This thesis employs a network perspective in studying ecosystems and natural resource management. It explores the structural characteristics of social and/or ecological networks and their implications on societies’ and ecosystems’ ability to adapt to change (i.e. adaptive capacity) and cope with disturbances and surprises while still maintaining essential functions and structures (i.e. resilience). It is shown that in many cases the structural characteristics of these networks seem to significantly affect systems behaviors, although there may be inherent juxtapositions between different structural characteristics, which need to be balanced in what we envision as network structures conducive to sustainable natural resources management. The thesis also shows that we need knowledge of both structures and processes to better understand important characteristics of social and ecological systems. Furthermore, the network approach of viewing systems as sets of components with patterns of interactions provides for a common systems perspective and a common methodology which, as this thesis shows, can create bridges across different scientific disciplines and facilitate integrated research approaches.

The thesis begins (Paper I) by introducing concepts and terminology from the network sciences and putting these into the context of ecology and natural resource management. Important concepts such as modularity, i.e. the level of compartmentalization in a network, and control of flow, i.e. how the structure affects the flow, spread, and distribution of resources in networks, are presented and explained. The paper presents examples from the food-web literature, briefly discusses data gathering issues, and discusses how the network perspective can contribute to increased understanding of social processes of particular importance in natural resource management.

Then follows an ecological section (Paper II and III) focusing on landscape fragmentation and how it affects the generation of ecosystem services. It uses a spatially explicit network-oriented modeling approach to study an agricultural landscape in southern Madagascar. The studied landscape mainly consists of cultivated land, but there are numerous forest patches of varying sizes (<0.5 ha to 95 ha) scattered across the agricultural landscape. These patches, many of which are sacred and protected from exploitation, harbor many species and thus provide several ecosystem services. Here, two ecosystem services that depend on these forest habitats were addressed: (1) crop pollination services by wild and semi-domesticated bees (Apoidea), essential for local crop production, and (2) seed dispersal services by Ring-Tailed Lemurs (Lemur catta). It is shown that further removal of the smallest forest patches in the study area could have a major negative impact on the
landscape’s capacity to support these ecosystem services. The paper concludes that in heavily fragmented landscapes, small forest patches should increasingly be viewed as essential for maintaining ecosystem services. Paper III goes on to present how the network-oriented modeling approach in landscape studies can be enhanced by incorporating other methods from the broad field of network analysis.

In Papers IV and V, the network approach is used to study social networks and the impact their structural characteristics may have on the management of natural resources. Paper IV uses a theoretical simulation modeling approach to study the potential impact of network density on utility returns in a management setup where adaptive managers exchange management experiences in a social network. It is found that networks of low- to moderate link densities significantly increased the probability for relatively high and stable utility returns whereas too high link densities caused occasional large-scale ecological crises between periods of stable and high utility returns. A constructed network structure involving a small set of experimenting managers was capable of combining high utility returns with high robustness, i.e. resilience, conforming to theories underlying the concept of active adaptive management.

On the other hand, the social networks in Paper V were compiled from empirical data gathered in a rural fishing community in eastern Africa. These networks and their structural characteristics were then analyzed in terms of their potential impacts on communication, ecological knowledge and on the community’s ability to initiate community-based co-management. The results indicate that these patterns of communication partly explain the distribution pattern of ecological knowledge among the villagers, and that the gear type used by the small-scale coastal fishermen strongly correlates with their patterns of communication. Analysis of the network structure also shows that groups most central, and hence potentially most influential, are dominated by one type of fisherman. Without the appropriate incentives and knowledge, these favorably positioned actors will not exploit their positions to initiate collective action. As such they may, in fact, be acting as barriers to collective action since highly motivated but less central actors have difficulty in initiating action due to less favorable positions.
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II Örjan Bodin, Maria Tengö, Anna Norman, Jakob Lundberg, and Thomas Elmqvist, 2006. The value of small size: loss of forest patches and ecological thresholds in southern Madagascar (accepted for publication in Ecological Applications)

III Örjan Bodin and Jon Norberg, A network approach for analyzing spatially structured populations in fragmented landscapes (Manuscript)

IV Örjan Bodin and Jon Norberg, 2005, Information network topologies for enhanced local adaptive management, Environmental Management 35(2):175-193

