DOI: 10.1007/s00267-003-0101-7

Adaptive Comanagement for Building Resilience in Social–Ecological Systems

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ABSTRACT / Ecosystems are complex adaptive systems that require flexible governance with the ability to respond to environmental feedback. We present, through examples from Sweden and Canada, the development of adaptive comanagement systems, showing how local groups self-organize, learn, and actively adapt to and shape change with social networks that connect institutions and organizations across levels and scales and that facilitate information flows. The development took place through a sequence of responses to environmental events that widened the scope of local management from a particular issue or resource to a broad set of issues related to ecosystem processes across scales and from individual actors, to group of actors to multiple-actor processes. The results suggest that the institutional and organizational landscapes should be approached as carefully as the ecological in order to clarify features that contribute to the resilience of social–ecological systems. These include the following: vision, leadership, and trust; enabling legislation that creates social space for ecosystem management; funds for responding to environmental change and for remedial action; capacity for monitoring and responding to environmental feedback; information flow through social networks; the combination of various sources of information and knowledge; and sense-making and arenas of collaborative learning for ecosystem management. We propose that the self-organizing process of adaptive comanagement development, facilitated by rules and incentives of higher levels, has the potential to expand desirable stability domains of a region and make social–ecological systems more robust to change.

Learning how to deal with uncertainty and adapt to changing conditions is becoming essential in a world where humanity plays a major role in shaping biospheric processes from genetic levels to global scales (Falkowski and others 2000; Folke and others 2002; Palumbi 2002). Successful adaptive approaches for ecosystem management under uncertainty need to (1) build knowledge and understanding of resource and ecosystem dynamics, (2) develop practices that interpret and respond to ecological feedback, and (3) support flexible institutions and organizations and adaptive management processes (Berkes and Folke 1998). It is increasingly proposed that knowledge generation of ecosystems should be explicitly integrated with management practice and evolve with the institutional and organizational aspects of management (Dale and others 2000; Walker and others 2002) in what we refer to as adaptive comanagement systems (Berkes and others 2003).

KEY WORDS: Adaptive management; Comanagement; Social–ecological systems; Resilience; Self-organization

Published online June 23, 2004.

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Adaptive comanagement systems are flexible community-based systems of resource management tailored to specific places and situations and supported by, and working with, various organizations at different levels. Folke and others (2002, p. 20) define adaptive comanagement as a process by which institutional arrangements and ecological knowledge are tested and revised in a dynamic, ongoing, self-organized process of learning-by-doing. Adaptive comanagement combines the *dynamic learning* characteristic of adaptive management (e.g., Holling 1978) with the *linkage* characteristic of cooperative management (e.g., Pinkerton 1989; Jentoft 2000) and with collaborative management (e.g., Buck and others 2001). It is a way to opertionalize adaptive governace (Dietz and others 2003) The sharing of management power and responsibility may involve multiple institutional linkages among user groups or communities, government agencies, and nongovernmental organizations. Adaptive comanagement relies on the collaboration of a diverse set of stakeholders operating at different levels, often in networks, from local users, to municipalities, to regional and national organizations, and also to international bodies.

The purpose of the article is to analyze how the dynamic process of adaptive comanagement may help build resilience in social–ecological systems and, more generally, to support ecosystem management. The first part addresses knowledge in relation to ecosystems as seen as complex adaptive systems faced with uncertainty and surprise [for a synthesis of uncertainty and surprise in relation to science and policy, see Kinzig and others (2003)]. We stress the necessity to expand from knowledge of structures to knowledge of processes that sustain the social–ecological capacity to respond to ecosystem change (Berkes and others 2003). Such knowledge is seldom generated in a social vacuum but tends to evolve with working rules and organizational dynamics. In the second part, we present the development toward adaptive comanagement systems with examples from Sweden and Canada showing how local groups self-organized, learned, and actively adapted to social and ecological change. In the last part of the paper, we identify social features that support and facilitate the emergence of adaptive comanagement systems. We discuss how these features have the potential for building social–ecological resilience to deal with pervasive uncertainty and transformations of human life-support systems (Folke and others 2002).

Complex Adaptive Ecosystems, Knowledge, and Institutions

Sustainable use of ecosystem services is unlikely without improved understanding of the capacity of ecosystems to provide these services (Gunderson and Holling 2002). Ecosystems are complex adaptive systems, characterized by Levin (1998) as systems in which properties and patterns at higher levels emerge from localized interactions and selection processes acting at lower scales and may feed back to influence the subsequent development of those interactions. They are characterized by nonlinear relations, threshold effects, historical dependency, multiple possible outcomes and, limited predictability (Scheffer and others 2001).

Carpenter and Gunderson (2001) stress the need for continuously testing, learning, and developing knowledge and understanding for coping with change and uncertainty in complex adaptive systems. We have previously illustrated that many community-based management systems seem to have coevolved with resource and ecosystem dynamics and have developed knowledge and practice for how to live with change and uncertainty (Gadgil and others 1993; Berkes and Folke 1998; Berkes and others 2003). Traditional ecological knowledge is an attribute of societies with historical continuity in resource use practice (Dei 1993; Williams and Baines 1993) and is defined as 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). Local ecological knowledge and practice is an attribute of more recently evolved resource management systems and refers to a cumulative body of knowledge applied and developed by actors in a local context. It consists of externally and internally generated knowledge about resource and ecosystem dynamics (Olsson and Folke 2001). It has been proposed that the management of complex adaptive systems may benefit from the combination of different knowledge systems (McLain and Lee 1996; Johannes 1998; Ludwig and others 2001; Berkes and Jolly 2001;Gadgil and others 2003). The Malawi principles of the Biodiversity Convention stress that the ecosystem approach should consider all forms of relevant information, including scientific and indigenous knowledge. The role of community-based knowledge systems in ecosystem assessment and management is presently addressed in the Millennium Ecosystem Assessment (www.millenniumasessment.org).

