *Linking* volume found that maintaining resilience was important for both resources and social institutions, and that the wellbeing of social and ecological systems was thus closely linked. Many of the chapters analyzed social-ecological linkages, mainly in local community-based institutions, and illustrated how adaptiveness and resilience have been built into institutions so that they are capable of responding to and managing processes, functions, dynamics and changes in a fashion that contribute to ecosystem resilience. The fact that such linked social-ecological systems are found so widely and have a track record often over a long period, suggests that they are highly adaptive.

The cases in the *Linking* volume also supported the second hypothesis that successful knowledge and resource management systems will allow disturbance to enter at a scale which does not disrupt the structure and functional performance of the ecosystem, and the services it provides. Conventional resource management often aims to block out disturbance, such as fires, and may be "efficient" in a limited sense in the short-term. But since disturbance is endogenous to the cyclic processes of ecosystem renewal, conventional resource management tends to *increase* the potential for larger-scale disturbances and even less predictable and manageable feedbacks from the environment. These feedbacks, or surprises, can have devastating effects on ecosystems and on societies that depend on the resources and services that ecosystems generate. As resilience or the buffering capacity of the system gradually declines, flexibility is lost, and the linked social-ecological system becomes more vulnerable to surprise and crisis (Holling 1986).

Although crisis may be a necessary condition to provide the understanding and impetus for change (Gunderson et al. 1995), it is obviously risky to allow crises to build up to a level where they challenge the survival of the community, region, or society as a whole. The cost of learning from such crises may be extremely high, and social and economic consequences severe. Several of the management practices and associated social mechanisms identified in the *Linking* volume function to prevent the build up of large-scale crises. They allow disturbance to enter at a lower level in the *panarchy* of nested adaptive cycles (Gunderson et al. 1997) (Fig. 3), and they build resilience. It seems that such social-ecological systems allow for internal renewal while maintaining overall structure. We believe that such adaptations have been made possible through management practices that are founded on ecological knowledge and understanding, generated, accumulated and transferred through a trial-and-error learning process.

The third hypothesis of the *Linking* volume dealt with social mechanisms behind management practices. These were in evidence in many of the case studies, and suggested a *co-evolutionary* relationship, a two-way feedback mechanism, between local institutions and the ecosystem in which they were located. These social practices and mechanisms were found to provide a reservoir of active adaptations in the real world that may be of universal importance in designing for sustainability.

However, the cases also revealed that social mechanisms were often vulnerable to disruption from a multitude of causes. For the social-ecological system to persist, it appeared that the integrity of locally adapted systems in which the practices and mechanisms are embedded, had to be protected (but not isolated) from external driving forces. These forces included factors such as technology change, population growth and commercialization, as well as more recent forces such as macroeconomic policies or trade opportunities that may encourage unsustainable resource exploitation.

Protection and support of social-ecological systems were often provided by "umbrella" institutions, or through nested institutions (Ostrom and Schlager 1996; Alcorn and Toledo 1998). Sustainable systems of governance were often best accomplished through the legal recognition and support of local systems, and the sharing of resource management and power between government agencies and local institutions. An example was the co-management process in Maine's soft-shell clam fishery and the sharing of rights and responsibilities between the State of Maine and the local community (Hanna 1998).

Most of the social-ecological linkages summarized below are drawn from the chapters of the *Linking* volume. They are derived from empirical observations in both contemporary and traditional resource management systems and combinations thereof. The use of separate headings for *practices* and *mechanisms* is not meant to imply that they are separate phenomena. We consider them inter-linked and co-evolving.

Management Practices Based on Ecological Knowledge

Many of the social-ecological linkages discussed in the *Linking* volume were not previously identified specifically for their role in the management of resources and ecosystems. The present project is designed to explore these further. As well, the new project will contribute to the overall objectives of the Resilience Network[1] by analyzing the institutional dimensions of these linkages. Management practices that we have found in the case studies of the *Linking* volume (Table 1) can be classified into three categories:

[1] The goal of the Resilience Network is to understand how properties of ecological resilience, economic adaptability, and institutional flexibility interact in complex systems of humans and nature. What produces resilience, flexibility and adaptive capacity? At what temporal and spatial scales are there particularly serious mismatches between the scales of problems and the scales of remembered experience? How can incentives be developed to maintain and enhance resilience, when signals of its erosion are perceived too late? (Folke et al. 1995; Gunderson 1997; Anon. 1998). The core funding for the Resilience Network is provided by the John D. and Catherine T. MacArthur Foundation.

- *Practices found both in conventional resource management and in local and traditional societies.* These include monitoring the status of the resource and change in ecosystems, protection of certain species, vulnerable life-history stages, specific habitats, and temporal restrictions of harvest.