V Beatrice I. Crona and Örjan Bodin, WHAT you know is WHO you know? – communication patterns among resource extractors as a prerequisite for co-management (Manuscript)

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INTRODUCTION

The natural environment provides a vast array of indispensable resources and services to human beings (Prugh 1999). Furthermore, as the magnitude of human impacts on the ecological systems of the planet becomes apparent, there is increased realization of the intimate connections between these systems and human health, the economy, social justice, and national security (Lubchenco 1998). This intimate coupling between the natural environment and human societies suggests that these systems should be seen as a coupled social and ecological system. A basic assumption that is used throughout this thesis is that such coupled social and ecological systems can be described as complex and intricate webs of interactions between, and among, different social and/or ecological components. Furthermore, this thesis adheres to the assumption that the actual structural characteristics of these networks may influence social and ecological systems’ processes (see e.g. Janssen et al. In press). Likewise, these processes may in turn shape the structures of these networks.

First, consider the natural environment. Natural systems are very dynamic and are characterized by an inherited long-term unpredictability (Levin 1998). For example, in the early 70s, Robert May (1974) showed that even rather simple mathematical representations of population dynamics could in fact generate unpredictable and purely chaotic outcomes. In ecological systems, high-level patterns emerge from localized interactions and selection processes acting at lower levels (Levin 1998). Another essential aspect of ecological systems are historical dependency and multiple possible outcomes of dynamics within these systems (Levin 1998). A central concept in the scientific field of ecology is the ecosystem. Ecosystems, although defined in many, slightly, different ways, are systems of interacting species limited by constrains arising from the physical environment (for a historical overview, see e.g. Norberg 1998). Thus, ecosystems can be abstracted as systems of components, e.g. species or individuals, and their interactions, e.g. predation or symbiosis. This systems perspective, i.e. systems as a set of components and their patterns of interactions, is hereafter called the network perspective (Figure 1).
The network perspective has been successfully applied in various ways in ecology (e.g. Pimm 1982, Higashi and Burns 1991, Keitt et al. 1997). For example, the patterns of predator-prey interactions between a set of species are often represented as a network (i.e. a food-web). Analyses of food-webs can, for example, reveal species compartmentalization, i.e. find groups of species that seem to be more interlinked, and thus more dependent on other species within the same group than to members of other groups (Krause et al. 2003). Food-web analysis can also reveal individual species that are much more connected than others, thus suggesting that they are relatively more important than others in structuring the whole ecosystem (see e.g. Paper I). A highly connected species could be a keystone species, although it must be clearly stated that a keystone species does not necessarily have to be well connected. Closely related to the study of keystone species is the study of cascading secondary extinctions. Using simplistic models of food-webs, which only include up to 10 different species, Ebenman and colleagues (2004) have shown that single species extinctions can lead to catastrophic, cascading secondary species extinctions that are very hard to predict and control.

Furthermore, landscapes of fragmented habitats can be abstracted as networks; where habitat patches are nodes and the potential for inter-patch species dispersal are links (Keitt et al. 1997). Network-based analyses of landscapes can be used to analyze a landscape’s level of fragmentation as experienced by different dispersing species (Urban and Keitt 2001, Paper II and III). Recently, scholars have also started to analyze how various flows across the landscape (such as fluxes of nutrients) influence local food-web structures (Polis et al. 2004).

Secondly, consider our social environment. As for ecosystems, our social environment can be abstracted as patterns of interactions between different social entities.
This perspective fits well with the well-established assumption among social scientists that individuals’ behaviors and opinions are rooted in the structure to which people belong (Degenne and Forsé 1999). These social structures can be modeled as networks of relations among individuals. Such a social network could, as in Paper V, consist of the inhabitants in a village (i.e. the nodes) and the pattern of knowledge- and information exchange among these inhabitants (i.e. the links). Originating from the social sciences, this structural perspective on social systems has developed into a broad transdisciplinary scientific field of its own (Social Network Analysis, see http://www.insna.org). The social network perspective has, over a considerable time, shown itself to be useful in studying and explaining social phenomena (Freeman 2004). For example, it has been used to study information diffusion (e.g. Abrahamson and Rosenkopf 1997), different group structures and their possible social consequences (e.g. Johnson et al. 2003), and power relations (e.g. Markovsky et al. 1988). Thus, the social network perspective seems to be an interesting framework to apply to the study of the social side of natural resource management as well. This argument is further strengthened by the numerous studies that have shown that the existence of informal social networks among, and between, various stakeholders and groups is very important in successful cases of bottom-up community-based natural resource management (e.g. Gunderson 1999, Folke et al. 2003, Olsson 2003). For example, networks of socially interconnected water temples (centers of local farmers) can suppress pest outbreaks in an water-limited irrigated agriculture system by facilitating coordinated harvesting activities (Lansing et al. 1998). Furthermore, it has been argued that knowledge of the complex patterns of interactions between and among various subgroups in communities is crucial in studying co-management (described further on) of natural resources (Carlsson and Berkes 2005). By applying a network-oriented research approach in studying co-management, these complex patterns of interactions can be revealed, quantified and analyzed further (see e.g. Paper V).