Numerous investigations by research institutions, governmental agencies, and nongovernmental organizations have been conducted to describe, analyze, and sometimes tap traditional knowledge that relates to the structures of nature such as species and their diversity or ecosystem goods. Examples include identification of hot-spot areas, medicinal knowledge among traditional peoples, and genetic information and associated intellectual property rights issues. The bulk of ethnobiological studies, for example, deal with knowledge of structures such as species (taxonomy) or particular resources like food and how they are utilized by certain groups of people. Such knowledge does not capture the capacity of ecosystems to sustain species, resources, or ecosystem services crucial for societal development; nor does it couple local knowledge to ecosystems management and environmental feedback. During the last decade, we have tried to expand the focus to also embrace resource users' knowledge and management of ecosystem dynamics that acknowledges uncertainty and surprise (Berkes and others 2003). It comes as no surprise that knowledge of resource and ecosystem dynamics and associated management practices exists among communities that, on a daily basis over long periods of time, interact for their benefit and livelihood with ecosystems (Berkes and others 2000; Colding and others 2003).

Schindler (1998) claims that experiments at less than ecosystem scales are inappropriate and may even cause erroneous management decisions. They seldom provide insights on the complex dynamics of ecosystems or connect temporal and spatial scales and they tend to avoid the issue of uncertainty (Kinzig and others 2003). Jackson and others (2001) stress that lack of long-term data in experimental science makes it difficult to reach informed decisions and tends to lead to conservation efforts that focus only on the most recent symptoms of the problem rather than on their deep historical causes. Carpenter and others (2001) describe the several-decade-long research process that it took to develop an understanding of key variables that structure lakes and rangelands. In this context, Dale and others (1998) point to the need for an "institutional memory" as a part of ecosystem management, in order to reduce the risk of management responses that are not in tune with ecosystem dynamics.

There are knowledge systems and associated institutions that represent a reservoir, a memory, of long-term social–ecological adaptations to dynamics and change (Berkes and Folke 2002). The institutional memory of such knowledge is often difficult to unravel because it tends to be embedded in local cultures (Berkes 1999). We have focused on the concept of management practices for this purpose (Berkes and Folke 1998). Management practices and associated rules-in-use (institutions) and organizational structures seem to have developed through learning-by-doing, building knowledge and experience in the process (Pálsson 1998).

Knowledge acquisition is an ongoing dynamic learning process; perhaps, most importantly, knowledge and associated management practices of local resource users and communities seldom exist in a vacuum but seem to require social networks and an institutional framework to be effective. This is exemplified in a study on frontier colonist farmers in the Brazilian Amazon (Muchagata and Brown, 2000). The investigators found that people moving from one area to another easily gained detailed knowledge of particular resources and species, but peoples' knowledge of processes and functions of the underlying ecosystem that sustains those resources was patchy and incomplete. It seems like knowledge and understanding relevant for management of ecosystem dynamics takes a much longer time to develop. This suggests that dwelling for long periods of time in specific places is helpful in generating an understanding of ecosystem dynamics and sustainable management practice (Nabhan 1997).

Furthermore, knowledge and understanding of ecosystem dynamics is very difficult, if not impossible, to develop at the level of the human individual. It requires collaboration. Understanding ecosystem processes and how to manage them seems to be a progression of social–ecological coevolution, and it involves learning and accumulation of ecosystem knowledge and understanding in a "social memory" (the arena in which captured experience with change and successful adaptations embedded in a deeper level of values is actualized through community debate and decision-making processes into appropriate strategies for dealing with ongoing change (McIntosh 2000). The knowledge system itself becomes part of the processes of social learning (Lee 1993) for how to deal with ecosystem dynamics. In this sense, a collective learning process that builds experience with ecosystem change evolves as a part of the social memory, and it embeds practices that nurture ecological memory (Folke and others 2003). Such a process of social learning is linked to the ability of management to respond to environmental feedback and direct the coupled social–ecological system into sustainable trajectories (Berkes and others 2003). It is in this context that we will address adaptive comanagement in the remaining parts of the article.

Case Studies from Sweden and Canada

Environmental Crises and the Emergence of Catchment-Based Management in Lake Racken, Western Sweden

Local steward associations may self-organize in response to an environmental crisis over a short time span. The social response to acidification in the Lake Racken area, western Sweden (Figure 1) illustrates how an environmental crisis can trigger a social reorganization response toward ecosystem management in less than 10 years. This reorganization provided a platform for collective action and social learning (Ostrom 1990; Lee 1993) necessary to be able to respond to environmental feedback. It played a key role in developing local ecological knowledge and creating, reevaluating, and reshaping management practices, rules, and organizational structures.

The threats of acidification to freshwater ecosystems in Sweden were well known in the late 1960s and countermeasures were developed at the national level involving scientists, politicians, and the Swedish Environmental Protection Agency (EPA) (Lundgren 1998). In the Lake Racken area, there was a growing concern that acidification was threatening water quality and recreational and sustenance fishing. This concern was based on the observation by a local resident of decreasing pH levels in the tributaries and small lakes of the Lake Racken catchment. This person, a technician at the