- *Practices abandoned by conventional resource management but still found in local and traditional societies*. These include succession management, resource rotation, and multiple species management. To some extent, such practices are being rediscovered in resource management, as reflected for example in the growing emphasis on ecotechnology (Mitsch and Jörgensen 1989), ecosystem restoration (Cairns 1995) agroecology (Carroll et al. 1990) and integrated aquaculture and polyculture (Troell 1996).

- *Practices related to the dynamics of complex systems only found in local and traditional societies.* These include watershed-based management, management of landscape patchiness, managing ecological processes at multiple scales, responding to and managing pulses and surprises, and nurturing sources of ecosystem renewal.

Practices related to the dynamics of complex systems are largely absent in resource management of Western industrial societies. This may be partly due to difficulties in coordinating and implementing cross-sectoral governmental management. There are exceptions, however, and they include evolving practices of fire management in forests and rangelands. Such practices sometimes involve the rejection of conventional management and attention to local and traditional practices (Lewis 1989; Leach and Mearns 1996), and watershed-based management by various institutions of resources and ecosystem services generated by freshwater, forests and agricultural systems (van Wilgen et al. 1996; Cullen 1996).

What is interesting is that such adaptive practices have parallels in the increasing emphasis on complex systems theory in science, stressing non-linear relationships, threshold effects, multiple equilibria, the existence of several stability domains, cross-scale linkages in time and space, disturbance, and surprise.

To explore these parallels further, in the following section, we will attempt to place the management practices discussed above in the dynamic adaptive renewal cycle of ecosystems developed by Holling (1986, 1992) (Figure 2). Our purpose is to investigate if the management practices that we have found in the *Linking* volume (Table 1) could be related to the dynamic sequence of ecosystem development (Figure 2) – when and where they may be of most relevance for adaptive resource management in complex systems.

Exploitation and conservation phases of the adaptive renewal cycle

The exploitation and conservation phases of Holling's adaptive renewal cycle, the "figure eight" (Figure 2), depict the usual process of ecological succession. If one concentrates on part of the adaptive renewal cycle corresponding to the two boxes of exploitation and conservation, one obtains a logistic curve, showing the typical curve of population growth and stabilization of individual species. It starts with slow growth, proceeds to rapid growth, followed by a change in the rate of growth at the inflection point of the curve (which occurs at the very center of figure eight). It continues with decelerating growth up to a peak which usually depicts, in conventional resource management, the carrying capacity, K. It is this part of the figure eight with which conventional resource management concerns itself. In effect, the sigmoid curve reflects the single-equilibrium model predominantly used in conventional resource management.

Several local practices of Table 1 may be located in the exploitation and conservation phases of figure eight. These include succession management, rotation, multiple species management, monitoring the status of the resource, and to some extent, management of landscape patchiness.

We propose that during these two phases *local and traditional ecological knowledge is complementary to scientific knowledge* in the following fashion. Scientific knowledge is predominantly concerned with *quantitative* information, whereas local and traditional is mainly based on *qualitative* information.

An example will help illustrate the complementary relationship (Box 1). The scientific approach tends to focus on quantitative measures for the management of a population of caribou by investigating and estimating the number of individuals in each herd by sex and age-class. By contrast, the local and traditional approach tends to focus on qualitative information such as the fat content of the caribou. Such knowledge informs resource users on trends or the direction of change, whether the population is increasing or decreasing, more healthy or less. It is based on knowledge generated, accumulated and transferred within and between local resource users and generations.

Similarly, traditional "stock assessment" of salmon in rivers in the Pacific Northwest was not based on counting the ascending salmon. It was based on observing a given salmon run and its intensity, and allowing several days of escapement, in the form of a ritually imposed taboo. Depending on the results of observations in the context of many previous years of experience, the length of the taboo period could be adjusted before salmon fishing was declared open (Swezey and Heizer 1977). Here again, monitoring is qualitative as opposed to quantitative, but it can potentially lead to good management if the traditional leader is experienced, that is holds a memory of ecological knowledge and understanding, and if the tribal group is respectful of rituals and rules.

Release and reorganization phases of the adaptive renewal cycle

The adaptive renewal cycle stresses that the sequence of gradual change of the S-curve (exploitation through conservation phases) is followed by a sequence of rapid transformation, triggered by disturbance (Figure 2). This view emphasizes that disturbance is endogenous to ecosystem development, and that periods of gradual change and periods of rapid transformation coexist and complement one another.

