Building capacity for resilience in social-ecological systems

Per Olsson

Department of Systems Ecology
Stockholm University
S-10691 Stockholm
Sweden

Stockholm 2003

Doctoral Dissertation 2003
Per Olsson

Natural Resource Management
Department of Systems Ecology
Stockholm University
S-10691 Stockholm
Sweden

ISBN 91-7265-695-6
Printed in Sweden by
Akademitryck AB, Edsbruk
Cover: A man and his grandson fishing
for crayfish in Lake Racken, Sweden.
Photo by Per Olsson

Abstract

This thesis analyzes social-ecological dynamics with the purpose to contribute to the understanding of adaptive capacity in social-ecological systems. It focuses on mechanisms for building social-ecological resilience in a world that is continuously changing. This involves the capacity of actors in such systems to cope with change and uncertainty without reducing the ability of complex ecosystems to generate goods and services essential for societal development. It explores the social aspects of ecosystem management, which includes adjustment of management practices and associated organizational and institutional structures and processes, guided by monitoring of feedback signals of environmental change.

The first paper analyzes how people in natural disturbance-prone geographical settings, who rely heavily on their local ecosystems for survival, have developed knowledge and risk-spreading strategies to avoid large-scale social and ecological crisis. The study reveals a range of social and ecological practices that deal with change and uncertainty by evoking small-scale disturbances, inhibiting a full-scale release, and nurturing sources for ecosystem renewal. Social structures and processes, such as property rights and rituals, maintain these practices during stable times.

Using case studies from Sweden and Canada, papers II, III and IV investigate the emergence of adaptive co-management of ecosystems. Paper II analyzes the development of a catchment approach to crayfish management by a local fishing association in Western Sweden as a response to environmental change. Local knowledge of ecosystem dynamics, associated management practices, institutions and their cross-scale relations are identified and analyzed. Paper III addresses the role of ecosystem knowledge in adaptive co-management and identifies essential conditions of this process in relation to social-ecological resilience. These include enabling legislation that creates social space for ecosystem management; funds for responding to environmental change and for remedial action; monitoring and responding to environmental feedback; information flow through social networks; combination of various sources of information and knowledge; vision, leadership and trust; sense-making for ecosystem management; and arenas for collaborative learning for ecosystem management. Paper IV analyzes the creation of an adaptive co-management system in a wetland landscape in southern Sweden. The results illustrate that a window of opportunity enabled ecosystem managers to transform a social-ecological system from an undesirable trajectory to a new one that developed into an adaptive co-management system founded on an ecosystem perspective.

The results of those analyzes illustrate that multiple-actor groups can self-organize, learn and actively adapt to and shape change. The development of ecosystem management in these cases took place through a sequence of responses to environmental events that created and widened the scope of local management from a particular issue or resource to a broad set of issues related to ecosystems processes across scales and from individual actors, to group of actors to multiple-actor processes. Social networks developed that connected institutions and organizations across levels and scales and facilitated information flows. Knowledge accumulation of ecosystem dynamics is central throughout the process of adaptive co-management development, and it seems to emerge as a collaborative effort to become part of the organizational and institutional structures. Knowledge for ecosystem management is mobilized through social networks and complements and continuously refines local

practice for ecosystem management. Key individuals play a fundamental role in the social-ecological dynamics of adaptive co-management development. Such stewards or leaders are able to promote institution building and organizational change in relation to ecosystem dynamics and facilitate horizontal and vertical linkages in adaptive co-management processes.

The results of this thesis support the argument that ecosystem management is neither local nor central in origin, but requires multi-level management and matching of social and ecological dynamics across scales. The findings indicate that the adaptive co-management approach have the potential to serve this need and build capacity for resilience in social-ecological systems. We conclude that such management may contribute to expanding desirable stability domains of social-ecological systems, making them more robust to change.

List of papers

This thesis is based on the following papers, referred to by their Roman numerals. All papers are reproduced with the kind permission of the copyright holders.

I.
Colding J, T Elmqvist, and P Olsson. 2003. Living with disturbance: Building resilience in social-ecological systems. In: Berkes, Colding, Folke (eds.) *Navigating Social-Ecological Systems: Building Resilience for Complexity and Change.* Cambridge University Press. (© Cambridge University Press 2003)

II.
Olsson P and C Folke. 2001. Local Ecological Knowledge and Institutional Dynamics for Ecosystem Management: A Study of Lake Racken Watershed, Sweden. *Ecosystems* 4: 85-104. (© 2001 Springer-Verlag)

III.
Olsson P, C Folke, and F Berkes (manuscript). Adaptive co-management for building social-ecological resilience. Submitted to Environmental Management

IV.
Olsson P, T Hahn, and C Folke (manuscript). Social-Ecological Transformations for Ecosystem Management: The Development of Adaptive Co-management of Wetland Landscapes in Southern Sweden. Submitted to Conservation Ecology.

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1. Introduction

The Second Session of the Preparatory Committee for the World Summit on Sustainable Development states that "Human activities are having increasing impact on the integrity of complex natural ecosystems that provide essential support for human well-being and economic activities… Managing this natural resource base is essential for protecting the land, water and living resources on which human life and development depends."

In a co-evolutionary process, human social and economic systems shape and are shaped by the ecological endowments of a region (van der Leeuw 2000, Kinzig 2001) and such processes are occurring at a variety of scales, from local to global. Therefore, a stream of scholars has recently suggested that the focus of sustainability science should be on linked "social-ecological systems" (Costanza et al. 1993, Gunderson et al. 1995, Berkes and Folke 1998, Kinzig 2001). This approach adds social aspects to ecosystem management[1]. It underscores the fact that humans are an integrated part of ecosystems. Berkes and Folke (1998) state that "social and ecological systems are in fact linked…the delineation between social and natural systems is artificial and arbitrary". A theoretical framework is starting to emerge for the analysis of such linked social-ecological systems (Berkes and Folke 1998, Gunderson and Holling 2002, Berkes et al. 2003).

1.1 Ecosystem dynamics and resilience

This theoretical framework for social-ecological systems recognizes the fact that ecosystems are complex adaptive systems[2] (Levin 1998) characterized by non-linear relations, threshold effects, historical dependency, and multiple possible outcomes (Scheffer et al. 2001). Ecosystem structures and processes are linked across spatial and temporal scales. Due to their complexity and the range of positive and negative feedback across scales, the predictability of these systems is limited (Gunderson 1999). This makes them a "moving target" for management (Holling 1993) and the challenge is to understand and adjust social structures and processes to match this complexity in order to maintain the capacity of ecosystems to generate goods and services essential for societal development.

Changes, or disturbances[3], are a natural part of the dynamics of ecosystem development (Appendix 1). For example, a fire can seem devastating for parts of a boreal forest from a human perspective, but the forest tends to recover to the status of a functioning forest system after disturbance. In other cases disturbance can cause ecosystems to shift to other states with a corresponding alteration of ecosystem functions (Appendix 1). Such phase shifts build on the notion that complex adaptive systems, such as ecosystems, tend to have multiple stable states or stability domains (Holling 1973). The ability of ecosystems to remain within a stability domain has been referred to as ecological or ecosystem resilience, defined as the magnitude of disturbance that can be absorbed or buffered before the ecosystem re-defines its structure by changing the variables and processes that control its functional characteristics[4] (Holling and Meffe 1996, Gunderson 2000, Berkes et al. 2003) (Appendix 1 Figure 3). The diversity of functional groups of species and their capacity to respond differently to disturbances contributes to ecosystem resilience (Peterson et al. 1998, Done et al. 1996).

Disturbances can be suppressed by humans in order to prevent their appearance. Suppressing natural disturbances, like floods or fires, is a common example that exacerbates their effects at a later stage. Since such events are part of ecosystem development and dynamics they tend to accumulate within the system and eventually erupt on a greater scale. Management that tries to prevent change, through rigid control systems that suppress disturbance and remove diversity, generally erodes resilience and, paradoxically, can lead to a shift from a desirable ecosystem state into an undesirable. Holling and Meffe (1996) and Gunderson et al. (1995) provide several examples of what they refer to as the pathology of command-and-control management of complex adaptive ecosystems and natural resources.