Finally, consider coupled social and ecological systems. As stated above, abandoning the dichotomy between social- and ecological systems is central for improved understanding of sustainable management of complex natural systems (Scoones 1999). In addition, there are many cases where formal authorities have started to discard top-down, command-and-control management of natural resources in favor of more community-oriented, co-management approaches (Folke et al. 2005, Norberg and Cumming forthcoming). That shift also brings with it an increased need for understanding of the interplay between social and ecological systems since the authorities’ new role is to provide the conditions for co-management approaches rather than trying to control nature with top-down management policies.
However, to facilitate the development of such knowledge, transdisciplinary research approaches are central (e.g. Berkes et al. 2003). The network approach is herein put forward as a fruitful way to integrate research on coupled social-ecological systems. The network approach has already, as presented above, been successfully applied in both the natural- and the social sciences; and this thesis continues this line of work but aims to use networks as a common, cross-discipline, systems perspective (and methodological toolbox) to facilitate trans-disciplinary research in social-ecological systems. The approach may be: (1) used to study ecological- or social systems separately, although with the objective of revealing common characteristics and to communicate these across disciplines (the main application in this thesis) and/or (2) be applied in studying social-ecological systems in a tightly integrative fashion (cf. Janssen et al. In press).

More specifically, this thesis sets out to explore the implications that certain structural characteristics of networks in social and/or ecological systems may have on societies’ and/or ecosystems’ ability to adapt to change (i.e. adaptive capacity, see e.g. Carpenter et al. 2001) and cope with disturbances and surprises while still maintaining essential functions and structures (i.e. resilience, Holling 1973).

**ENABLING SUSTAINABLE NATURAL RESOURCE MANAGEMENT**

Having established the complexity of natural and social systems, the question that then arises is how can, and should, we manage our ecosystems for sustainability? Reliable predictions of responses within these systems are hard, if not impossible, to compile and therefore optimal control is seldom a realistic approach (Kinzig et al. 2003, Peterson et al. 2003). Hence, management of natural resources has often to be undertaken based on limited knowledge and without the aid of reliable scientific predictions.

Environmental policy considerations have normally been assigned to public agencies. Those agencies have usually relied on command-and-control practices that aim to maintain a stable flow of resources (Prugh 1999). However, the failure of this “traditional” way of natural resource management is quite well documented. Holling and Meffe (1996) describe how management targeted at reducing variation and increasing predictability, despite short-term success, tends to deplete the resource base in the long run. Due to the complex behavior of natural systems, it is impossible to lock a system into a steady state for eternity, or to manage it for stability and security in a command-and-control fashion (Folke et al. 2003).
Adaptive management (Holling 1978, Walters 1986) is a suggested alternative to command-and-control management since it embraces the complexity and uncertainty described above. In adaptive management, policies are regarded as experiments; constantly being up for review and change. The major themes in adaptive management are uncertainty and learning – it will never be possible to fully understand and control the behaviors of ecosystems and therefore management practices are always expected to need changes/adjustments following the accumulation of new information and knowledge. The development of new knowledge, based on ecosystem feedback resulting from changes in management practices, is an integral part of adaptive management. This approach to natural resource management seems very promising since it addresses the inevitable unpredictability of natural systems described earlier. There are, however, rather few examples of successful real-world implementations of adaptive management at present. This is suggested to be due to e.g. institutional barriers (Walters 1997, Lance Gunderson, personal communication).