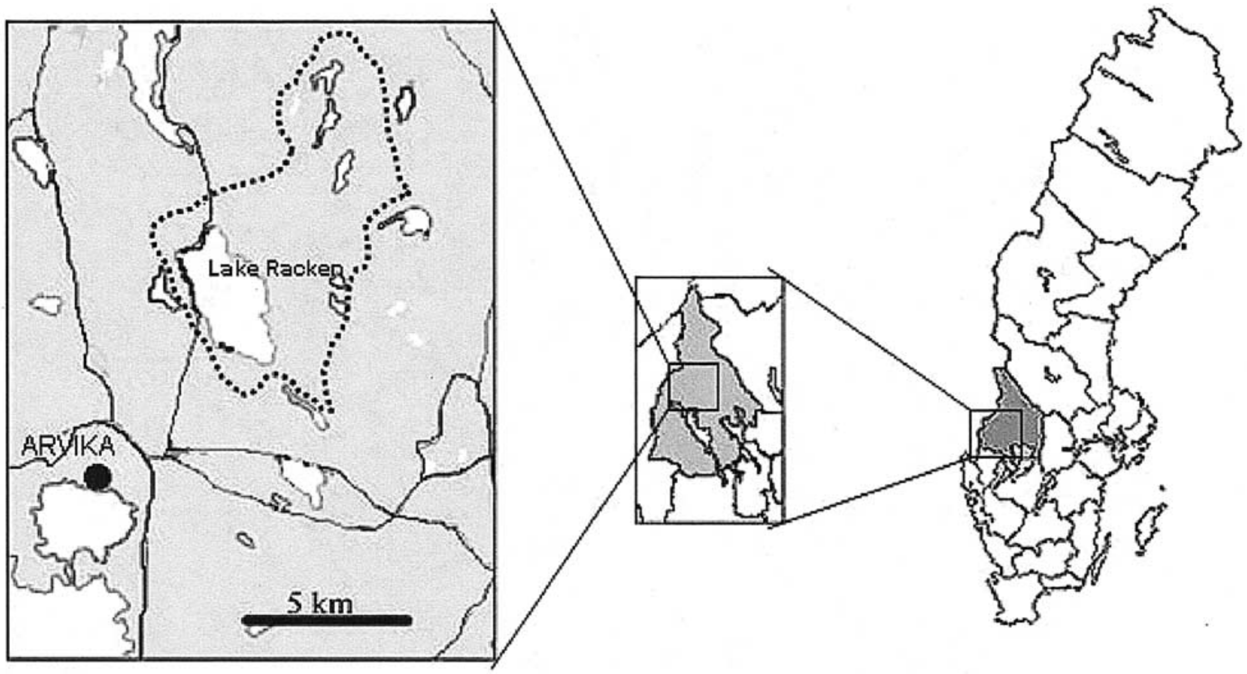

Figure 1. The Lake Racken catchment, Sweden [modified from Olsson and Folke (2001)].

municipal water works at Lake Racken, had the necessary skills and equipment for measuring the pH and had begun monitoring the pH in 1971. He mobilized other residents and formed a liming group that limed the lake, with technical support from consultants. The group was chartered in order to take advantage of Swedish government funds that were available to formal liming groups. The county administration has monitored water bodies, including Lake Racken, since 1985. Thus, the local initiative preceded the national monitoring program. The local response reversed the acidification trend in the area and started a knowledge-accumulating process with the objective of maintaining Lake Racken's desirable ecosystem state of a clear water lake with fish and associated ecosystem services.

The initiative to monitor the water bodies in the watershed, the collective action and formation of a liming group, and the institutional space and funding to lime the lake were all important to deal with ecosystem changes in the area. However, the response to acidification by the people of Lake Racken is not a long-term solution to the problem of airborne pollution from central Europe. Additional to the local strategies, international negotiation that involved the Swedish government was needed to get to the source of the problem.

The liming group self-organized into the Lake Racken Fishing Association, consisting of local landowners, and the association was formed in 1986. The noble crayfish population of the lake had decreased dramatically since the 1960s and the decrease became of major concern for the members of the Lake Racken Fishing Association. The major threats to the noble crayfish that the association was faced with were acidification (Appelberg 1986), a fungal disease called crayfish plague (Fjälling and Fürst 1988), and overexploitation of the crayfish. To become a fishing association, some criteria set by the state had to be fulfilled. Fishing association members may only include those with clear property rights identified by Arvika Land Survey District (*Lantmäteridistrikt*) within a given management area as defined by the Swedish Land Survey (*Statens Lantmäteri*), whose work was funded by the Municipality of Arvika.

Since 1986, the fishing association has worked with preventive measures to enhance brown trout (*Salmo trutta*) and noble crayfish populations by improving habitats and reducing threats within the Lake Racken catchment. In 1994, there was an important change in national legislation that gave local fishing associations the decision-making authority regarding the use and management of fish and crayfish in inland freshwater bodies (with the exception of the three largest freshwater lakes in Sweden). Prior to this change, local fishing associations had been required to consult with the county administration board (*Länsstyrelsen*) about any change in management practices. This change provided increased flexibility and space for further self-organization, such as testing different management practices and rules at the local level, thereby tightening environmental feedback loops.

The knowledge for ecosystem management applied by members of the fishing association is a combination of scientific knowledge and local observation and it is stored in the social memory of the group. The management strategy has generated knowledge within the group and it continues to draw on external sources of information in an enduring learning-by-doing process. For example, members of the association are aware of local temporal and spatial variations in acidification and how they are linked to water quality and organisms; for instance, they describe how acid shocks during snowmelt affect crayfish physiology and reproduction and they implement measures with the aim to reduce the risk of such shocks. The association also utilizes internal monitoring for fish and crayfish management. Members monitor the pH, alkalinity, calcium levels, metal concentrations, and several indicator species such as insects, mollusks, and fish. The diversity of practices that have evolved as a part of the self-organizing process toward catchment management of fish resources is described by Olsson and Folke (2001).

The noble crayfish population has slowly recovered but not close to the levels experienced in the 1950s and 1960s and recovery is very uneven across the lake. Although the fishing association's efforts has, at least not yet, resulted in an immediate, dramatic recovery of the noble crayfish population, they have produced a perhaps more important result. The primary users of the fish resources in Lake Racken now have a much more sophisticated understanding of the underlying ecosystem dynamics that affect the crayfish and trout. In addition, they have developed adaptive management processes at the ecosystem scale based on continuous learning that are flexible enough to respond to fluctuating ecological and external conditions (Figure 1).

The restoration of spawning grounds for the native brown trout in the tributaries of Lake Racken is another example of how the fishing association mobilizes sources of skills and knowledge to deal with ecosystem dynamics. This was done together with a consultant who specializes in the restoration of watercourses. The restoration consisted of improvements in the gravel beds and removal of migration barriers. Shortly after the completion of the restoration, an accident at the power plant in an upstream tributary caused siltation of spawning grounds and destroyed trout eggs. The fishing association had invested time and money into the stream and had a strong incentive to sustain and monitor it. Because they had been closely monitoring the spawning grounds, they were able to quickly identify the effects of the accident. The fishing association therefore demanded and was awarded compensation from the power company and, once more, restored the spawning areas using the same consultant. The association's ability to respond effectively to environmental events, perceived as crisis, shows the value of a coordinated, collective action process where the fishing association can act as a unified body to secure the delivery of fish resources and recreational opportunities.