Ecosystems are not only dynamic but also hierarchically scaled. A recent term "Panarchy" has been proposed to capture the dynamics of ecosystem development across scales. It represents a nested set of adaptive renewal cycles (Appendix 1, Figure 2) that interact with one another across spatial and temporal scales (Gunderson and Holling 2002, Holling 2001) (Appendix 1, Figure 4). Sustainable use of ecosystem goods and services is unlikely without an improved understanding of such cross-scale ecosystem dynamics (Nyström and Folke 2001, Bengtsson et al. 2003) and the social mechanisms that foster ecosystem capacity.

1.2 Social-ecological resilience and adaptive capacity

Maintaining ecological resilience is strongly linked to and dependent on social mechanisms (Berkes et al. 1998). This implies that changes in key social mechanisms could affect the ecosystem state as much as changes in key structuring ecological variables. Hence, the loss of a key social mechanism like trust (e.g. Shannon 1998, Pretty and Ward 2001) could not only jeopardize collaborative learning processes (Baland and Platteau 1996) but also the ability to maintain a desirable ecosystem state (Paper IV). Therefore, a definition of resilience that incorporates social-ecological linkages has been developed (Carpenter et al. 2001, Berkes et al. 2003, and Walker and Holling in manus) and has the following characteristics:

- the amount of change a system can undergo and still retain essentially the same function, structure and identity (still be in the same state - within the same basin of attraction)
- the degree to which the system is capable of self-organization
- the degree to which the system expresses capacity for learning and adaptation.

A consequence of a loss of resilience and adaptive capacity is loss of opportunity and response options (Walker and Holling in manus). This in turn could increase the probability that the social-ecological system will move into undesirable trajectories. In a resilient social-ecological system, events such as disturbances can create opportunities for development and innovation. In a vulnerable social-ecological system even a small event may be devastating.

This puts the focus on the capacity of actors in a social-ecological system to cope with change without limiting future options (Berkes et al. 2003). In a social-ecological system with high *adaptive capacity*, human actors have the ability to sustain the combined system of humans and nature in a desirable state, along a desirable trajectory, in response to changing conditions and disturbance events (Carpenter et al. 2001). In short, adaptive capacity is the capacity to respond to and shape change (Folke et al. 2003). The social part of this capacity for ecosystem management can include the diversity of expertise and knowledge within organizations such as networks, which gather and store ecosystem knowledge and experience, create flexibility in institutions[5] and problem solving, and balance power among interest groups (Berkes et al. 2003). However, the social structures and processes that sustain the adaptive capacity of social-ecological systems in a world that is constantly changing need to be further investigated and understood.

Addressing how people and organizations involved in ecosystem management respond to periods of change or impending change, and how they reorganize following change and foster ecosystem capacity, is the most neglected and the least understood aspect of conventional resource management and science (Gunderson and Holling 2002, Berkes et al. 2003). In this respect I concur with several scholars that the institutional and organizational landscape should be approached as carefully as the ecological landscape, in order to elucidate what builds adaptive capacity and contributes to the resilience of social-ecological systems (Barrett et al. 2001, Kinzig 2001, Berkes et al. 2003, Paper III). Such research needs to focus on social mechanisms that address the reorganization phase of the adaptive renewal cycle of ecosystems and focus on how to maintain stability in the face of change. Several scholars from a wide variety of research fields have started to address this question, for example King 1995, Abel 1998, Scoones 1999, Danter 2000, McIntosh et al. 2000, Adger et al. 2001, Brown et al. 2002, and Westley 2002.

1.3 Adaptive co-management of social-ecological systems

Folke et al. (2003) identify and develop four critical factors in social-ecological systems that interact across temporal and spatial scales and that seem to be required for dealing with natural resource dynamics during periods of change and reorganization: learning to live with change and uncertainty, nurturing diversity for reorganization and renewal, combining different types of knowledge for learning, and creating opportunities for self-organization towards social-ecological sustainability. In this thesis I use the adaptive co-management approach[6] to explore these four factors and their interaction for building adaptive capacity and nurturing desirable social-ecological trajectories.

1.3.1 Learning to live with change and uncertainty

Proponents of the ecosystem approach argue that since 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 et al. 2000). This learning approach to ecosystem management is also the idea behind adaptive co-management. Adaptive co-management simultaneously allows for tests of different management policies and emphasizes learning as we use and manage resources. This includes monitoring and accumulating ecosystem knowledge along the way and constantly adjusting the rules that shape our behavior to match the change and uncertainty inherent in the social-ecological system. The adaptive co-management approach treats policies as hypotheses and management as experiments from which managers can learn, accepting uncertainty and expecting surprises (Holling 1978, Walters 1986, Gunderson et al. 1995).

Adaptive co-management recognizes the importance of environmental feedback learning in ecosystem management. The adjustment of management practices and associated organizational and institutional structures and processes are guided by monitoring of feedback signals of social-ecological change (Berkes and Folke 1998, Berkes et al. 2003, Paper I-IV). This allows for social learning[7] and building adaptive capacity. By responding to and managing feedback from ecosystems, instead of blocking them out, adaptive co-management has the potential to avoid the command-and-control pathology of conventional resource management (Gunderson et al. 1995).

Such management tends to erode ecosystem resilience and threaten the existence of many social and economic activities (Holling and Meffe 1996). It often fails to respond to signals of environmental change (Wilson 2002) and ignores the release and reorganization phases of the adaptive renewal cycle (Appendix 1 Figure 2); the backloop phases of ecosystem development (Berkes and Folke 2002). Berkes et al. (2003) argue that adaptive capacity is lost when management fails to address the backloop phases; when management tries to get rid of change and uncertainty instead of learning about ecosystem dynamics and nurturing resilience.

Gunderson (2003) argues that ecosystem resilience sustains the opportunity for social learning in a dynamic environment by providing a buffer that protects the system from the failure of management actions based upon insufficient understanding. It allows managers to learn and to actively adapt resource management policies also in the backloop of the adaptive renewal cycle (Paper I) thereby reducing the likelihood of moving into unsustainable and undesirable development trajectories.

1.3.2 Nurturing diversity for reorganization and renewal

Understanding ecosystem processes and how to manage them seems to be a progression of social-ecological co-evolution, and it involves learning and accumulation of ecosystem knowledge and understanding in a social memory[8] (Paper III). The knowledge system itself becomes part of the process of social learning about how to deal with ecosystem dynamics (Lee 1993). In this sense a collective learning process that builds experience with ecosystem change evolves as a part of social memory, and it embeds practices that nurture the dynamic capacity of ecosystems to generate essential ecosystem services, including the role of functional diversity in this context (Folke et al. 2003). Social memory is important to linking past experiences with present and future policies. Such social learning processes are linked to the ability of management to respond to environmental feedback and direct the coupled social-ecological system into sustainable trajectories (Berkes et al. 2003).

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). Over time, the ability to deal with uncertainty and surprise seems to be improved, which increases the capacity to deal with future change. Carpenter et al. (2001) describe the several decade long research process needed to develop an understanding of key variables that structure lakes and rangelands. In this context, Dale et al. (1998) point to the need for an "institutional memory" of large-scale ecosystem disturbances as a part of ecosystem management, in order to reduce the risk of management responses that are not in tune with ecosystem dynamics. Institutional memory is an accumulation of experiences concerning management practices and rules-in-use and is particularly important during periods of change and crisis. It provides the foundation for the modification of rules (Hilborn 1992). An adaptive co-management process can build memory. This memory provides the context for social responses to ecosystem change and thus increases the likelihood of flexible and adaptive responses, particularly during periods of crisis and reorganization. Adaptive co-management therefore draws on experience but allows for novelty and innovation. It provides a repertoire of general design principles that can be drawn on by resource users at multiple levels to aid in the crafting of new institutions to cope with changing situations (Ostrom et al. 2002).