Originating from adaptive management, the concept of adaptive co-management (Gadgil et al. 2000, Olsson 2003) has emerged. It combines the element of dynamic learning in adaptive management with collaborative management (e.g. Buck et al. 2001): linking groups of stakeholders for the joint management of resources (Olsson 2004). The underlying hypothesis is that adaptive management could benefit from a more explicit collaboration among different groups at different levels. Co-management addresses the critical issue of scale-matching and decoupling, i.e. people and organizations located and operating at the scale of a natural resource are often very well suited to taking an active part in management since they are often very knowledgeable about local conditions (Berkes and Folke 1998) and, as they are often strongly affected by management failures, incited to take care of the resource (Ostrom 1990). Adaptive co-management thus appears to be a plausible approach to enhance sustainable natural resource management in many cases. For example, in southern Sweden, a successful and ongoing wetland restoration management process, with different stakeholders at different hierarchical and organizational levels that jointly take action in the management process, has been characterized as adhering to the principles behind adaptive co-management (Olsson 2003).

Even rather small communities can display quite complex patterns of interactions between different user groups, and both formal and informal organizations and institutions. As such, there is rarely one single group of local stakeholders, rather communities are defined by complicated patterns of subgroups with different
perceptions, interests, resources and amount of influence (Carlsson and Berkes 2005, Nygren 2005). Among these groups of stakeholders, a reasonable level of consensus and mutual understanding of the resource’s status is essential for sustainable management of common resources such as the natural environment (Ostrom 2005). Hence, adaptive co-management requires cooperation between various, sometimes very different, stakeholder groups - a requirement that may be very hard to fulfill in many cases. Thus, inquiries into identifying factors behind successful (and unsuccessful) cases of co-management of natural resources should, among other things, consider the influence these intricate webs of social relations may have on cooperation and management (cf. Carlsson and Berkes 2005). This discussion of community structures emphasises the complexity of the social systems in which we are all embedded. Human societies, cultures and economies are probably just as complex as our natural environment. Thus, sustainable natural resource management is not just about how we should manage ecosystems, but it is equally important to consider our social systems’ characteristics, patterns, drivers and processes; ranging from small-scale local communities all the way up to the global level of multinational organizations and corporations (cf. Ostrom et al. 1999, Folke et al. 2005). Ecosystem management practices should be coupled with social patterns and processes in order to be resilient to ecological and social disturbances and surprises.

**SCOPE OF THE THESIS**

This thesis uses the network structural perspective, along with its methodologies and toolboxes, as a means to study ecosystem and natural resource management. The overarching line of inquiry is the effect structural network characteristics of social and ecological systems may have on adaptability, resilience and other related important systems characteristics. Quantitative and qualitative methods are utilized using computer-based simulations, field studies – including the use of interviews/questionnaires, conceptual models, statistical data processing and various formal mathematical models and methods borrowed mainly from the field of social network analysis. Hopefully, this thesis contributes to an improved understanding of pattern- and process interactions in social and ecological systems, and shows how the network perspective can be applied to facilitate transdisciplinary research in natural resource management.

The thesis consists of a mostly ecological-oriented block (Papers II and III), and a mostly social-oriented block (Papers IV and V). The ecological block addresses landscape fragmentation and the generation of ecosystem services. The study area is an agricultural landscape in southern Madagascar. Utilizing a network perspective,
the landscape’s ability to continuously support organisms’ movement between patches of habitats is assessed and the consequences of future and ongoing land-use changes are projected. The studies address the issue, among others, of to what extent current and projected future landscape configurations support seed dispersal and crop pollination. Paper III also demonstrates and suggests how network-centric methods developed in other disciplines can be applied in analyzing the ecological consequences of different landscape configurations. These papers demonstrate the relative simplicity of the network perspective when used in studying fragmented landscapes. They also demonstrate that it is, in addition to being simple, powerful and integrative since it combines landscape pattern with important ecological processes in the analysis.