When dealing with the social–ecological dynamics associated with fish and crayfish management, members of the fishing association use a variety of information sources and knowledge skills. Requisite skill exists within the organization for discovering and interpreting biogeochemical changes like the pH issue described earlier. In other cases, the fishing association recruits expertise in the form of consultants or other external sources, for example, when restoring trout spawning grounds or sending crayfish to a university laboratory to be checked for disease. The fishing association has also begun to build networks of information sharing and knowledge transfer about how to respond to environmental feedback. These are mainly horizontal linkages. For example, a social network called the Arvika fishing circuit was created with several other fishing associations within the Municipality of Arvika. This umbrella structure provides continuous information about how to manage fish and crayfish, inviting practitioners and scientists to share their knowledge and experience.

The local fishing association was recently invited to participate in a joint project between Norway and Sweden with the objective of securing and enhancing the noble crayfish populations. Their local management efforts have now become recognized outside their catchment. This is part of a Norwegian and Swedish policy initiative, an action program to secure noble crayfish populations (APNC), which outlines criteria for the definition and management of noble crayfish areas (Söderbäck and Edsman 1998). A lake district shared by Norway and Sweden, which includes Lake Racken, has been proposed as an area of special interest for the APNC. The APNC envisions that the management of defined areas will be based on collaboration among individuals at several organizational levels. It provides leadership, vision, and a platform for comanagement, linking existing knowledge, institutions, and organizational structures. The goal is not necessarily the creation of new institutions but, rather, cooperation and coordination among existing organizations with common goals and visions. The APNC includes county administration boards, municipalities, rural economic and agricultural associations (*Hushållningssäll-*

skap), local fishing associations, the Swedish EPA, and the fishery departments of both countries. It is funded by the European Commission's Interreg program, three Norwegian and two Swedish county administrations boards, and several Norwegian municipalities. The organization of the APNC underscores the fact that conservation and management of the noble crayfish requires a coordinated process because problems are not confined within lakes or streams, but are connected across spatial and temporal scales.

There are those that have opposed the current direction of crayfish management in Lake Racken and have pled for alternative methods of crayfish population enhancement such as building of hatcheries or stocking the lake with the American crayfish (*Pacifastacus leniusculus*). These alternative pathways of crayfish management will most likely counteract incentives for responding to environmental feedback and erode the current ecosystem approach. Such alternative pathways may easily alienate local inhabitants from the work of ecosystems on which social and economic development depends (Odum 1989; Folke 1991).

In Olsson and Folke (2001), we asked whether the current ecosystem approach to crayfish management is robust enough to respond in a resilient manner to such alternative management options. We believe that the recent incorporation of the fishing association into the Nordic crayfish APNC initiative indeed strengthen the possibility of sustaining the ecosystem-based catchment approach of Lake Racken management. We also believe that the emergence of the adaptive comanagement system from the liming group, to the fishing association, to the social network of associations, to linkages with municipal and county levels, and recently, to the APNC may increase the likelihood of building social–ecological resilience in the area.

Dealing with the Impacts of Development in the Estuaries of James Bay, Canada

The responses of indigenous groups in northeastern Canada to address problems of environmental change caused by large-scale development projects show some remarkable parallels to the development of local steward associations in Sweden. The similarities include the way in which indigenous groups dealt with as series of linked problems, combined their local knowledge with outside scientific expertise, and forged different sets of horizontal and vertical linkages to solve their problems.

The case begins with the announcement by the Government of Quebec in 1971 of the gigantic (15,000 MW) James Bay hydroelectric development project. Facing one of the largest energy development projects ever built, the Cree people of James Bay and their Inuit allies in the Hudson Bay area went to court to assert their aboriginal rights and to stop the project.

They were successful in obtaining an injunction in 1973, but the decision was overturned a few weeks later by a higher court, forcing the Cree and Inuit to the negotiating table for the surrender of their aboriginal claims and to open the way for development. In 1975, the Cree and Inuit, along with the governments of Quebec and Canada and the crown corporations involved in the project (Hydro-Quebec and SEBJ), signed the James Bay and Northern Quebec Agreement (JBNQA), the first of the modern comprehensive land claims agreements in Canada. The Agreement included provisions for environmental assessment and impact-related remediation through an agency called SOTRAC. It also established a comanagement agency (*Comite conjoint*) for the joint management of fish and wildlife resources of the area (Berkes 1989).

The full story is complicated and involves impacts on land, wildlife, and people, as well as impacts on aquatic resources (Berkes 1981; Rosenberg and others 1997). For the purposes of this article, the case study will only deal with the series of impacts and concerns about one social–ecological subsystem: the estuary of the La Grande, its resources, and the people who harvest them. The case develops through impacts on the lower La Grande and the estuary, followed by an expanded scale of impacts extending into the bays and coastal waters of southern Hudson Bay (Figure 2).

When the construction of LG 2, the first large dam, started on the La Grande River, the major concern of the inhabitants of the Cree village of Chisasibi (formerly Fort George) was the impact of the dam on their estuarine fish resources, a main source of local food. The La Grande, as the largest river in the region, maintained the largest stocks of anadromous whitefishes (*Coregonus clupeaformis* and *C. artedii*) and a few associated species (Morin and others 1980). Cree fishers had good knowledge of the life cycles of the whitefish through their year-round fishing: Both species spawned in the freshwater of the lower river in the fall, they fed in the brackish estuarine waters after ice breakup, and they migrated back into the La Grande in the fall. The Cree harvested them with gillnets under the ice in November in the lower estuary but did not fish them through the winter (Berkes 1979).