It seems that conventional resource management does not address the release and reorganization phases, at least not in any effective fashion, and tends to regard climax and the carrying capacity as an end-point. Conventional resource management measures tend to support the phases of gradual change, that is exploitation and conservation, but strive towards avoiding rapid transformation, that is, release and reorganization. Such management aims at removing disturbance and reducing variability of the ecosystem. Social and economic resilience may be created in the short term, but at the expense of loss of ecological resilience (Folke et al. 1997). This strategy leads to more "brittle" systems, and eventually a resource crisis (Holling 1986; Holling et al. 1998). However, as Gunderson et al. (1995) explain, crises may have a constructive role to play -- by triggering the opportunity for renewal and re-design in systems capable of learning and adapting. We believe that several of the management practices that were identified in the *Linking* volume reflect such social and institutional learning and adaptation, and argue that the existence of a memory of ecological knowledge and understanding in the system was a necessity for successful redevelopment and renewal of the resource.

In the *Linking* volume we found local and traditional management measures for the *release and reorganization phases*, measures that are important for building social-ecological resilience. Local and traditional practices that seem to function in the release and reorganization phases of the adaptive renewal cycle may prove a valuable complement to conventional resource management which has developed little understanding and few tools to address these two phases of rapid change.

The implementation of such practices is to a lesser extent based on monitoring. Instead the practices have developed as a result of actual experience with disturbance in nature, as a result of a trial-and error process of social-ecological adaptation. They let disturbance enter at lower levels in the panarchy of adaptive renewal cycles (Figure 3) and conserve sufficient memory (both ecological and social/institutional) to allow learning and reorganization. Thereby they maintain resilience of the adaptive renewal cycle, keep it within the same stability domain, and reduce the risk for collapse of the social-ecological system as a whole (i.e. a collapse higher up in the panarchy).

For example, there are local and traditional practices that behave like a disturbance and that nurture sources of renewal. Among those are aboriginal uses of fire (Lewis and Ferguson 1988), small-scale patch clearing in traditional agroforestry (Alcorn and Toledo 1998), and pulse grazing by migratory cattle as practiced by African herders (Niamir-Fuller 1998).

Furthermore, there are management practices that are analogous to the functional role of biodiversity as insurance in ecosystems (Folke et al. 1996). In ecosystems there is a great deal of biodiversity that seems redundant during ecological succession. But these redundant species may become of critical importance in the release and reorganization phases (Holling et al. 1995). An example of a social analogue to such redundancy is groups of species used as emergency food among the tribes of the Pacific Northwest. Turner and Davis (1993) identified over 100 species of plants that were not normally eaten but saved as special foods, alternative foods, emergency foods, and hunger and thirst suppressants. Species redundancy in biodiversity, which helps buffer disturbance and maintain opportunity for innovation and novelty in ecosystems, may also function to buffer disturbance (e.g. famines) and maintain opportunity in social systems.

Similarly, management practices that may seem irrelevant from a conventional management perspective may be important to deal with variability and disturbance and even surprise. One example is the establishment of range reserves within the annual grazing areas of African herders. These reserves provide an emergency supply of forage which functions to maintain the resilience of both the ecosystem and the social system of the herders, and serve as buffer when drought challenges the process and function of the dryland ecosystem (Niamir-Fuller 1998). Other examples that shape the release phase include the use of sacred groves serving as firebreak (Gadgil et al. 1998), the use of tree branches cut and placed in paddy fields for reducing pest outbreaks in India (Pereira 1992), and grazing patch management at the forest landscape level by sheep herders in the Western Himalayas

(Davidson-Hunt 1997).

Developing such practices builds buffer capacity in the sense that redundancy "*puts the brakes*" on the release phase.

As compared to the release phase, there seem to be fever practices that fall in the reorganization phase, at least among the case studies in the *Linking* volume. However, it is worthwhile to mention that the protection of keystone species (Colding and Folke 1997), protection of vulnerable life-history stages, habitat protection (Gadgil et al. 1993) and patch management as practiced by local and traditional societies may be of importance for reorganization (Berkes et al. 1995).

Habitat protection through sacred groves or taboos may help secure recruitment of seeds and larvae into an area affected by a disturbance. For example, the reorganization of a coral reef hit by a hurricane, and a forest burnt by a fire is dependent on such *spatial resilience*. It is therefore of interest to note that sacred areas or sacred groves used to be common in the terrestrial ecosystems in all parts of the world, from the Americas to Asia and Africa. They were less common in the marine environment, but they did exist in such areas as East Africa until the 1950s (McClanahan et al. 1997).