The social-oriented block addresses how social networks among stakeholders, managers and users can affect management of natural resources. Many scholars have highlighted the importance of social networks in successful cases of natural resource management. Past and ongoing research within the social sciences also shows that structural characteristics of social networks have profound effects on social outcomes (see e.g. Degenne and Forsé 1999); thus understanding the impact of the structural characteristics of social networks on natural resource management is important in developing a better understanding of sustainable natural resource management. Hence, this block of the thesis addresses the structural characteristics of social networks and their impact on management outcomes in natural resource management. Paper IV uses a computer-based simulation approach to study the management consequences of information sharing in networks of natural resource managers. A field study of the social networks in a small fishing community on the eastern coast of Africa is presented in Paper V, where the observed networks of information and knowledge exchange are analyzed to reveal any tendencies the villagers may have to form groups/clusters, to find possible explanations behind such tendencies, to assess the effects such tendencies may have on the distribution of ecological knowledge, and to hypothesize on the possible effects these networks may have on the community’s ability to initiate collective action.
METHODS

The network perspective is used throughout this thesis. Much of this research is based on the use of theoretical models and methods. Conceptual, mathematical, statistical and simulation models have been applied throughout the papers. The network perspective can be described as a conceptual model itself, i.e. a conceptual model of a system consisting of separate components and their patterns of interactions. Departing from the abstraction of a system as a network, numerous analytical methods exist to analyze the structure of the network. These methods have been developed in disciplines such as sociology, computer sciences and mathematics over a considerable amount of time (Freeman 2004). These methods aim to quantify the structural characteristics of a network in terms of clustering (i.e. different sets of nodes form distinct coherent groups), density of links, patterns of link distribution among the nodes, degree of centrality, and much more (see e.g. Paper I for a brief overview). Subsets of these analytical/mathematical methods have been applied in the different papers in this thesis and are explained throughout the papers. Furthermore, the main objective of Paper III is to introduce some of these analytical methods, which are commonly used in analyzing social networks, to study ecological consequences of different landscape patterns and configurations.

Paper IV is built on a special kind of model: an agent-based simulation model. Here, a model which embodies some plausible assumptions about the world, for example by formalizing some rules of behavior for some model entities, is first created. Then, a simulation is undertaken by running the model through (simulated) time. Such computer-based simulations have recently become common in the social sciences as well as in other sciences such as physics and biology (Gilbert and Troitzsch 1999). Simulations introduce a new way of thinking about social and economic processes, originating from the idea that complex behaviors emerge from relatively simple activities (Gilbert and Troitzsch 1999). The term “agent-based” implies that these simulation models depart from an interaction perspective, i.e. they model the environment as a set of more or less autonomous, but interacting, components (i.e. agents). Agent interaction follows designed rules and procedures, and the emergent outcomes of these multi-agent interactions are the focus of interest.

Papers I, II and V make use of direct empirical data. Paper III also uses empirical data (geographical landscape data), but only to exemplify the analysis. Paper IV is completely different, since the agent-based simulation is used to actually generate the data, which is subsequently analyzed and discussed.
RESULTS AND SUMMARY OF PAPERS

PAPER I: A NETWORK PERSPECTIVE ON MODULARITY AND CONTROL OF FLOW IN ROBUST SYSTEMS

This paper derives from the standpoint that networks are an easily comprehensible and relevant representation of both ecological and social systems, and that a network perspective has the advantage of addressing not only the members of the system, but their interactions as well. The paper gives a broad overview of how the network perspective can be used in studying both social and ecological systems, and includes a brief introduction to network theory (graph theory) and its concepts and terminology, and data collection issues. Recent findings of large real-world network characteristics are revised and attention drawn to social- and ecological systems.

For example, scale-free networks (Barabási and Albert 1999) appear to be quite common in social systems, whereas networks in ecology (e.g. food-webs and fragmented landscapes) are not, although they exhibit a degrees of distributions that are often still skewed towards few nodes with many connections. The paper also relates the network perspective to complex adaptive systems (Levin 1998), and especially the network perspective’s potential in analyses of robustness, modularity and scale. Definitions of robustness in networked systems are briefly discussed. A common definition of robustness is the vulnerability of the network to defragmentation, but the risk for congestion can also be an important consideration. The concept of congestion in networks assumes that the links carries flows of some resources, and individual nodes that receive too many resources per time unit can experience congestion. The important network concepts of groups/clusters and the effect of different structural positions are described, and formal measures are presented, and the concepts are discussed in relation to characteristics of social and ecological systems. Examples of ecologically relevant network groups are the clusters of strongly interacting species in a food-web (often called modules or compartments), and an example of a structural position is the “broker”, i.e. a node that connects two or more otherwise separated groups of nodes. A person occupying such position in a social network can be said to possess a relatively high level of social capital due to his/her ability to act as a broker and control the flow of resources between the groups.