The Chisasibi Cree had been fishing these stocks for generations. Research reports based on data collected in the 1930s in the same area established the importance of the same two species. The 1930s catches showed an age distribution similar to those in the late 1970s, suggesting that the Cree fishery had maintained sustainable levels of catch. Further, the Cree subsis-

Figure 2. The James Bay as a part of the Hudson Bay catchment.

tence harvest of these two species in some years exceeded the entire Quebec commercial catch and outperformed other major Canadian subarctic fisheries on a catch per unit effort basis (Berkes 1979) (Figure 2).

Hence, this was a significant resource and the potential impact on the fishery was the first environmental crisis faced by the Cree regarding the estuary. The developers' plan was to block the La Grande to fill the reservoir of LG 2. The filling would start in Fall 1978 and continue over the winter months. The problem was that the natural river regime of winter flows under the ice was necessary to maintain a freshwater lens of overwintering habitat. The scientific judgment was that whitefish species were not physiologically capable of overwintering in saltwater.

The Cree sought solutions through the comanagement body under the Agreement and through the remedial works corporation (SOTRAC). Modeling studies showed that without a winter flow to maintain a freshwater lens, saltwater would move upriver and the overwintering habitat would disappear by the end of winter. Supported by their tribal organization, the Cree of Chisasibi used the provisions of the Agreement to put pressure on the dam-building authority (SEBJ) to maintain a certain minimum level of river flow through the winter as the dam was being filled.

Surveys undertaken by SOTRAC and the SEBJ during the winter and following spring showed that a small overwintering habitat was indeed maintained (Roy and Messier 1989). At least there were no visible fish kills. Subsequent joint work with Cree fishers in spring and summer of 1979 showed that about one in three to one in four of the *Coregonus* was considered unhealthy by Cree standards. The Cree visually examined the mesentery fat in the body cavity and discarded those fish considered thin and watery in texture. Interestingly, the standard biological method for fish body condition, using a length–weight analysis, in fact did not show a statistically significant reduction in condition in the fish stock as a whole (Berkes 1982).

A second environmental crisis occurred after the LG 2 dam was filled and river flow restored. The operation of the dam altered the natural pattern of seasonal flow — characterized by maximal flows in spring and minimal flows in winter. The dam stores water to produce electricity according to seasonal demands. Because the maximum need for electricity is in winter in Canada, LG 2 produced more power in winter and released high volumes of relatively warm water (reservoirs act as heat traps), so much so that the lower La Grande River would never freeze again, even in the dead of winter. The Cree of Chisasibi had never before seen an ice-free La Grande in the winter. Their first reaction to the information from SOTRAC was one of disbelief, and the hydrological expert sent to meet with the Cree to explain the situation was nearly run out of town.

However, the hydrological model was correct. The river that would be frozen solidly enough to cross by late November or early December in a normal year was now largely ice-free. This created a problem for the Cree. Winter is the main season for hunting and trapping, and quite a few families needed to cross the river but could not. The Cree Trappers Association (CTA) of Chisasibi worked with SOTRAC to find a solution: Safety of ice crossing would be monitored, and when crossing was unsafe, families would be flown to their hunting camps. Ice did form further out in the estuary. However, because it was eroded from underneath by high winter flows of warm water, the Cree thought that their traditional knowledge of ice (judging the thickness of ice by the color and by the sound produced by tapping) was no longer reliable. Hence, the CTA established and operated a system to core the ice periodically and mark the area of safe crossing, not an indigenous approach but nevertheless effective (Berkes 1988).

A third environmental crisis gradually became apparent in the 1980s. At the end of 1984, after all the reservoirs of the La Grande system were filled and the two river diversions into the La Grande completed, the mean annual flow of the La Grande was doubled from natural (Roy and Messier 1989). The large freshwater discharge of the La Grande, especially in the winter months, was spreading further than most imagined (Messier and others 1986). It was suspected by the Cree and the Inuit that the plume of the La Grande was changing sea-ice patterns, currents, and the distribution of sea mammals, and affecting geese through freshwater damage to eelgrass (*Zostera marina*) feeding beds in bays in the region north of the La Grande toward Hudson Bay. The signs of such widespread impacts were noticed in the day-to-day life of the Cree and Inuit but were nearly impossible to prove.

The prospect of a new hydro project scheduled for the Grande-Baleine (Great Whale) River in the 1990s, in addition to the existing projects in the Hudson–James Bay basin, and the reluctance of federal and provincial agencies to conduct a cumulative environmental impact assessment was of great concern to the people of the region. If the impacts of the James Bay project could be felt as far as Hudson Bay, what might be the combined and cumulative effects of dams in Manitoba, Ontario and the proposed Grande- Baleine development? These questions were being asked by many communities. However, they were especially important to the tiny Inuit community of Sanikiluaq located in the Belcher Islands just west of the Grande-Baleine and north of the La Grande.

Sanikiluaq took the lead for a regional environmental study, initiated in 1992 and completed in 1995. It involved 78 elders or active hunters from 28 Cree and Inuit communities around Hudson and James bays. This was a very unusual study: The research was designed and conducted by the indigenous peoples themselves and it was based on the traditional ecological knowledge of the Inuit and the Cree (McDonald and others 1997). Because the geographic scope of the project was so large, travel and communication with so many scattered communities required a large budget. The Canadian Arctic Resources Committee (CARC), a national NGO,became a partner in the project, raising money from a number of foundations and procuring in-kind support from regional native agencies and government departments.

The objective was to document what the communities said about the changes occurring in their environment, to combine these local observations into a regional whole, and to use this information as a baseline in the face of additional hydroelectric projects being contemplated. The information was collected through six regional meetings and recorded as Geographic Information Systems (GIS) maps and transcripts. A second round of regional meetings was held to fill information gaps and to verify results. Progress reports were used in workshops with government and university scientists and the final report, "Voices from the Bay," was compiled a year later (McDonald and others 1997).