The adaptive practices of the release and reorganization phases do not only serve ecological means but also social and institutional objectives. These practices help conserve sufficient structure and function for making reorganization possible, while at the same time creating room for innovation and novelty. They conserve enough memory for a restart of the adaptive renewal cycle, and thereby the generation of the critical flow of natural resources and ecosystem services on which social and economic development depends.

To sum up, we propose that local and traditional resource management practices are valuable in resource management. It seems like they complement conventional resource management through

- Qualitative monitoring and management during the exploitation and conservation phases, the two phases of main concern in conventional resource management; and
- Management practices that build resilience during the release and reorganization phases, the phases that seem to be largely ignored by conventional resource management.

Social mechanisms behind management practices

The *Linking* volume did not find many examples of local and traditional practices that addressed the reorganization phase (Figure 2), but it did find many *social mechanisms* that did. Social/institutional memory may be of particular importance for reorganization.

Accumulated ecological knowledge, experience over historical time, and wisdom are key components of this memory. These key components provide the link between ecosystems and institutions, as shown in Figure 1, and help restart the adaptive renewal cycle of the social-ecological system. A social system that lacks ecological knowledge and understanding in its social/institutional memory is less likely to implement appropriate management practices and may lose resilience and adaptability to such an extent that it will flip into another stability domain.

The social mechanisms we found in the *Linking* volume could be grouped into four clusters, as a hierarchy that proceeds from ecological knowledge to institutions, mechanisms for cultural internalization, and worldviews (Table 1). Institutions, in the sense of rules-in-use, provide the means by which societies can act on their social-ecological knowledge, their memory, and use it to produce a livelihood from the resources in their environment. Both ecological knowledge and institutions require mechanisms for cultural internalization, so that learning can be encoded, accepted and remembered by the social group. Worldview or cosmology gives shape to cultural values, ethics, and basic norms and rules of a society.

Generation, accumulation, and transmission of ecological knowledge

The evolution of the Cree caribou hunting system, following a resource crisis, illustrates how a society can *reinterpret signals for learning.* The crisis caused by the disappearance of caribou in the 1910s triggered learning, and the redesign of the management system was encoded in ethical and cultural beliefs of the Cree (Berkes 1998). The case also provides an example of the *revival of local ecological knowledge* as part of the social/institutional memory for restoring a resource population. *Folklore and knowledge carriers* help maintain ecologically sound management practices. For example, tales of a maize culture hero are associated with all stages of the *milpa* agroforestry system. The hero warns people of impending doom if people stop making *milpa* properly. *Intergenerational transmission* of ecological knowledge is accomplished through the *milpa* script that is passed on to children and sustained by cultural beliefs, mythologies, and yearly festivals (Alcorn and Toledo 1998). Several of the chapters of the *Linking* volume give examples of the *integration of knowledge.* The Maine's soft-shell clam fishery is characterized by the integration of informal local ecological knowledge and formal scientific information generated locally (Hanna 1998). Niamir-Fuller (1998) illustrates the existence of g*eographical transfer of ecological knowledge* between local communities. Similarly, there is evidence that learning and redesign of beaver management diffused across communities in the Canadian sub-arctic in the 1800s

(Berkes 1998).

Structure and dynamics of institutions

Pinkerton (1998) explains how a clan chief developed and pursued his vision of the future Gitksan forest, a telling case of the *role of stewards/wise people.* The collective leadership of stewards is the key common-property resource management institution among the Cree. It is common that a hunt leader acts as a steward of the resources on behalf of the community, as well as a social and in the old days also a spiritual leader (Berkes 1998). *Community assessments* in the Maine clam fishery assure that time and effort to develop and implement management plans are proportionally shared by the major beneficiaries of the resource through inclusion of users in resource surveys and other assessments (Hanna 1998). C*ross-scale institutions* operate at more than one level. In the Maine clam fisheries the bundle of rights moving from the citizen to state level are nested in ascending levels of authority (Hanna 1998). *Taboos and other regulations* on game and fish are part of *caboclos* and *caiçaras* cultures, where species are avoided due to toxic, medicinal, or ecological reasons (Begossi 1998). Taboos and other rules are enforced by s*ocial and religious sanctions.* The Gitksan of British Columbia sanction those who do not follow the norms and rules of the community through questioning their right to their Gitksan name and social status (Pinkerton 1998). Among Mesoamericans, traditional curers reinforce socially appropriate behavior during their interactions with patients, by relating illness to misuse of resources and other misbehavior (Alcorn and Toledo 1998). Other social mechanisms in this group include *coping mechanisms* which are short-term responses in abnormal periods of stress; the *ability to reorganize under changing circumstances;* and *incipient institutions* with rules that seem to "kick in" following certain kinds of stresses (Berkes and Folke 1998).