1.3.3 Combining different types of knowledge for learning

Adaptive co-management relies on all forms of relevant information for increasing understanding for improved management of complex adaptive systems, like ecosystems, including different knowledge systems (Warren et al. 1995, McLain and Lee 1996) and their combination (Berkes and Jolly 2002, Gadgil et al. 2003, Paper II-IV). The evolution of many community-based management systems seems to reflect resource and ecosystem dynamics and these communities have by necessity developed knowledge and practices for living with change and uncertainty (Gadgil et al. 1993, Berkes and Folke 1998, Colding and Folke 2001, Berkes et al. 2003, Paper I). For example, Riedlinger and Berkes (2001) describe the people of Hudson Bay, Canada, who have knowledge about changes in slow variables in relation to climate and link this knowledge to the long history of close interaction with local and regional ecosystems. Traditional ecological knowledge[9] is an attribute of societies with historical continuity in resource use practice (Dei 1993, Williams and Baines 1993, Berkes 1999, Paper I, the Canadian example in Paper III) whereas local ecosystem knowledge[10] and practice is an attribute of more recently evolved resource management systems (Papers II and IV).

Proponents of ecosystem management emphasize the necessity of expanding from knowledge of structures to knowledge of functions that sustain social-ecological capacity to respond to ecosystem change and support ecosystem capacity to generate essential services for societal development (Dale et al. 2000, Folke et al. 2003, Papers II and III). Knowledge acquisition is an ongoing dynamic learning process; knowledge and associated management practices of local resource users and communities seldom exist in a vacuum but tend to evolve with working rules and organizational dynamics (Berkes and Folke 1998, Folke et al. 2003).

Scientific understanding of complex adaptive systems and their dynamics could be enriched by insights from local systems with an experience of ecosystem management (Folke et al. 2003) to expand the sources of information that guide decision-making (Ludwig and others 2001). Learning from local communities with long-term experience of environmental variability and uncertainty may yield insights for managing complex ecosystems for resilience (Paper I). This is one of the objectives of the Millennium Ecosystem Assessment project (Ayensu et al. 2000), which aims to strengthening capacity for successful ecosystem management.

Monitoring and responding to feedback by local resource users may help increase understanding of ecosystem function and possibly help avoid challenging critical thresholds in a diversity of ecosystems. For example, local users can provide early information about ecosystem change and complement scientific monitoring. In the Newfoundland cod fisheries, coastal fishers registered changes in the ecosystem long before the collapse of the fishery occurred. These signals of change were perceived neither by large-scale offshore fisheries nor governmental decision-makers (Finlayson and McCay 1998).

1.3.4 Creating opportunity for self-organization

The ability to self-organize is particularly important in adaptive co-management and is an essential element of adaptive capacity. An opportunity to self-organize can materialize after disturbance or crisis in the reorganization phase and may even result in alternative pathways or trajectories for social-ecological systems. Social memory seems to play an important role in the self-organization process and key individuals draw on social memories of other scales in the reorganization following change (Folke et al. 2003).

Certain institutional structures can impede and stifle self-organization processes including local initiatives and commitment that otherwise contribute to the diversity of ideas and solutions to environmental problems (Berkes 2002, Bawden 1994). On the other hand, multi-layered or polycentric governance structures[11] can nurture diversity for self-organization. Ostrom (1998) argues that simple, large-scale, centralized governance units do not, and cannot, have the variety of response capabilities that complex, polycentric, multi-layered governance systems can have. An advantage of polycentric arrangement in this context according to Imperial (1999a) is that it provides "institutionally rich environment [that] improves the prospects of resolving complex problems. It can encourage innovation and experimentation by allowing individuals and organizations to explore different ideas about solving problems". Such arrangements create a variety of feedback loops at different scales and contribute to scale matching of social ecological dynamics.

Polycentric governance could therefore be a way to match organizational and institutional structures with ecological dynamics at different spatial and temporal scales and address linkages between those scales (Holling and Meffe 1996, Folke et al. 1998, Berkes et al. 2003). Such scale-matching is crucial in ecosystem management. Lee (1993b) argues that "[if] human responsibility does not match the spatial, temporal, or functional scale of natural phenomena, unsustainable use of resources is likely, and it will persist until the mismatch of scales is cured". This has often been ignored in conventional management (Holling and Meffe 1996) since governmental bodies frequently assume that a centralized and large-scale institutional arrangement results in more effective natural resource management (Imperial 1999a). The inability to address the scale issue can lock social-ecological systems into trajectories that reduce resilience and thereby remove options for future generations (Holling and Meffe 1996, Berkes and Folke 1998). For example, the National Research Council (1999) argues that the past and current management structure of much of the world's large-scale marine fisheries may be undermining possibilities for future generations to use the resource.

1.4 Transformative capacity

As stated above, there are many examples of conventional management that have masked feedback signals from ecosystems. Such management systems also contain learning and adaptive capacity but it is based on economic and social feedback and tends to ignore environmental feedback. They become decoupled from the resource base (Gunderson et al. 1995). Due to the co-evolutionary relationship of social-ecological systems such mismanagement can cause the linked system to enter unsustainable and undesirable trajectories and ecosystem states (Holling and Meffe 1996) and result in social traps (Costanza 1987). This has been referred to as perverse learning (Ascher 2001), which reduces resilience and increases vulnerability of social-ecological systems (Gunderson and Holling 2002, Berkes et al. 2003).

The last of the four factors identified by Folke et al. (2003), "creating opportunities for self-organization towards social-ecological sustainability" is linked to another capacity identified as important for building social-ecological resilience. *Transformative capacity* is the focus of Paper IV. Transformative capacity is the ability of a social-ecological system to move to new or different configurations or create new stability domains; to re-define itself through acquisition of new variables or allowing them to emerge (Walker and Holling in manus). Such capacity is important since many management projects today requires restoration of degraded ecosystems and recondition of social structures and processes.

2. Objectives, methods, and summary of papers I-IV

2.1 General objectives

Papers I and II of this thesis build on the work of Berkes and Folke (1998) which addresses (1) how local social systems have developed management practices based on ecological knowledge for dealing with the dynamics of ecosystem(s) in which they are located and (2) social mechanisms behind these management practices. The work of Berkes and Folke sets out to improve ecosystem management by compiling, analyzing, and learning from a range of local management systems and their dynamics. It advocates the "mobilization of *a wider range* of considerations and sources of information than those used in conventional resource management" (Berkes and Folke 1998).

Papers I and II contributed to their next volume Berkes et al. (2003) which explores (1) how human societies deal with change in social-ecological systems and (2) how capacity can be built to adapt to change and, in turn, to shape change for sustainability. Papers III and IV draw on this work (Berkes et al. 2003), investigate adaptive capacity and contribute to the theoretical framework for studying social-ecological dynamics.

In this thesis I analyze social-ecological dynamics with the purpose to start to unravel what build capacity for resilience in social-ecological systems. More specifically, I focus on local interactions between humans and their natural environment in order to identify social mechanisms for dealing with change and uncertainty in ecosystem management. Figure 1 describes a starting point for this analysis, the interface between social and ecological systems. The focus is on knowledge of ecosystem dynamics and how it is used in management practices to tighten feedback loops. I also address how these practices are embedded in institutional and organizational structures and processes in relation to resilience in social-ecological systems.

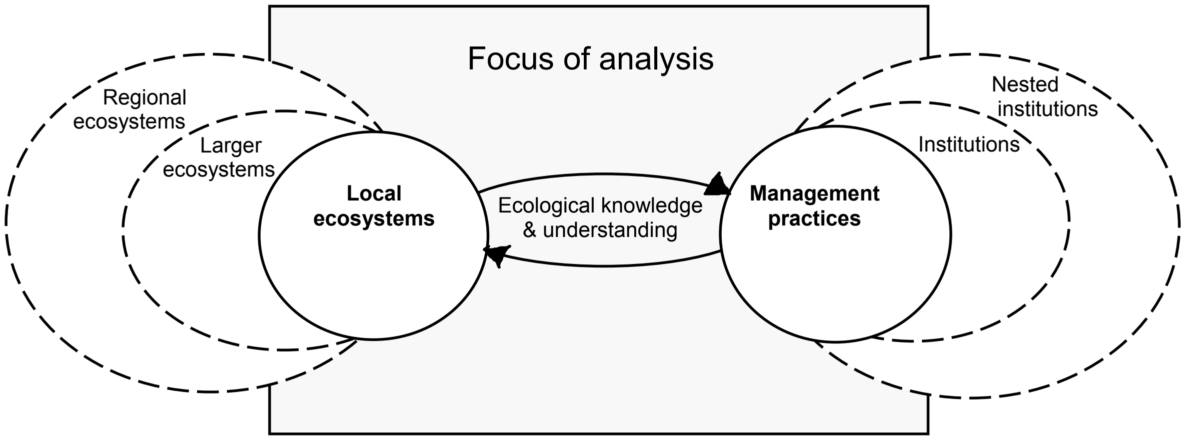

Figure 1. A conceptual framework for the analysis of linked social-ecological systems. Local ecosystems are nested within other ecosystems. Management practices are embedded in institutions, and these can be nested within other sets of institutions. Ecological knowledge is a key link between social and ecological system and help us monitor, interpret, and respond to signals of change and create functioning feedback loops in social-ecological systems (modified from Berkes and Folke 2002).