The idea that an intermediate level of modularity, a balance between the tendency for group formation and “global” connectivity (access to distant nodes), is favorable for robustness in both ecological and social systems is put forward and discussed. The right balance contributes to robustness by combining the benefits of access to distant resources with the possibility of limiting the spread of disturbance among groups.
Suggestions, and some examples, on how the network perspective could provide a quantitative toolbox applicable to current research in natural resource management follow. Characteristics of social networks such as degree of centrality, tendency for group formation and the degree of connectivity between separate groups are discussed in relation to adaptive management, adaptive co-management and leadership/key individuals. For example, the degree of bridging relations between governmental agencies and various stakeholder groups probably has a major impact on the ability to establish common rules and cooperation in managing natural resources. Finally, the limitation of the network approach when it comes to dynamic and evolving networks is briefly discussed.

PAPER II: THE VALUE OF SMALL SIZE: LOSS OF FOREST PATCHES AND ECOLOGICAL THRESHOLDS IN SOUTHERN MADAGASCAR

This paper presents spatial modeling of the generation of ecosystem services in a human-dominated landscape in southern Madagascar where forest habitat patches, protected by local taboos, are located in a matrix of cultivated land. In the study area, the forest is severely fragmented into several hundred patches (<1-95 ha in size), constituting islands in a sea of agriculture. Human land-use brings forth constraints on the existence, spread, and expansion of forest patches in the landscape, but local taboos also provide strong and well-enforced protection for the existing patches. Two ecosystem services that depend on the forest habitats are addressed: (1) crop pollination services by wild and semi-domesticated bees (Apoidea), which is essential for local crop production of e.g. beans, and (2) seed dispersal services by Ring-Tailed Lemurs (Lemur catta). The following questions are specifically addressed:

• How does the present landscape support crop pollination and seed dispersal services generated by bees and Lemur catta?
• What are the effects of sequential forest patch removal on the proportion of the study area covered by pollination services?
• What are the effects of sequential forest patch removal on seed dispersal services carried out by Lemur catta?

The network-centric graph theoretical approach (Keitt et al. 1997, Urban and Keitt 2001) has been applied to model the effect of the spatial pattern of forest patches on seed dispersal carried out by Lemur catta. The resulting network of habitat patches represents the spatial structure of connectivity in the landscape, which
encapsulates the ability of *Lemur catta* to disperse seeds in the landscape by moving from one patch to another. To quantify the area potentially covered by pollination services, a circular zone around patches larger than 0.5 ha has been applied. We define this as the Crop Pollination Zone, and its radius has been set to a distance range that equals the foraging distances for a range of bee species.

The results indicate that, in spite of the fragmented nature of the landscape, the fraction of the landscape presently covered by both crop pollination and seed dispersal services is surprisingly high. It seems that the taboo system, although indirectly and unintentionally, contributes to upholding the generation of these services by protecting the forest patches and thus helps to sustain local livelihoods. Both services are, however, predicted to be very vulnerable to the successive removal of small patches. For crop pollination, the rate of decrease in area covered by the service is high even when only the smallest habitat patches are removed. The capacity for seed dispersal across the landscape displays several thresholds with habitat patch removal. The thresholds for rapid declines in the ecosystem services in response to patch removal are generated by changes in the spatial configuration of patches rather than reduction of area per se. The results suggest that in order to maintain the capacity for seed dispersal across the landscape and crop pollination cover in the study area, the geographical location of the remaining forest patches is more crucial than their size. We argue that in heavily fragmented production landscapes, small forest patches should increasingly be viewed as essential for maintaining ecosystem services, such as agricultural production, and be included in the ongoing process of tripling the area of protected habitats in Madagascar.