Mechanisms for cultural internalization

Rituals, ceremonies and other traditions provide examples of mechanisms for cultural internalization. Rituals help people remember the rules and interpret signals from the environment appropriately. Ritual obligations, rights to community resources, and obligations to manage those resources are often linked. *Coding or scripts* can function *as cultural frameworks for resource management*. The *milpa* system is a cultural script, an internalized plan consisting of a series of routine steps with alternative subroutines, decision nodes, and room for experimentation. Ecological knowledge is encoded in the local variation of the *milpa* script, derived from experiences and experiments of farmers over generations. The making of *milpa* is the central, most sacred act, one which binds together the family, the community, the ecosystems, the universe (Alcorn and Toledo 1998).

Worldview and cultural values

Expression of worldview through respect, patience, humility, and the concepts of being a part of nature is common in many traditional societies. These expressions and concepts remain as social principles even when they are being violated in practice as circumstance change. The Lax'skiik and Gitksan of British Columbia have a personal and spiritual identification with their territories and resources; the fate of the land parallels their own fate, and this relationship forms the basis for their management of the land and its resources (Pinkerton 1998). The *caiçaras* in Brazil believe in forest guardians; in spirits that protect animals and spirits of the water who punish those who fish too much (Begossi 1998). Among the Huastec of Mexico, the real owners of the land and forest are divine beings and spirits (including ancestors), and the Earth is a member of the community. The community has the obligation to treat the Earth and all community members with respect and concern for their continued wellbeing (Alcorn and Toledo 1998). In the Cree view of the natural world, human-animal relationships continue to be a spiritual and religious matter, and there is reciprocity between the hunter and the animal. As seen in the caribou and beaver cases, limiting the harvest and avoidance of waste are two of the main ways, along with various rituals, in which respect is shown (Berkes 1998).

Towards a New Research Agenda

The adaptive renewal cycle provides one framework, and certainly not the only one, through which management practices and their social mechanisms can be systematically investigated to explore the dynamics of ecosystem-social system linkages. Since practices of the release and reorganization phases (Figure 2) seem to be the less appreciated, we propose that research focus on those. The reorganization phase is where novelty occurs. This is the phase in which a society draws on previous knowledge, experience and wisdom – key components of its memory, combines it and also makes room for experimentation and innovation. The release or "creative destruction" (Schumpeter 1950) phase creates opportunity for innovation and active adaptation in the reorganization phase. But the potential for exploring novelty and innovation and to reorganize depends on the existence of resilience in the social-ecological system. If redundancy, variability and memory is reduced or lost, resilience is reduced or lost and the social-ecological system may not be able to absorb disturbance and create novelty and innovation.

The new research agenda also needs to include theoretical and empirical studies that focus on institutional needs for resilience. More systematic information is needed about institution-building, use of adaptive management, and the design of policies that support local and traditional resource management. The research agenda will include more attention to the resilience of social systems and the avoidance of ecological surprises, social and institutional learning (Gunderson et al. 1995), and the study of adaptive renewal cycles in social systems (Holling and Sanderson 1996).

Holling (1986) observed that institutions, like ecosystems, can become "brittle" over time, and resource crises can result in release and reorganization (Gunderson et al. 1995). These observations can lead to new empirical and theoretical work on linkages between social and ecological systems, and more specifically to the questions of

- what produces adaptive capacity in linked social-ecological systems,
- sources of adaptive resilience and the role of remembered experience for innovation,
- the conditions under which complex processes of co-evolution of the coupled social-ecological system either builds resilience (creating harmony) or erodes resilience (creating dissonance).

These questions open up a new vista by focusing on dynamic relationships between ecosystems and institutions in the context of resilience. More specifically, regarding the adaptive renewal cycle of Figures 2 and 3, the research agenda includes the questions of "sources" and "sinks" of novelty**,** and the role of wisdom. Novelty, a little known process in both social and ecological systems, seems to occur in rapid phases of reorganization, in transient moments, and may play a key role in the development of adaptive capacity. Similarly, wisdom, which is valued highly in traditional societies, may play a key role by providing corporate memory, interpreting observations, nurturing novelty, and producing adaptive capacity by guiding the social learning process.