In the meantime, the Grande-Baleine project (also called the James Bay II project) was indefinitely postponed in 1995, after completing its environmental assessment report in 1993. The political opposition by the indigenous groups and the nonparticipation of the Cree in the environmental assessment process was a factor. "Voices from the Bay" became a widely acclaimed model for traditional knowledge studies and showed that the knowledge of indigenous hunters and fishers was not merely local or static. Traditional knowledge from individuals and communities could be systematically combined to produce large regional pictures of change, based on indicators rarely monitored by science (Fenge 1997). Some of the local observations were followed up by scientists. For example, Sanikiluaq hunters reported winterkills of eider ducks (*Somateria mollissima*) associated with recent changes in currents and sea ice; Robertson and Gilchrist (1998) provided scientific cross-verification.

Development of Adaptive Comanagement Systems for Social–Ecological Resilience

The development of adaptive comanagement systems may involve the crafting of new institutions, but such systems may also emerge through organizational change within existing institutional arrangements (Olsson and others in press). In the literature, comanagement is often treated as formal arrangements between governments and local groups and often involves institution building (e.g., Jentoft 1985). An alternative view of comanagement sees it as a self-organizing process for problem solving (e.g., Buck and others 2001). Ruitenbeek and Cartier (2001) argue that comanagement is an emergent property of resource management systems, not an arrangement that can be legislated top-down, but one that self-organizes bottom-up.

Throughout our work, we have found that leadership plays a significant role in the self-organizing process. Leaders often initiate key processes that are required in ecosystem management (Pinkerton 1998; Westley 2002). Some might have special skills that may depend on a person's background and social status (Blaikie and others 1997) and may be viewed as key stewards (Berkes and Folke 2002). The ecosystem management vision and the ecosystem knowledge and understanding that stewards possess is of crucial importance for which trajectory is chosen in response to change (Olsson and Folke 2001; Folke and others 2003). Leadership is also critical in conflict resolution and more robust institutions develop mechanisms for solving conflicts when they arise (Ostrom 1990). In both cases presented here, leadership emerged within the communities and assisted the self-organizing process. Hence, individual actors serve as key players in institution building and organizational change in relation to ecosystem dynamics and facilitate horizontal and vertical linkages in the adaptive comanagement process.

Trust is a fundamental characteristic in social self-organizing processes toward ecosystem management. Trust lubricates collaboration (Pretty and Ward 2001). Lack of trust between people is a barrier to the emergence of collaborative arrangements (Baland and Platteau 1996) such as adaptive comanagement systems. All cases of successful comanagement involve often long periods of trust building (Kendrick 2003; Pretty and Ward 2001). In the James Bay case, trust building between the Cree and SOTRAC was crucial in addressing problems of the lower La Grande River. Documenting large-scale impact and changes in Hudson Bay required trust-building at a larger geographic scale between the Inuit and the Cree, two indigenous groups that did not always get along well historically.

Although adaptive comanagement must be seen as emerging from existing resource management systems (McCay 2002), we are of the view that conditions can be created to facilitate its emergence (Table 1). These conditions reflect the cross-scale dynamics of adaptive comanagement and involve the role of key individuals and trust- building throughout the process. They include support that enables local ecosystem management and concerns the flow of information and knowledge in this context.

Enabling Legislation That Creates Social Space for Ecosystem Management

To enable local people to be participants in ecosystem management rather than managed as subjects, governments should transfer power to local authorities and other local decision-makers (Ribot 2002). It can provide local users the "independence to make and enforce rules within a circumscribed scope of authority

Table 1. Essential features for self-organization and emergence of adaptive comanagement of ecosystems

- Enabling legislation that creates social space for ecosystem management
- Funds for responding to environmental change and for remedial action
- Ability for monitoring and responding to environmental feedbacks
- Information flow and social networks for ecosystem management
- Combining various sources of information for ecosystem management
- Sense-making for ecosystem management
- Arenas of collaborative learning for ecosystem management

for a specified geographical area" (Ostrom 1998). Such "framed creativity" (Folke and others 2003) seems to be of significance because the capacity of communities to self-govern their ecosystems in a sustainable manner cannot be assumed (Barrett and others 2001). Comanagement arrangements have created space for local people and associated organizations to initiate and participate in ecosystem management (Pinkerton 1989; Hanna 1998; Berkes and others 2001). For example, Chambers (1985) pointed out that a number of Tanzanian laws that were enacted for local level self-sufficiency later created the political space to support community-based conservation in protected areas.

In the James Bay case, JBNQA was legislated into federal and provincial law and this legislation formed the basis of governmental responsibility for environmental protection in the area, regarding environmental impacts on the lower La Grande. However, the JBNQA and related legislation provided little support for the conduct of the regional Hudson Bay study, except perhaps indirectly. The inability of the government to address regionwide cumulative impacts provided the political space for the indigenous communities to design and carry out their own research.

Two key institutional and organizational changes have helped the Lake Racken fishing associations to self-organize and develop, refine, and implement rules. The first was a new law (SFS 1981:583) that redefined the relevant management area for local fishing associations as the entire catchment area rather than just the water body. This widened the scope of management and enabled the development of an ecosystem approach concerned with the interaction of species and processes throughout the Lake Racken catchment. The second was a law (SFS 1994:1716) devolving management responsibility for fish and crayfish in inland lakes, rivers, and streams to local fishing associations. The transfer of power creates space and codified shared management responsibility of the catchment. Consequently, practices for fish and crayfish management used by the Lake Racken Fishing Association are embedded in institutions at different organizational levels, which constitute a nested set of institutions (Costanza and others 2001; Ostrom and others 2002).

Funds for Responding to Environmental Change and for Remedial Action

The development of an ecosystem approach is facilitated by financial support. The availability of such support may trigger self-organization. In the Swedish case, financial support was available throughout the process of adaptive comanagement development. For example, the state funded the liming project and the municipality funded the establishment of the fishing association's management area and property rights among members. Funding for remedial action to restore brown trout spawning grounds was provided by a private power company under the threat of legal action from the fishing association.