**PAPER III: A NETWORK APPROACH FOR ANALYZING SPATIALLY STRUCTURED POPULATIONS IN FRAGMENTED LANDSCAPES**

In this paper we extend Urban and Keitt’s (2001) network-centric approach in studying landscapes (i.e. the graph theoretical approach used in Paper II) by applying network-based methods mainly developed in the social sciences. Such methods have even already been successfully applied to a number of studies on structural patterns in food-webs (e.g. Krause et al. 2003, Luczkovich et al. 2003). The methods we propose are suitable to (1) identify individual habitat patches that are disproportionally high in importance in preserving the ability of organisms to traverse the fragmented landscape, and (2) find internally well-connected compartments of habitat patches that contribute to a spatial compartmentalization of species populations.
Important habitat patches were successfully identified using the Betweenness Centrality Index (Freeman 1979). This network measure estimates a node’s degree of betweenness, i.e. to what extent a node sits between other nodes. We expect patches with a high score of the Betweenness Centrality Index to: (1) reduce the overall network distance between habitat patches, (2) bring together otherwise largely separated or even isolated patches and/or groups of patches, and (3) be more frequently visited by organisms moving through the landscape, i.e. they make up the backbone of the landscape. To find internally well-connected compartments of habitat patches we suggest using the method called Community Structure that was recently proposed by Girvan and Newman (2002). This method was chosen because it fulfills three criteria we find important when identifying biologically relevant compartments in fragmented landscapes: (1) it does not require complete isolation between compartments as in the previous method proposed by Urban and Keitt (2001), (2) it is hierarchical, thus multiple compartment membership is not allowed for single patches, which is preferable since we are interested in finding separable compartments of habitat patches, and (3) it does not discriminate against peripheral nodes.

We use the agricultural landscape with scattered dry-forest patches in southern Madagascar, inhabited by the ring-tailed lemur Lemur catta (see Paper II), to demonstrate the utility of these methods. We compare the Community Structure method with two established methods, network components as used by Urban and Keitt (2001) and sliding window (e.g. Bruinderink et al. 2003). The results show that (1) the component-based method is not always fine-scaled enough to capture all relevant compartments, and (2) the compartments revealed by the Community Structure method partly resemble those identified by the sliding window approach, but it seems that the Community Structure method is, in our case, better at accounting for the details that the sliding window method leaves out due to its averaging procedure.

Further, the set of patches found by using the method proposed by Urban and Keitt (2001) to identify the most important patches for species’ long-range movements was compared to the set of important patches found using the Between Centrality Index. Results indicate that the Between Centrality Index method is better at finding important patches that uphold the traversability of the landscape. Management targeting cost-effective prevention of further fragmentation of the landscape and upholding the gene-flow between, more or less, localized populations could, then, focus its efforts on preserving the habitat patches with the highest Betweenness Centrality Index.
We suggest that both of these methods are particularly suitable in landscapes where species' traversability is not fully inhibited by fragmentation, but merely limited. These methods are also potentially highly relevant in studying spatial aspects of resilience and in the design of natural reserves. Finally, we introduce a publicly available software tool for doing many of the analyses presented in this paper.

**PAPER IV: INFORMATION NETWORK TOPOLOGIES FOR ENHANCED LOCAL ADAPTIVE MANAGEMENT**

This paper sets out to explore how different social network structures among natural resource managers can affect their utility returns. Of focal interest are the implications of the structure, or topology, of the underlying information (social) network among management units on the ability for sustainable natural resource management to emerge at an aggregated level (e.g. community level). It draws from the theoretical frameworks of co-adaptive management (Gadgil et al. 2000, Olsson 2003) and common pool resources (Ostrom 1990), where the importance of linkage between management units, e.g. the inter-unit relational network, is identified as a common denominator of these theoretical frameworks.

This study uses a modeling approach, and the model itself is derived from the field of agent-based simulations (Gilbert and Troitzsch 1999, Wooldridge 2002, Janssen 2003). We use computerized agents, representing individual management units, with adaptive decision-making algorithms with the following three fundamental constraints: (1) complete understanding of the processes underlying the natural resource can never be achieved, (2) agents can only learn by experimentation and information sharing, and (3) memory is limited. The computerized managers, i.e. the agents, were given the task to manage a simulated ecological system that has two states, one that provides high utility returns and one that provides low returns. Management experiences were exchanged within different network structures of interconnected agents; thus the resulting impact of the network structure on utility returns can be measured. In this study, the network’s structural characteristic of interest is the link density.

We find that networks of low- to moderate link densities significantly increase the probability for relatively high and stable utility returns. Networks of high link densities contribute to a highly synchronized behavior of the agents, which causes occasional large-scale ecological crises between periods of stable and high utility returns. A constructed network structure involving a small set of experimenting agents was capable of combining high utility returns with high robustness, i.e.
resilience, conforming to theories underlying the concept of active adaptive management (Walters 1986) and adaptive co-management (Gadgil et al. 2000). We demonstrate that in a coupled social-ecological system the system-wide state transition occurs not because the ecological system flips into an undesired state, but because the managers lose their capacity to reorganize back to the desired state.