The use of the adaptive renewal cycle may help pinpoint where windows of opportunity may lie regarding innovation and renewal. With respect to adaptive management, the adaptive renewal cycle may help indicate when and where experiments may be possible. The adaptive renewal cycle as a conceptual model may also be helpful in identifying and analyzing barriers to change. A preliminary set of hypotheses to guide a new research agenda may be posed on the basis of the above considerations:

- There are certain ecological knowledge and management practices that in particular contribute to building (a) ecosystem resilience, (b) institutional resilience, and (c) a match between ecosystems and institutions;

- Self-organization plays a key role (a) in the ordering or structuring of ecological knowledge, and (b) in the emergence of institutions;
- It is in the combination of social/institutional and ecosystem memories that innovation and novelty for social-ecological resilience and sustainability may take place;
- There are local and traditional management practices compatible with the slow variables in ecosystems, as well as those compatible with the fast variables;
- There is a small set of key processes that shape the structure of institutions (analogous to the key variables/processes that control ecosystem structure and function);
- There is a small set of key processes that shape the linkage between ecosystems and institutions;
- Local and traditional knowledge may have certain capabilities to help avoid thresholds and ecosystem flips;
- Historical and cultural contexts are important in the shaping of institutions;
- Local and traditional management systems are complementary to conventional resource management through (a) qualitative monitoring and management during the exploitation and conservation phases, the two phases of concern in conventional resource management; and (b) management practices that build resilience during the release and reorganization phases, especially practices that function in "putting the brakes" on release.

During the last century, and in particular since World War II, technological advances and social and economic changes have increasingly been at the expense of ecological resilience. This is not sustainable since the former ultimately depends on the latter (Levin et al. 1997). The challenge is instead to build resilience of the combined social-ecological system for sustainability. It is this challenge that will be addressed in the project *Understanding Dynamics of Ecosystem-Institution Linkages for Building Resilience.*

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Appendix

Definitions of Terms and Concepts

Some definitions are needed to establish a common vocabulary, following the *Linking* volume. Our overall management objective is *sustainability,* defined by WCED (1987) as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Sustainability, as used here, is a process and includes ecological, social and economic dimensions. We recognize that the question of "what is to be sustained" has to be addressed on a case by case basis and is scale dependent (Costanza and Patten 1995). For our general purposes, sustainability implies not challenging ecological thresholds on temporal and spatial scales that will negatively affect ecological systems and social systems. *Social systems* that are of primary concern for this volume deal with property rights, land and resource tenure systems, systems of knowledge pertinent to environment and resources, and world views and ethics concerning environment and resources. The term *ecological system* (ecosystem) is used in the conventional ecological sense to refer to the natural environment. 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. Such views, however, are not yet accepted in conventional ecology and social science. When we wish to emphasize the integrated concept of humans-in-nature, we use the terms *social-ecological system* and *social-ecological linkages*.

The term *local knowledge* is used as a generic term referring to knowledge generated through observations of the local environment and held by a specific group of people. *Indigenous knowledge* (IK) is used to mean local knowledge held by indigenous peoples, or local knowledge unique to a given culture or society, consistent with Warren et al. (1995). The term can be used interchangeably with traditional knowledge. But we prefer to use *traditional ecological knowledge* (TEK) more specifically to refer to a cumulative body of knowledge and beliefs, 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, in prep.). The word *traditional* is used to refer to historical and cultural continuity, but at the same time recognizing that societies are in a dynamic process of change, constantly redefining what is considered "traditional".

Traditional and local management is contrasted with *Western resource management,* defined as resource management based on Newtonian science and on the expertise of government resource managers. We use the term interchangeably with *scientific resource management* and *conventional resource management*. We recognize that all societies have their own science, but identify Western science and scientific method to represent a particular brand of science which is used as the basis of resource management by centralized bureaucracies in all parts of the world.

Institutions are defined as "humanly devised constraints that structure human interaction. They are 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 (the working rules or rules-in-use) by a set of individuals to organize repetitive activities that produce outcomes affecting those individuals and potentially affecting others" (Ostrom 1992). The emphasis in the project is on institutions that deal with property rights and common property resources. Here we define *property* as the rights and obligations of individuals or groups to use the resource base. 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. A property right is a claim to a benefit stream that some higher body - usually the state - will agree to protect through the assignment of duty to others who may covet, or somehow interfere with, the benefit 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). Institutions have to deal with the two fundamental management problems that arise from the two basic characteristics of all such resources: how to control access to the resource (the exclusion problem), and how to institute rules among users to solve the potential divergence between individual and collective rationality (the subtractability problem).

Capital is a stock resource with value embedded in its ability to produce a flow of benefits. We make a distinction among three kinds of capital: (a) *Human-made capital* is generated through economic activity through human ingenuity and technological change, the produced means of production. (b) *Natural capital* consists of non-renewable resources extracted from ecosystems, renewable resources produced by the processes and functions of ecosystems and environmental services sustained by the workings of ecosystems. (c) 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 (Berkes and Folke 1994). Coleman (1990, pp. 300-321) used *social capital* to refer to features of social organization such as trust, norms and networks. Ostrom (1990, pp. 190, 211) used social capital to refer to the richness of social organization, and *institutional capital* to refer to the supply of organizational ability and social structures, literally the "capital" of institutions that a society has at its disposal.