In the James Bay case, the JBMQA established a remedial works corporation (SOTRAC) which had funds available to hire consultants and to carry out environmental research to study the conditions of the lower La Grande River. The SOTRAC funds were established at the signing of the James Bay Agreement. The Cree (the Chisasibi Band Council and the Cree Trappers Association) had some of their own funding and were able to access SOTRAC funds as well. In the case of the regional study in Hudson Bay, fund raising by CARC was essential. Without foundation support through CARC, community research and consultations could not have been completed.

Monitoring and Responding to Environmental Feedback

Monitoring ecosystem processes and dynamics is essential in increasing the ability to respond to change and shape institutions and management practices in order to sustain desirable ecosystem states (Berkes and Folke 1998). A constructive approach is to involve local resource users in monitoring, which may enhance incentives to learn about local ecosystem dynamics and increase the probability of managing complex systems.

Local residents can provide early warnings of environmental change.

For example, in the Swedish case, a key individual detected acidification in the Lake Racken catchment before the government monitoring program started. Currently, members monitor the pH, alkalinity, calcium levels, metal concentrations, and several indicator species such as insects, mollusks, and fish. This has similarities to the case of Newfoundland cod fisheries, where coastal fishers registered changes in the ecosystem long before the collapse of the fishery happened (Finlayson and McCay 1998).

In the James Bay case, monitoring and responding to environmental feedback followed a complicated course, mainly because the hydro project produced novel and (to the Cree) unexpected impacts on the lower La Grande River. Hence, the Cree relied on scientific styles of monitoring (e.g., coring for ice thickness), rather than their own traditional monitoring (e.g., judging safety of ice by color and the sound of tapping stick). However, in the case of regional monitoring in Hudson Bay, the Cree and Inuit took the matter into their own hands and used their own knowledge of sea ice, currents, and animal and plant distributions to carry out the work.

Such monitoring and responding to feedback by local communities may help increase the understanding of ecosystem functioning and, possibly, avoid challenging critical thresholds in a diversity of ecosystems. Monitoring at several levels may provide a richer set of information of ecosystem dynamics and help create feedback loops for improved management.

Information Flow and Social Network Building for Ecosystem Management

Management of ecosystems is an information-intensive endeavor (Imperial 1999). Key stewards are important in establishing functional links within and between organizational levels and therefore facilitating the flow of information and knowledge from multiple sources to be applied in the local context of ecosystem management. Social networks develop for this purpose (Scheffer and others 2002). Through these social networks, local users can draw on external sources of information and knowledge (e.g., among scientists and practitioners). These stewards and their functional roles in ecosystem management are part of the social memory and capacity to deal with change (Folke and others 2003). Furthermore, Westley (2002) argue that the capacity to deal with the interactive dynamics of social and ecological systems requires the entire network of interacting individuals and organizations at different levels that create the right links, at the right time, around the right issues.

In the Canadian case, 35 communities formed a network for information sharing. This enabled a joint effort to tackle a region wide synthesis of location-specific traditional knowledge and local observations of environmental change. The key linkages were horizontal: community-to-community discussion facilitated by the leadership provided by three people from Sanikiluaq. Vertical linkages with regional tribal organizations (e.g., Cree Regional Authority) were secondary, and those with government agencies were merely informal. Consistent with indigenous values, individuals (rather than organizations) were key in trust-building and network-building.

In the Swedish case, horizontal linkages seem to be fairly well developed and utilized on a regular basis, but vertical links could be improved. When acidification was discovered in Lake Racken area, people of a neighboring watershed were consulted to help the Lake Racken community form a liming group. The Lake Racken fishing associations often share information during formal meetings at the Arvika fishing circle of 23 fishing associations or during informal meetings such as fishing competitions. Vertical links that connect the fishing association to other organizational levels like the municipality, county administration board, or the Swedish EPA are not as obvious. However, the inclusion of the fishing association in the APNC for managing the noble crayfish of whole nations provides a pathway to establish such links.

Combining Various Sources of Information for Ecosystem Management

In the Swedish case, external information is combined through social networks, members own experiences based on their occasional observations and systematic monitoring, published books or reports of scientific studies, surveys carried out by authorities at the municipality, county, or national levels, and media. Stewards can interpret scientific information and put it into management practices that other members of the local fishing association can mimic. Members of the Lake Racken Fishing Association possess knowledge of how ecosystem structures and processes at different temporal and spatial scales affect crayfish and trout populations and use this knowledge to develop practices for managing these processes in a catchment context.

The Canadian case has parallels to the Swedish one in the use of several kinds of information together, especially regarding the flow interruption problem during the filling of the LG 2 dam. Several kinds of external information was used: fish physiology expert knowledge on tolerance levels of Coregonus species in winter; results of modeling studies on saltwater intrusion into the lower La Grande River; and SOTRAC/SEBJ field studies on fish survival through the winter. This mix of information was considered and interpreted by the Cree and combined with the results of their own fishing in the following spring period. The ability of the Cree and the Inuit to tackle a much larger monitoring program in the 1990s, almost entirely on their own, probably represents the results of knowledge building and the development of self-confidence through successive experiences with hydro impacts through the 1970s and the 1980s.

With such knowledge, ecosystem management practices can be formed that treat target resources as inseparable components of a complex network of structures and functions at different spatial and temporal scales (Gadgil and others 1993; Berkes and Folke 1998; Berkes and others 2003). The key in both cases is that several sources of information and knowledge systems are combined in a local context.

Sense-Making for Ecosystem Management

Combining several sources of information and knowledge in an adaptive management process requires interpretation and sense-making (Weick 1995). Sense-making implies taking interpretations seriously, inventing and reinventing a meaningful order, and then acting upon it (Westley and others 2002). Strong values and vision are essential components in the sense-making process for management of complex system. Key stewards provide vision, skills, and leadership for team work in this process (Pinkerton 1998; Westley 2002). A clear and convincing vision comprehensive stories, good social links, and trust with fellow stakeholders may mobilize several interest groups and start a self-organizing process toward adaptive comanagement of ecosystem dynamics (Scheffer and others 2002).