2.2 Methods

In this thesis I contribute to the development of an understanding of adaptive capacity for dealing with change. It provides insights on how to further study linked social-ecological systems. The cases in this thesis are examples of local interactions of actors and their natural environment and were selected for studying social mechanisms behind ecosystem management. The cases of Paper I were selected because they were examples of risk spreading management strategies. From this understanding, hypotheses can be developed which can be empirically tested and generate generalizations of social-ecological systems' dynamics.

Paper I is based on case studies from the literature and field observations by T. Elmqvist. The field studies for Papers II and III were conducted by me except for the Canadian case study in Paper III (conducted by F. Berkes). In Paper IV, I did most of the fieldwork.

The research design included a combination of qualitative and quantitative methods (Patton 1980; McCracken 1988; Shaffir and Stebbins 1991; Bernard 1994; Kvale 1996) with the biased towards the former. Qualitative methods and analysis provide a means to generate the detail and depth needed to understand social-ecological dynamics in situations that have not previously been investigated. Communities are treated as heterogeneous (Brown 2002, Barrett et al. 2001) and methods are used to tease out key individuals (Folke et al. 2003) and their knowledge and skills, worldview, and strategies for achieving goals (including dialogue, trust-building, sense-making, collaborative learning and conflict resolution). It also includes in what way the social-ecological system deal with change and uncertainty as well as identification of institutional and organizational structures and processes.

2.3 Specific objectives and summary of results

2.3.1 Relationship among Papers I-IV

Although much of the empirical work upon which this thesis is based was produced in parallel, the papers are structured to develop and test theories of adaptive co-management in a logical order. The four papers alternate between literature and case study reviews aimed at identifying and developing the theory and hypotheses (Papers I and III) and in-depth case studies where the theories and hypotheses are used to design the studies and guide analyses. The purpose is to generate a deeper understanding of social mechanisms for dealing with ecosystem change (Papers II and IV).

The results from Paper I helped develop an understanding of how communities may relate change and more specifically, adaptations and risk spreading strategies to deal with disturbance and crisis. Its results were tested in Paper II, a study of social mechanisms for dealing with ecosystem change in Lake Racken, Sweden. The results from Paper II are used in Paper III to develop the concept of adaptive co-management of ecosystems and identify conditions necessary to achieve such management. The definitions of these conditions are then tested and further developed in Paper IV.

Paper I contributed to the development of the four factors required for dealing with natural resource dynamics during periods of change and reorganization identified by Folke et al. (2003). It contributes especially to the first and second factor: *learning to live with change and uncertainty* and *nurturing diversity for reorganization and renewal*. In Paper II these factors are used for analyzing the interactions between a local fishing association and a lake ecosystem in western Sweden. In Paper III, the four factors are further expanded to seven conditions necessary for initiating adaptive co-management processes that builds adaptive capacity for dealing with change. Paper IV uses these conditions in the analysis of social-ecological dynamics in southern Sweden and provides further insights on the components of transformative capacity and changing management structures and processes toward adaptive co-management of ecosystems.

Paper	Method	Objective	Result
I	Case studies/ theory development	Description of ecosystem management strategies	Identification of management strategies to sustain ecosystem goods and services during/after disturbance and crisis
II	In-depth case study/ theory testing	In-depth analysis of management practices defined in Paper I	Detailed description of actors, knowledge and management practices in one local fishing association--test of theory developed in Paper I
III	Case studies/ theory development	Analysis of the dynamics of adaptive co-management	Identification of conditions necessary to achieve the management structures described in Papers I and II
IV	In-depth case study/	In-depth analysis of the dynamics of	Identification of social structures necessary to arrive at the conditions

	theory testing	adaptive co-management	identified in Paper III--test and further development of theory developed in Paper III

2.3.2 Paper I

Paper I identifies ecological and social strategies in local communities for responding to and coping with large-scale infrequent disturbances, and analyzes these strategies in the framework of the adaptive renewal cycle (Appendix 1). It investigates how these communities build social-ecological resilience in the face of rapid change, reflected in practices for managing resources and ecosystems. We review the case study literature from local communities in Asia, Africa, and the Pacific. The Asian and African case studies material was based on existing literature, while the Pacific case study was based on empirical results generated by one of the authors (T. Elmqvist). These communities, situated in disturbance-prone geographical settings, rely heavily on the sustainable management of their local ecosystems for survival and have developed a number of risk-spreading strategies to avoid large-scale social ecological crisis. We found a range of social and ecological practices that deal with disturbance and address the release and reorganization phases of the adaptive renewal cycle (Appendix 1 Figure 2). Such practices include evoking small-scale disturbances, inhibiting a full-scale release, and nurturing sources for ecosystem renewal.

For example, the advanced polyculture systems developed by communities of Samoa are discussed in relation to recurrent cyclones. These traditional agricultural systems entail cultivating annual crops mixed with a large number of shrub and tree species. Besides securing a diverse food supply these systems provide a range of goods and services including erosion control, soil improvement, medicines, ornaments, and rubber (see Clarke and Thaman 1993 for more details). Cyclones are unpredictable events in both a temporal and spatial sense and may severely reduce agricultural production at variable intervals. Crop species vary in terms of their ability to withstand and recover from cyclones. In general, cash crops are damaged more than subsistence crops, which mean that in the absence of outside subsidies, farmers that invest exclusively in cash crop monoculture take very high risks. The idea that a diverse set of crop species and cultivars may reduce the risk of a total loss of food supply in areas where tropical cyclones are recurrent was supported by interviews with farmers.

The management practices used by these communities are embedded in institutional and organizational structures. For example, permanent habitat protection in the form of "sacred groves" is commonly found among local resource users in various parts of the world. Strong religious beliefs and social conventions often enforce such protection. Ecosystem structures like sacred groves may play a critical role as sources for restoring degraded ecosystems, as well as providing habitats for species important in the re-colonization of disturbed ecosystems, such as pollinators and seed dispersers. Keystone species may also be associated with sacred groves in India, such as those of the genus *Ficus* and *Quercus* (Ramkrishnan, 1998). Hence, the protection of such species may be highly functional for the maintenance of biological diversity and for building resilience in a landscape.

We also show that several communities induce disturbance as part of their management strategies. Such practices can also be embedded in institutional structures like the ritual of "fire bathing" among the Aravalli hills villagers in India whereby they set fire to forest lands to please a local hill god (Pandey, 1998). This practice helps recycle soil nutrients and enhance the growth of grass. Creating small-scale disturbances in the landscape can also be important for reducing the effects of large-scale natural disturbances. For example, controlled burning of grass and deadwood reduces the spread of accidental, large-scale fires by preventing the slow buildup of fuel (Gottesfeld Johnson, 1994).

2.3.3 Paper II

Paper II describes how members of a local fishing association, in a rural community of western Sweden, are managing a population of noble crayfish (*Astacus astacus*) in the face of social and ecological change. We investigate the local knowledge of ecosystem dynamics among members of the Lake Racken fishing association, if it exists, what it consists of, and how it is reflected in management practices and associated institutions. Moreover, we analyze the distribution of knowledge among local users, as well as the development of the fishing association in relation to environmental change.