Systems approach broadly refers to a holistic view of the components and the interactions of a system. The term *feedback* is used in the conventional systems sense to refer to the result of any behavior which may reinforce (positive feedback) or modify (negative feedback) subsequent behavior. More specifically, the book is concerned with the recognition of environmental feedbacks (e.g., depletion of particular resources, decline of catch per unit of effort) that signal for changes in management responses, and the ability of resource management institutions to receive and to respond to these signals.

Resilience is the buffer capacity or the ability of a system to absorb perturbations; the magnitude of disturbance that can be absorbed before a system changes its structure by changing the variables and processes that control behavior (Holling 1973; Holling et al. 1995). Resilience conserves "memory" (e.g. information, knowledge, experience, wisdom) for making reorganization and also innovation possible (Gunderson et al. 1997). It is a measure of the opportunities conserved by the system for novelty and renewal (Folke et al. 1997). Resilience, as we use the term, is different from stability. Resilience is the capacity of the system to survive disturbance, its capacity to undergo stress and yet recover, and even to endogenize the disturbance and transcend it. Stability has to do with how resistant the system is to disturbance, whereas resilience has to do with how resistant the system is to crashing. The *self-organizing* ability of the system, as exhibited in release and reorganization phases of the adaptive renewal cycle (Figure 2), determines its capacity to respond to stresses and shocks. If the resilience of a system is lost or exceeded, it crashes. In effect, such a crash moves a system into another equilibrium. *Threshold* is the point where a system flips from one equilibrium state to another. *Surprise* denotes the condition when perceived reality departs *qualitatively* from expectation. Surprises occur when causes turn out to be sharply different than was conceived, when behaviors are profoundly unexpected, and when action produces a result opposite to that intended (Holling 1986).

Adaptive management emphasizes learning-by-doing, and takes the view that resource management polices can be treated as “experiments” from which managers can learn (Holling 1978; Walters 1986). Organizations and institutions can “learn” as individuals do, and hence adaptive management is based on social and institutional learning (Lee 1993). 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. The process is iterative; it is feedback and learning-based. It is co-evolutionary (Norgaard 1994) in the sense that it involves two-way feedback between management policy and the state of the resource. We define *co-evolution* as self-organization through mutual feedback and entrainment (Colding and Folke 1997).

Figure 2 shows the *adaptive renewal cycle* or “Holling’s figure eight”. In a forest ecosystem, there is a dynamic four-stage cycle of exploitation - conservation – release - reorganization. The first two phases, exploitation (the establishment of pioneering species) and conservation (the consolidation of nutrients and biomass into a climax stage) lead to a system which is so stable, so dependent on conditions remaining constant, that it eventually becomes “brittle”. Such brittleness invites environmental surprises such as fire, insect pest outbreak or disease. When surprise happens, accumulated capital is suddenly released for other kinds of opportunity (creative destruction). This 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 exploitation stage starts over (Holling 1986; Holling et al. 1995).

Recently Gunderson et al. (1997) used the term *panarchy* to capture the dynamics of adaptive renewable cycles that are nested within one other across space and time scales (Figure 3). For example, the largest of the three nested figure eights may refer to a biome (e.g., Boreal forest), the middle one to an individual forest, and the smallest one to a forest stand. Each level may go through the cycle of growth, maturation, destruction and renewal. Gunderson et al. (1997) suggested that all living systems, ecological as well as social, exhibit properties of the adaptive renewal cycle across scales.

Box 1. Conceptual pluralism: Combining traditional ecological knowledge and Western scientific knowledge.

In the eastern sub-arctic region of Canada, studies show that the traditional Cree Indian management system for caribou monitors much the same information base as does Western science—geographic distributions, migration patterns and their change, individual behavior, sex and age composition of the herd, fat deposits in caribou, and the presence/absence and effect of predators. Of these indicators, the fat content of the caribou seems to receive relatively more attention by the Cree than by biologists.

This finding may be significant because there are evidence that other traditional peoples and their management systems may also be monitoring fat content. Examples include the Inuit of Northern Quebec and Labrador, the Innu of Labrador, and a number of different indigenous groups in the Northwest Territories of Canada. The recording of the fat content will be a major study method in a project in Alaska to integrate Inupiat traditional knowledge and Western science about the Western Arctic Caribou Herd. As a rule of thumb, the monitoring of fat content for caribou management makes a great deal of sense because it provides an index of health of both the individual animal and the herd. Fat as indicator of population health integrates the combined effects of a number of environmental factors, such as the condition of feeding range, acting on the caribou population. It is therefore not surprising that the monitoring of caribou fat content is not merely an area-specific bit of *local knowledge* but rather a *principle of traditional ecological knowledge* widely applicable across the full range of caribou distribution from Labrador to Alaska.