The vision among key stewards in the Swedish case is the sustenance of a healthy Lake Racken with viable fish and crayfish populations, recognizing that the environment needs to be actively managed in a catchment context to fulfill this vision. In the Canadian case, sense-making is largely in the realm of indigenous elders. The Cree of Chisasibi did not passively observe the impacts of the hydro project, but learned from the impacts, and processed and disseminated their knowledge. The remarkable document, "Voices from the Bay" (McDonald and others 1997), is, in part, a product of holistic indigenous thinking. In part, it is the result of sense-making whereby the Cree observed, for example, that changes in the freshwater–saltwater balance not only affected fish distributions but also marine grasses, which, in turn, affected the geese feeding on them.

Arenas of Collaborative Learning for Ecosystem Management

Adaptive comanagement is about creating platforms or arenas, involving user groups and interest groups for knowledge sharing and collaborative learning about ecosystem management. For example, Blann and others (2003) emphasize the importance of bringing diverse interest groups together in temporary learning systems, or platforms for learning (Röling 1994), in the management of complex systems. Kendrick (2003) discusses the role of comanaging information and knowledge among interest groups with different worldviews, characterizing them as mutual learning systems. It involves not losing sight of larger objectives, trust, and a vision in the direction toward ecosystem management.

The collaboration between the Lake Racken Fishing Association and the other actors involved in the APNC policy initiative has initiated an arena for mutual problem solving in relation to crayfish conservation. The current APNC initiative can help strengthen the ecosystem approach when the development of the Lake Racken catchment is challenged by alternative visions.

The same seems to be true in the James Bay case, where several arenas of collaborative learning were created. The lower La Grande impacts of the 1970s and the 1980s involved collaborative learning with the Cree, SOTRAC, SEBJ, and university scientists. In the 1990s, we find that the arena of collaborative learning suddenly explodes geographically through networks of horizontal linkages. As results of the Hudson Bay study started to come in, a series of workshops brought together the Cree and Inuit experts with government and university experts, greatly expanding the impact of the findings and the scope of the collaborative learning network.

In this sense, it seems like the arenas of collaborative learning along with the social networks that have expanded both vertically and horizontally into the adaptive comanagement processes of Lake Racken and James Bay can help strengthening the ecosystem approach in competition with other mental models of societal development.

Conclusions

Proponents of the ecosystem approach argue that because knowledge about the complexity and interconnectedness of ecosystems is incomplete, management should be adaptive and include a means of learning about ecosystem dynamics from policy experiments

(Holling 1978; Dale and others 2000). It is further argued that the diversity of stakeholders should be part of the learning process of ecosystem management (Buck and others 2001; Walker and others 2002) and build knowledge and understanding of how to respond to environmental feedback (Berkes and Folke 1998). In addition, the social processes that enable ecosystem management need to be further investigated and understood. Therefore, the institutional and organizational landscape should be approached as carefully as the ecological in order to clarify the features that contribute to the resilience of social–ecological systems (Barrett and others 2001; Kinzig 2001; Berkes and others 2003).

As illustrated in this article, the social and ecological dynamics are combined in the adaptive comanagement process and learning how to respond to environmental feedback is essential in the process. We have proposed that such systems of governance have the potential to enhance the capacity to deal with uncertainty and change (Folke and others 2003).

In this article, we have initiated the search for essential features of the adaptive comanagement process. In Table 1, we list some social features that seem important in this context. Based on our case studies, we observe the following in relation to the self- organizing process toward adaptive comanagement of ecosystems:

- In both cases, there is a sequence of responses to environmental events that widen the scope of local management from a particular issue or resource to a broad set of issues related to ecosystems processes across scales.
- Management expands from individual actors, to group of actors, to multiple- actor processes.
- Organizational and institutional structures evolve as a response to deal with the broader set of environmental issues.
- Knowledge of ecosystem dynamics develops as a collaborative effort and becomes part of the organizational and institutional structures.
- Social networks develop that connect institutions and organizations across levels and scales. Social networks facilitate information flows, identify knowledge gaps, and create nodes of expertise of significance for ecosystem management.
- Knowledge for ecosystem management is mobilized through social networks and complements and refines local practice for ecosystem management.
- In the time series of events, the ability to deal with uncertainty and surprise is improved, which increases the capacity to deal with future change.

In adaptive comanagement, the capacity to deal with complex issues is widely dispersed across a set of loosely connected actors in social networks located at different levels of multiple centers or polycentric governance (Imperial 1999; McGinnis 2000). As problems solving develops in each of the cases, different clusters of players assume different decision-making roles. Such a dynamic structure implies flexible coordination of nodes so that subsets of the adaptive comanagement system can be envisioned as pulsing in active response to change. The cross-scale arrangements are particularly appropriate for solving problems of complex adaptive systems because there is experimentation and learning going on in each of the nodes. Such experimentation, combined with the networking of knowledge, creates a diversity of experience and ideas for solving new problems, stimulates innovation, and contributes to creating feedback loops at different scales. The information-intensive management system involves clusters with functional specialization (Imperial 1999) and functional groups of social memory (Folke and others 2003). Adaptive capacity can be generated.

This self-organizing process of adaptive comanagement development, facilitated by rules and incentives of higher levels, has the potential to make the social–ecological systems more robust to change. The resilience of social–ecological systems contributes to social capacity for learning about ecosystem dynamics by providing a buffer that protects the system from the failure of management actions that are based on incomplete understanding (Gunderson 2003). It allows managers to learn and to actively adapt ecosystem management policies and reduces the risk of entering unsustainable and undesirable development trajectories. The shared vision of the actors and the self- organizing process, supported and framed by enabling legislation and governmental institutions, have the potential to expand desirable stability domains of a region. It creates an "adaptive dance" between resilience and change with the potential to sustain complex social–ecological systems.

Acknowledgments

Funding for the work was provided by the Swedish Research Council FORMAS and the research school in ecological land use. We are grateful to our colleagues at Stockholm University and the Beijer Institute for inspiration. This study is part of the collaborative efforts of the Resilience Alliance.

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