The analysis in Paper II reveals that there is extensive local knowledge and understanding regarding biotic and abiotic factors affecting individual crayfish and extending through the watershed scale. This includes species and biological knowledge as well as knowledge of ecological processes and functions and how they are linked. More specifically, we found ecological knowledge among local users ranging from the behavior of the crayfish itself, to its population, its interaction with other organisms in the food web, and to characteristics of its habitat, as well as knowledge of drainage basin processes that affect the dynamics of the crayfish ecosystem. We found that local ecological knowledge is generated and reshaped through a combination of local monitoring, trial-and-error processes, imitation, scientific information, and the practices of governmental authorities.

The local fishing association is part of a polycentric governance structure for managing fish and crayfish of Swedish inland lakes and streams. The fishing association has control over part of the decision-making, which makes it possible to use local knowledge of ecosystem dynamics for forming rules. Local management practices observed in the area range from individual practices, to community practices, to larger institutional frameworks and are embedded in institutions at different organizational and governmental levels. The knowledge, management practices and associated institutions are part of a dynamic process of ecosystem management to enhance the crayfish population of Lake Racken.

The study also reveals that key stewards in the local community play significant roles in social-ecological dynamics. Some are more knowledgeable than others and are considered as experts by their peers. They play key roles in information flow. One steward played an important part in mobilizing an organized effort to deal with the acidification threat in the area and another in applying an ecosystem approach to crayfish management. The crisis of acidification of tributaries of the watershed triggered a self-organizing process that led to the formation of a local liming group. Further concern for of the crayfish population developed the liming group into a fishing association. Threats like acidification, overexploitation of crayfish, and crayfish disease, initiated a learning process and institutional development at the local level. This involved testing different rules and tuning management to the dynamics of Lake Racken catchment.

The fishing association's efforts have not, at least not yet, resulted in an immediate, dramatic recovery of the noble crayfish population. The noble crayfish population has slowly recovered but is still far from the levels experienced in the 1950's and 60's and recovery is very uneven across the lake. There are those that have opposed the current direction of crayfish management in Lake Racken, and have argued for the introduction of alternative methods to enhance the crayfish population such as building hatcheries or stocking the lake with the American crayfish (*Pacifastacus leniusculus*). These alternative crayfish management pathways would most likely decrease incentives for responding to environmental feedback and erode the current ecosystem approach and the associated knowledge of ecosystem dynamics. Such alternative pathways may easily alienate local inhabitants from the work of ecosystems on which social and economic development depends.

2.3.4 Paper III

Paper III analyzes how the dynamic process of adaptive co-management may help build resilience in social-ecological systems, and more generally support ecosystem management. We also address knowledge in relation to ecosystems as seen as complex adaptive systems faced with uncertainty and surprise. We analyze the development of adaptive co-management systems in Sweden and Canada and define conditions that can be created to achieve such management.

The results of Paper III underscore the necessity of expanding from knowledge of structures (as described in Papers I and II) to knowledge of functions that sustain the social-ecological capacity to respond to ecosystem change. This includes knowledge that supports the capacity of ecosystems to sustain species, resources or ecosystem services crucial for societal development. Knowledge acquisition is an ongoing dynamic learning process; 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. 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 and social networks.

Adaptive co-management systems are characterized by collaboration among a diverse set of stakeholders operating at different levels, often in networks, from local users, to municipalities, to regional, national and supranational organizations. We identified essential conditions for creating adaptive co-management and building the resilience of social-ecological systems. These include:

- *Vision, leadership and trust*
- *Enabling legislation that creates social space for ecosystem management*
- *Funds for responding to environmental change and for remedial action*
- *Monitoring and responding to environmental feedback*
- *Information flow through social networks*
- *The combination of various sources of information and knowledge*
- *Sense-making for ecosystem management*
- *Arenas of collaborative learning for ecosystem management*

We show how local groups self-organize, learn and actively adapt to and shape change. In both cases the development of adaptive co-management systems 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 ecosystems processes across scales and from individual actors, to group of actors to multiple-actor processes. Social networks developed that connected institutions and organizations across levels and scales and facilitated information flows.

Social and ecological dynamics are combined in the adaptive co-management process and learning how to respond to environmental feedback is essential. The results suggest that the institutional and organizational landscape should be approached as carefully as the ecological in order to strengthening capacity and resilience and secure a supply of ecosystem goods and services.

2.3.5 Paper IV

Paper IV attempts to unravel the web of social processes behind the adoption of a flexible and collaborative management of the wetland ecosystems of the lower Helgeå River catchment and the establishment of Ecomuseum Kristianstads Vattenrike (EKV) as a municipality organization. Further, we analyze how these processes relate to ecosystem management, especially how social transformations can help ecosystem managers move away from unsustainable and undesirable trajectories to new ones with the capacity to strengthen and enhance management of desired ecosystem states and associated values in Kristianstads Vattenrike (KV).

EKV is a flexible and dynamic network organization which promotes and facilitates ecosystem management within KV that (1) treats humans as part of ecosystems, (2) includes social, economic and ecological dimensions, and (3) builds on collaborative processes that include international associations, national, regional and local authorities, non-profit associations and land owners.

We found that several individuals of the area, representing different organizations, observed a continuing decline in natural and cultural values despite the fact that the wetlands of the lower Helgeå River had become a Ramsar Convention Site. In particular they observed declining bird populations, eutrophication and overgrowth of lakes, and a decrease in the use of wet grasslands for haymaking and grazing. A perception of a crisis developed.

One of these individuals played a significant role in developing and using strategies for creating and shaping the organizational change. He started a dialogue with other concerned individuals and groups and initiated a social network as a response to deal with ecosystem change. He compiled existing ecosystem knowledge and experience that existed within the network and linked people and ongoing projects in the area. He also provided overall goals and vision in a holistic approach to wetland management and used a window of opportunity to convince decision-makers of the need for a new organization and improved management of the wetlands. This steward coined the term *Kristianstad Vattenrike* (the rich wetlands of Kristianstad) and developed and realized the idea of EKV of which he is also the director.

EKV demonstrates an ability to respond to environmental feedback and to develop new knowledge and understanding about ecosystem management needs. Although initial work focused primarily on wet grasslands, EKV has widened the scope of management and initiated new projects to address a broader set of issues related to ecosystems processes across scales. These projects are based on collaborative processes including international organizations, national, regional and local authorities, non-profit associations and landowners. EKV has thus established essential conditions for adaptive co-management of wetland landscapes, which in turn can create functioning feedback loops at different scales.

As EKV's focus expands, social networks evolve that connect institutions and organizations across levels and scales and facilitate information flows. The steward played a key role in these processes by building trust, compiling and generating ecosystem knowledge, defining an area for management, developing goals and vision for ecosystem management, mobilizing broad support for change, and initiating collaborative learning involving stakeholders at different levels in society. The initiative of the key steward prevented the wet grassland ecosystems from entering undesirable trajectories that would have resulted in loss of ecosystem goods and services. We conclude that this social-ecological transformation and the adaptive co-management approach that was initiated have the potential to expand the desirable stability domains of the wetland and make the social-ecological system more robust to change.

3. Discussion

Change and uncertainty is inherent in complex adaptive systems, which makes it difficult to plan ecosystem management in a rational fashion. Due to the variety of environmental and social contexts that exist there is no "one form that fits all" (Berkes et al. 2003). Therefore, set prescriptions and cookbook approaches to ecosystem management superimposed on a particular place, situation or context should be avoided. One of the key lessons distilled from summarizing 15 years of research on institutions for common-pool resources is that "no particular institutional design can ensure successful management of all common-pool resources" (Stern et al. 2002). In this thesis, I claim that the same is true for organizational and institutional designs for ecosystem management. Based on the case studies of this thesis I suggest an adaptive collaborative approach to ecosystem management as a way to adjust and fit such designs to context specific problems and needs.

The adaptive co-management approach could be used to test different ecosystem management strategies in a continuous process of learning-by-doing. It is a way of tracking sustainable trajectories for social-ecological systems and building adaptive capacity along the way (Paper III). In this process the generation of ecosystem knowledge is integrated with management practices and evolves with the institutional and organizational aspects of management. In Papers II and III we specifically investigate the content or type of knowledge within ecosystem management that is needed for creating functioning feedback loops in social-ecological systems. This includes species and biological knowledge as well as knowledge of ecosystem processes and functions and how they are linked across scales. With such knowledge, ecosystem management practices can be developed that treat target resources as inseparable components of a complex network of structures and functions at different spatial and temporal scales (Berkes and Folke 1998, Berkes et al. 2003). In adaptive co-management systems members of local communities can provide knowledge and insights about ecosystem dynamics of significance for monitoring, interpreting, and responding to change and hence, for creating functioning feedback loops in social-ecological systems.