The Cree system has many similarities to the Western science of caribou management. But at the same time, it is fundamentally different from Western science that often gives priority to *quantitative* population models for management decision-making. The Cree system, by contrast, neither produces nor uses estimates of the population size. Rather, it uses a *qualitative* mental model that provides hunters with an indication of the *population trend over time.* This qualitative model reveals the *direction* (increasing/decreasing) in which the population is headed; it does not require the quantitative estimation of the population size itself for making management decisions.

Such traditional knowledge is complementary to Western scientific knowledge, and not a replacement for it. Monitoring fat content alone will not lead to good management decisions, for example, in the case of predator-limited (as opposed to range-limited) caribou populations, and in the case of a caribou population affected by two or three successive bad winters. On the other hand, exclusive reliance on biological population survey data will not lead to good management decisions either. There are several cases in the Canadian North and Alaska, with caribou and other wildlife, in which the results of biological censuses mislead management decisions, and were subsequently corrected by the use of other biological perspectives *and* traditional knowledge of indigenous groups. Such cases illustrate the complementarity of traditional and Western knowledge at a practical level, and highlight the need for conceptual pluralism in resource and ecosystem management.

Source: Berkes (in prep.)

Table 1. Social-ecological management practices and mechanisms for building resilience (from Folke et al. 1998).

1. Management practices based on ecological knowledge
    - monitoring change in ecosystems and in resource abundance
    - total protection of certain species
    - protection of vulnerable stages in the life-history of species
    - protection of specific habitats
    - temporal restrictions of harvest
    - multiple species and integrated management
    - resource rotation
    - management of succession
    - management of landscape patchiness
    - watershed management
    - managing ecological processes at multiple scales
    - responding to and managing pulses and surprises
    - nurturing sources of renewal

2. Social mechanisms behind management practices
    - a) generation, accumulation and transmission of ecological knowledge
        - re-interpreting signals for learning
        - revival of local knowledge
        - knowledge carriers/folklore
        - integration of knowledge
        - intergenerational transmission of knowledge
        - geographical transfer of knowledge
    - b) structure and dynamics of institutions
        - role of stewards/wise people
        - community assessments
        - cross-scale institutions
        - taboos and regulations
        - social and cultural sanctions
        - coping mechanisms; short term responses to surprises
        - ability to re-organize under changing circumstances
        - incipient institutions
    - c) mechanisms for cultural internalization
        - rituals, ceremonies and other traditions
        - coding or scripts as a cultural blueprint
    - d) worldview and cultural values
        - sharing, generosity, reciprocity, redistribution, respect, patience, humility

Figurelegends

Figure 1. A conceptual framework for the analysis of linked social-ecological systems. Ecological knowledge and understanding is a critical link between complex and dynamic ecosystems, adaptive management practices and institutions.

Figure 2. The Adaptive Renewal Cycle (from Holling 1986; Gunderson 1997).

Figure 3. Nested adaptive renewal cycles – a so called Panarchy (from Gunderson et al. 1997; Gunderson 1997)

Figure 4a. Local and traditional management practices of the exploitation and conservation phases of the adaptive renewal cycle. During ecological succession there are practices directed towards resource and ecosystem use. This usage is often preceded and determined by some form of monitoring, e.g. stock assessments of caribou (quantitative) or fat content of caribou (qualitative) (see Box 1). We call such practices "monitoring and active ecosystem management practices".

Figure 4b. Local and traditional management practices of the release and the reorganization phases of the adaptive renewal cycle. During periods of rapid change monitoring is not easily performed. Instead practices based on experience of disturbance and crisis, have developed to improve the chance for recovery of the ecosystem and thereby of the resources and services that is generated. Such practices will buffer disturbance, put the brakes on the release phase, and help conserve essential components of "memory" to make recovery possible. Thereby, they will also conserve the opportunity for innovation and novelty. We term such practices "memory and opportunity conserving practices".

Behaving like a disturbance through e.g.
- patch clearing
- fire management
- pulse fishing
- pulse hunting
- pulse grazing

Putting the brakes on release through e.g.
- saving banks
- emergency crops
- fire breaks
- landscape level patch management

Nurturing sources of renewal through e.g.
- recruitment areas
- seasonal closure of harvest
- protection of life-history stages
- protection of species
- protection of habitats