Adaptive co-management for matching scales

For some ecosystem management purposes local community action can be effective, but other circumstances require coordinated policies at the regional, national, or international levels (McGinnis 2000). For example, the initiative to monitor the water bodies in the Lake Racken watershed, the collective action and formation of a liming group, and the institutional space and funding to lime the lake, provided by higher levels, were all important for dealing with ecosystem changes in the area. However, the local community response to acidification in Lake Racken is not a long-term solution because it cannot address the root cause of the problem; air borne pollution from central Europe. In addition to the local strategies, international negotiation that involved the Swedish government was needed to address the wider issue (Paper II).

This thesis strengthens the argument that ecosystem management requires a multi-level approach to match social and ecological structures and processes operating at different spatial and temporal scales and address cross-scale linkages. Ostrom (1998) has suggested that polycentric, multi-layered systems of governance that are efficiently linked across scales increase the complexity of those systems and therefore the variety of possible responses to change. I argue in this thesis that the self-organizing process of adaptive co-management development in Papers II-IV, facilitated by rules and incentives of higher levels, has the potential to make the social-ecological system more robust to change. From a resilience perspective it seems to be beneficial if the capacity to deal with complex issues is widely dispersed across a set of actors located at different levels of multiple centers or polycentric governance (Imperial 1999b, McGinnis 2000). As problems solving develops in each of the cases, different clusters of players can assume different decision-making roles. Such a dynamic structure implies flexible coordination of nodes so that subsets of the adaptive co-management system can be envisioned as pulsing in active response to change (Paper III). 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. It seems like such experimentation, combined with the networking of knowledge, may create a diversity of experience and ideas for solving new problems, stimulate innovation and contribute to creating feedback loops at different scales.

Management initiatives do not always stem from resource users of a local community (as in Paper I) or community-based resource initiatives as described in Berkes (1989). For example in Paper III, a Norwegian/Swedish Policy Initiative was initiated by a fishery authority and operated by the Rural Economic and Agricultural Association (*hushållningssällskapet*) of Gothenburg and Bohus County; the Ecomuseum Kristianstad Vattenrike was initiated by the director of the Kristianstad County Museum and is operated by the Municipality of Kristianstad (Paper IV). Such social arrangement is referred to as a policy community which is “a diverse network of public and private organizations generally associated with the formation and implementations of policy in a given resource area...Policy communities are interactive networks of alliances around common interests” (Shannon 1998). The policy communities that emerged for the Norwegian/Swedish Policy Initiative (Paper III), James Bay in Canada (Paper III), and Kristianstad Vattenrike (Paper IV) are framed in local ecological contexts; recognize site specific environmental and social conditions and link local, regional, and national levels. The policy community has no formal power sharing but rather operates within an existing institutional framework in polycentric governance structures, which implies that there are no formal rules that forces actors to collaborate. However, it seems like institutional arrangements such as formal agreements between parties emerge from the collaborative process. It provides an example of open institutions (Shannon and Antypas 1997), with the potential to provide flexibility and build adaptive capacity through social learning (Folke et al. 2003, Paper IV).

This supports the view of a need of finding a balance between local and central governance in ecosystem management and highlights the significance of cross-scale interactions. It stresses the role of central authorities in creating conditions for facilitating adaptive co-management processes of ecosystems emerging from a local context through self-organizing processes (Paper III). Instead of ready-to-use plans for ecosystem management superimposed on local contexts, the role of central authorities could be to form legislation to enable self-organization processes, provide funding, and create arenas for collaborative learning in policy communities. These measures, I argue, are important for building adaptive capacity for resilience in social-ecological systems.

Key individuals for building adaptive capacity

The analysis of social-ecological dynamics in Papers II-IV shows the fundamental role of key individuals in the development of ecosystem management. The ecosystem knowledge and understanding that stewards possess is of crucial importance for determining which trajectory is chosen in response to change (Paper II, Folke et al. 2003). Leaders provide worldviews and visions of ecosystem management and sustainable development. For example, both the biology teacher in Lake Racken fishing association (Paper II) and the director of Ecomuseum Kristianstads Vattenrike (Paper IV) provide a vision in form of a holistic approach to the management of natural resources and ecosystems. Also of importance is their ability to manage existing knowledge within social networks for ecosystem management and further develop those networks (Paper IV). Key stewards establish functional links within and between organizational levels in times of change and facilitate the flow of information and knowledge applied in the local ecosystem management context. Social networks develop for this purpose (Scheffer et al. 2002). Through these social networks local users can draw on external sources of information and knowledge, such as scientists and practitioners and make it accessible in a local context. Throughout the process they play important roles in sense-making, synthesizing a variety of information into a coherent collective narrative (Waltner-Toews et al. 2003).

Key individuals can initiate key processes required in ecosystem management (Pinkerton 1998, Westley 2002). Such stewards or leaders are able to promote institution building and organizational change in relation to ecosystem dynamics and facilitate horizontal and vertical linkages in the adaptive co-management process (Folke et al. 2003, Papers II-IV). In the case of Kristianstad Vattenrike, the work of the key steward to link people and activities was part of the strategy to create social networks that draw on several sources or knowledge, solve complex problems and stimulate engagement in adaptive co-management of the wetland landscape. The proposals and the trust building process were important for mobilizing people in these networks and creating vertical and horizontal linkages. Westley (2002) argues 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. Social networks are therefore fundamental for ecosystem management and for dealing with uncertainty and change (Shannon 1998, Wilson 2002).

Trust is a fundamental characteristic in social self-organizing processes for ecosystem management (e.g. Brown et al. 2002). Trust lubricates collaboration (Pretty and Ward 2001). A lack of trust between people is a barrier to the emergence of collaborative arrangements (Baland and Platteau 1996) such as adaptive co-management systems. All cases of successful co-management involve long periods of trust building (Kendrick 2003, Pretty and Ward 2001). The Kristianstads case (Paper IV) shows the role of a key individual for continuous trust building among stakeholders. In the Canadian case described in Paper III, 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 historically have had trouble collaborating.

Social structures and processes can build social memory of ecosystem management, a memory that seems to be of significance for mobilizing adaptive capacity in times of change. In Kristianstads Vattenrike (Paper IV) key individuals can draw on the social memory of the network to quickly respond to social-ecological change. The Lake Racken fishing association in Paper II developed a social network to organize collective action as a response to acidification. This started to generate a social memory for crayfish management in a catchment context, implemented in management practices and then stored. 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. The social memory has the potential to maintain social and ecological structures and functions in times of stability and gradual change and thereby build adaptive capacity for social-ecological resilience and renewal in times of rapid change (Berkes and Folke 1998). Key individuals are important for accessing and sustaining this memory.

Transformative capacity

Paper IV addresses transformative capacity as an important characteristic in social-ecological systems and adaptive co-management processes. As stated in the introduction, transformative capacity can be understood as the capacity to initiate social transformation that moves away from unsustainable and undesirable trajectories, towards new social-ecological trajectories that strengthen and enhance management of desired ecosystem states and associated values. In Kristianstads Vattenrike, the entire ecological management system was transformed into a new configuration, a new social-ecological stability domain (Paper IV). The contact between the initiator of EKV and a local top politician provided a cross-scale link at a critical time that led to the adoption of an adaptive co-management approach to wetland ecosystems by the Municipality of Kristianstad. The worldview of a key actor was incorporated in the Municipality organization to guide their work and is an example of a “revolt” connection between different levels identified as crucial for building adaptive capacity and resilience in social-ecological systems (Appendix 1

Figure 4, Gunderson and Holling 2002, Berkes et al. 2003). The event helped widen the social-ecological stability domain for ecosystem management.

4. Conclusions and Challenges

As stated in the introduction, a major challenge is to increase understanding of social structures and processes that maintain and strengthen the ability of ecosystems to generate essential goods and services in the face of change. In this thesis I have analyzed social-ecological dynamics and generated some insights on social mechanisms that seem to build adaptive capacity for resilience in social-ecological systems. This understanding, however, is still in its infancy and coordinated efforts by the scientific community are needed to further address the subject. There are two promising efforts in this direction, of which my work is a part. The Resilience Alliance (www.resalliance.org), an international consortium of institutions that seeks an integrative approach to building adaptive capacity for sustainable futures; and Millennium Ecosystem Assessment (www.millenniumassessment.org), a 4-year international scientific assessment aimed at strengthening the capacity to manage ecosystems sustainably for human well-being. Based on these efforts and my thesis I provide some major research questions that need further attention.

As highlighted in this thesis, part of adaptive capacity is the ability to support flexible organizational and institutional designs for managing ecosystem dynamics. This thesis identifies three social mechanisms for flexibility; knowledge of ecosystems and their processes, key individuals, and social networks. Due to the scope of knowledge required for ecosystem management and the need for constant revision of such knowledge, an essential question is how to coordinate knowledge dispersed over a range of actors at different levels in society at critical times for responding to social-ecological change.

Key individuals play essential roles in several aspects of the development of adaptive co-management systems, including facilitating information flow and coordinating knowledge for dealing with change and uncertainty, facilitating collaborative learning, building trust and resolving conflict. Key individuals provide leadership and visions for choosing sustainable and desirable social-ecological trajectories in the face of change. They are needed to access and develop social memory and initiate self-organizing processes. Research should address the dynamic relationship between key individuals, social memory and resilience. Further investigation of key individuals and functional groups in social-ecological systems in relation to adaptive capacity, cross-scale interactions and enhancement of resilience is also needed.

Social networks play a crucial role in this respect. They operate with a range of actors at different levels of society and create nodes of expertise and a diversity of experiences and ideas for solving new problems. Social networks in polycentric governance structures should have the potential to create feedback loops for ecosystem management at different scales. Furthermore, social networks can serve as storage of social memory for ecosystem management, a memory that can be revived and revitalized in the reorganization following change. There is a need to further investigate the role of social networks and their cross-scale linkages in creating flexibility and resilience and in providing response options in times of social-ecological change. We also need to understand in what ways such cross-scale dynamics can widen desirable social-ecological stability domains and make systems more robust to change.

Research needs to continue to tease out elements of social-ecological transformations towards management designs that build adaptive capacity for resilience in social-ecological systems. Such investigations should involve the role of key individuals as policy entrepreneurs and in building transformative capacity to shape change and creating new and desirable configurations for social-ecological systems as reflected in the analyses of adaptive co-management systems. It should also involve the role of social networks and how they connect individuals, organizations and institutions. It may be that resilience resides in social networks which would imply that social-ecological systems with well developed networks would be less vulnerable to loss of key individuals.

A major policy implication of this thesis is that top down blue-prints for ecosystem management are not very likely to be successful if the goal is to build resilience in social-ecological systems. Instead policy should stimulate and frame self-organizing processes and social mechanisms among resources users for dealing with change and uncertainty, such as those unraveled in this thesis.

Acknowledgment

First of all I would like to thank my wife Amy for her love, inspiration, patience and support--for enriching my life and making it all worthwhile. Sofia, my daughter, just little but give me so much joy.

To Carl Folke, my advisor, co-author but most of all, my dear friend of big heart and generous mind. The opportunity to work with Professor Folke gave me the motivation and courage to continue my research, although I failed biology in high school! I am looking forward to many more great moments within and outside the workplace.in the future.

I would like to thank all my colleagues at the Department of Systems Ecology for helping me enjoy all the good times and supporting me when things seemed bleakest.
Special thanks to:
Fredrik Moberg, Johan Colding, Jakob Lundberg, Christina Schaffer and Magnus Nyström for being great friends whom I gotten to know on many levels. Magnus also for not letting me forget where I come from.
My co-authors Thomas Elmqvist and Thomas Hahn for great work, and many unforgettable moments
My co-authors Fikret Berkes and Madhav Gadgil, whose work has contributed to and inspired this thesis.
Line Gordon, my most faithful roommate with whom I shared many memorable moments
Lisa Deutsch, Åsa Jansson and Miriam Huitric for scholarly inspiration and good humour
Lisen Schultz, with whom I look forward to many years of collaboration on several planes: scholarly, musical and personal.
All the new PhD students at Natural Resource Management, whom I am looking forward to getting to know better and working with
Louise and Peder at albaeco
My mentor Jan Cederqvist for helping me to see the broader perspective
My co-advisor Janice Jiggins for inspiration and methodological guidance

Greatest thanks also to my and Amy’s families for all the love and support.

Thanks to FORMAS

Appendix 1 (Adaptive renewal cycle and ecological resilience)

Based on empirical work and synthesis of large-scale ecosystems Holling (1986) proposed a heuristic model of cyclic change in ecosystems called the adaptive renewal cycle. There are four basic phases for ecosystem development; exploitation, conservation, release and reorganization (Figure 2).

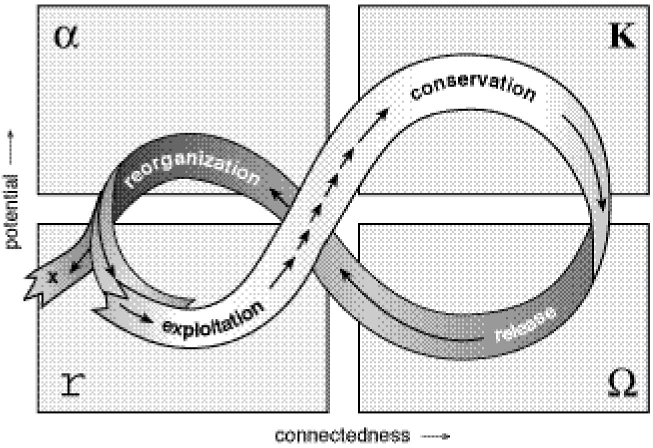

Figure 2. The "4-box" model or the adaptive renewal cycle where the system evolves by passing through four different phases, exploitation, conservation, release, and reorganization.

The exploitation and conservation phases are characterized by fairly stable conditions, productivity, and slow gradual change. The release and reorganization phases are characterized by rapid conversion. Through succession the system reaches the conservation phase from the exploitation phase. The conservation phase could be viewed as a climax state in a Clementsian sense (Clements, 1936) where K-selected species dominates. Disturbances such as fires, pests, or storms force the system to enter the release and reorganization phases. The climax system is more sensitive and susceptible to disturbances than earlier successional stages due to the increased connectedness and accumulation of stored capital in form of energy and matter (Holling, 1986). Disturbance is a natural part of the development of ecosystems and the release phase is also called "creative destruction" since it opens up opportunity for novelty and innovation in the reorganization phase. Events in the reorganization phase affect ecosystems' ability to buffer disturbance including the ability to self-organize and the trajectory of succession (Gunderson et al. 1995). The buffer capacity is referred to as ecological resilience and in a resilient ecosystem the four phases of the adaptive renewal cycle can repeat themselves over and over (Berkes and Folke 2003).

The "cup and ball" model in Figure 3 illustrates ecological resilience. The ball resembles the ecological community and the cup is referred to as the stability domain or basin of attraction. The ball is resting at the bottom of the cup but can be moved up along the side of the cup by a disturbance. Ecological resilience acknowledges the fact that complex ecosystems tend to have multiple stable states. This means that the community can be pushed into a different stability domain. The shift from one stability domain to another often involves passing a threshold.

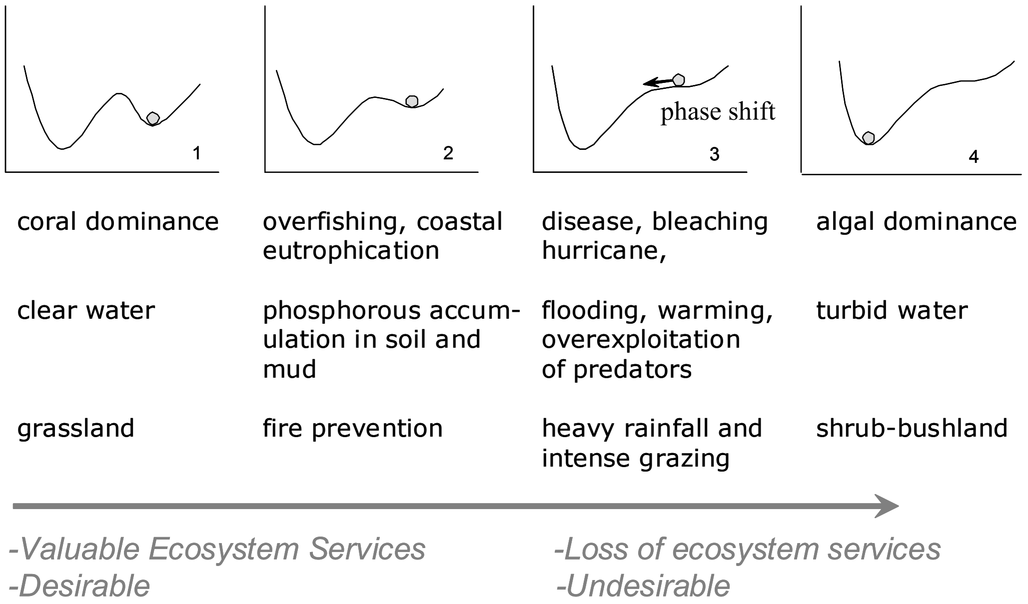

Figure 3. Phase shifts in three different ecosystems. A desirable ecosystem state with valuable ecosystem services (1). The stability domain is affected by various managment practices that reduce the resilience of the systemthe cup becomes shallower) (2). A disturbance that previously could be absorbed pushes the system into a new stability domain (3). The shift moves the system into a undesirable state with a loss of ecosystem services (4) (modified from Deutch et al. 2003).

As shown in Figure 3, the stability domain is not rigid but changes over time because the kinds of ecological processes behind these stability domains are often slowly changing variables (Gunderson et al. 1995, Gunderson 2003). Examples of such processes are mud in lakes (Carpenter et al. 1999), species composition in semi-arid rangelands (Walker et al. 1969), soil nutrient concentration in wetlands (Davis 1994), and spatial connectivity of old trees in spruce budworm forests (Ludwig et al. 1978). Changes in slow variables may lead to that the cup becomes shallower (the width and depth of the stability domain is reduced) and the system becomes more vulnerable to disturbance, i.e. there is loss of resilience. Loss of resilience implies that a small disturbance that previously could be absorbed and generate renewal may instead move a community over a threshold into other stability domains. Such change has been referred to as regime shifts (Scheffer et al. 2001) and a system with lower resilience tends to shift more easily than a system with ample resilience. Figure 3 provides examples of such shifts: from coralline to algae communities (Done, 1992), savannah to shrub land (Walker, 1993), and clear water to turbid water in lakes (Carpenter 2001). These shifts occur in nature but tend to be exacerbated by humans (Scheffer et al. 2001). Loss of resilience means loss of ecosystem structures and functions that are crucial for buffering disturbance and maintaining the capacity of ecosystems to produce goods and services on which social and economic development depends (Folke et al. 2002). Loss of resilience implies loss of opportunity for redevelopment and renewal following change (Gunderson and Holling 2002).

Complex systems are linked across spatial and temporal scales. The *panarchy* concept (Gunderson and Holling 2002) addresses the links between a nested set of adaptive renewal cycles at different scales. As shown in Figure 4, processes at smaller and faster scales can affect those at larger and slower scales and vice versa. Examples of such cycles in a forest are tree crowns as fast and small, forest patch as intermediate, and forest stand as slow and large scale. In social systems such scales might be correspond to local knowledge, management practices, and worldview or

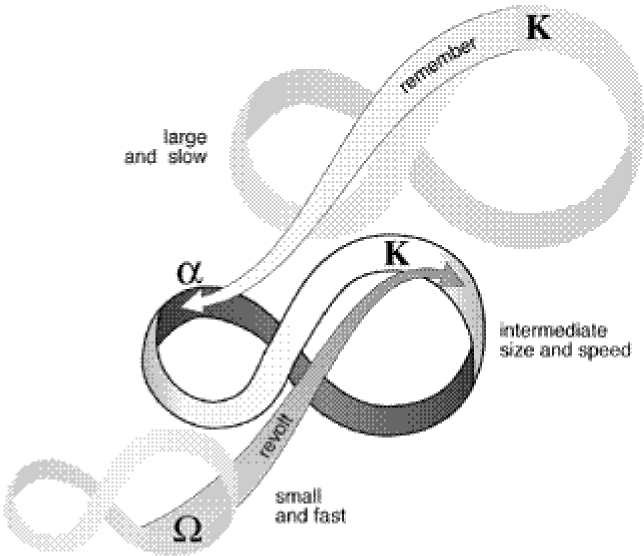

Figure 4. Nested set of adaptive renewal cycles and their cross-scale interactions.

operational rules, collective choice rules, and constitutional rules (Ostrom 1990, Folke et al. 1998). As shown in figure 4, "remember" and "revolt" have been identifies as especially relevant cross-scale connections for building adaptive capacity and resilience in social-ecological systems (Gunderson and Holling 2002, Berkes et al. 2003). The revolt of faster and smaller cycles can create critical change that may cascade to cause change in cycles of slower and larger levels. The remember connection draws on the stored memory of larger and slower levels for the reorganization phase and the context for self-organization at smaller and faster levels.

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Notes

[1] Ecosystem management is a holistic approach to environmental governance that according to Dale et al. (2000) "takes into account the full suite of organisms and processes that characterize and comprise the ecosystem and is based on the best understanding currently available as to how the ecosystem works. Ecosystem management includes a primary goal of sustainability of ecosystem structure and function, recognition that ecosystems are spatially and temporarily dynamic, and acceptance of the dictum that ecosystem function depends on ecosystem structure and diversity".
[2] 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 feedback to influence the subsequent development of those interactions.
[3] A disturbance is "any relatively discrete event in time that disrupts ecosystem community or population structure and changes resources, substrate availability, or the physical environment" (White and Pickett, 1985: 7).
[4] There are other definitions of resilience. In Pimm's (1984) definition there exists only one stability domain, i.e. globally stable equilibrium and resilience is the time it takes for a community to return to the stable state here illustrated as the bottom of the cup. This more static view is referred to as engineering resilience (Gunderson et al. 1995).
[5] Institutions are 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). Institutions are made up of formal constraints (rules, laws, and constitutions), informal constraints (norms of behavior, conventions, and self-imposed codes of conduct), and their enforcement characteristics (North 1990). Institutions are often thought of as departments, authorities, and public sector entities. Such entities are organizations—that is, interest groups in society (North 1990). Institutions form the constraints or the framework for organizations.
[6] Although the adaptive co-management concept is developed throughout this thesis our starting point is the definition by Gadgil et al. (2000) of adaptive co-management systems as flexible community-based systems of resource management tailored to specific situations and supported by and working in collaboration with concerned governmental agencies, educational institutions, and where appropriate nongovernmental organizations.
[7] Lee (1993a) states that social learning comes from the accumulation of knowledge within a network of organizations and from conflict between organizations and their environments. Brown et al. (2002) similarly states that social learning occur through collective activities such as discourse, imitation and conflict resolution.
[8] 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).
[9] Traditional ecological knowledge: 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)
[10] Local ecosystem knowledge: a cumulative body of knowledge applied and developed by stakeholders in a local context. It consists of externally and internally generated knowledge about resource and ecosystem dynamics.
[11] Polycentric governance involves local as well as higher levels of governance and aims at finding a balance between decentralized and centralized control (Imperial 1999a). E. Ostrom (1998) defines polycentric institutional arrangements as nested with quasi-autonomous units operating at multiple scales. A more elaborate definition is given by V. Ostrom (1999) of a polycentric order is "one where many elements are capable of making mutual adjustments for ordering the relationship with one another within a general system of rules where each element act with independence of other elements. Within a set of rules, individual decision-makers will be free to pursue their own interest subject to the constraints inherent in the enforcement of those decision rules".