**PAPER V: WHAT YOU KNOW IS WHO YOU KNOW?**

**- COMMUNICATION PATTERNS AMONG RESOURCE EXTRACTORS AS A PREREQUISITE FOR CO-MANAGEMENT**

As a contrast to the theoretical simulation model in Paper IV, the social networks in Paper V are compiled from empirical data gathered in the field. This study departs from the insight that structural properties of social networks are one factor determining the flow of information within communities (e.g. Abrahamson and Rosenkopf 1997) and, as such, may be important in determining patterns of knowledge distribution and may also be instrumental in enabling resource users to initiate community based management. In order to elaborate these hypotheses, we have mapped the social networks used for communication of knowledge and information related to natural resource extraction among villagers in a coastal seascape in Kenya. This community was chosen as it has not been successful in regulating its inshore local fishery which has led to a system currently diagnosed as overexploited. Reasons for this include the formal institutional set-up, which to some extent discourages local initiatives. However, lack of collective action to remedy an unsustainable situation may also be attributed to the structures of the social networks in the community.

Following the mapping of the social networks, different subgroups have been identified and their inter-relations examined, while measuring to what extent personal attributes such as occupation can explain observed group structures. We also compare the local ecological knowledge held by villagers of different occupations with the structure of the social network in order to map how well this structure can explain the distribution of ecological knowledge among villagers. Results show that the gear type used by the small-scale coastal fishermen in our study area correlates strongly with their patterns of communication when it comes to the exchange of knowledge and information regarding natural resources. The frequency of relations among fishermen using the same gear type is significantly higher than expected when assuming no correlation. Also, the communication between fishermen and non-fishermen is very limited. It appears that these patterns of communications, in part, explain the distribution pattern of ecological know-
ledge among the villagers. Such patterns can potentially impact a community’s ability to initiate and adopt self-imposed common-pool resource extraction regulations, since common understanding of the resource system has been shown to be an important prerequisite for self-governance to form (Ostrom 2005).

Analysis of network structure also shows that the most central groups, and hence potentially most influential, are dominated in numbers by migrant deep sea fishermen, who are hypothetically less motivated to initiate collective action for resource management. Without the appropriate incentives and knowledge, these favorably positioned actors will not exploit their positions to initiate collective action. As such, they may, in fact, act as barriers to collective action since highly motivated but less central actors have difficulty in initiating action due to less favorable positions.

We conclude that lack of collective action to remedy an unsustainable situation may be attributed to distinct aspects of the specific structure of the social network. Lack of communication between and among various fishermen and non-fishermen groups can explain differences in their perception of the inshore local fishery as being overexploited and/or in need of regulation efforts. Our results also demonstrate that a structural analysis of the relational networks reveals central and potentially influential actors. Furthermore, this study shows that social network analysis is a valuable tool for identifying de facto social groups, influential actors and patterns of communications.

**CONCLUDING DISCUSSION**

**STRUCTURES AND PROCESSES**

The papers show that nothing seems to exist in isolation; humans, species and other biotic and abiotic elements are interwoven in complex relational networks, i.e. in coupled social and ecological systems. Sustainable management of our natural resources relies upon a good understanding of how these coupled social and ecological systems work; the processes they uphold, the processes they depend on, how resilient these systems are are to change and disturbances and so forth. The main argument put forward in this thesis is that in order to understand these processes and how they affect resilience and adaptability, knowledge of the structural features of these systems is essential. The structural perspective used in this thesis is that of networks. This thesis shows that a structural network perspective has the potential to explain systems’ behaviors based on their structural patterns of
relations; this (argument) applies to systems in general and is not necessarily limited to certain scientific disciplines or epistemologies. Hence, it is truly interdisciplinary. However, a structural perspective will only be of any real value when we possess knowledge and/or well-grounded assumptions of important processes. For example, in the case of seed dispersal in a fragmented landscape in Papers II and III, the reachability of the network of habitat patches is only of interest given the assumption that seeds spread from individual patch to individual patch by the inter-patch movement of certain seed dispersing organisms is correct. Thus, assuming knowledge of processes (seed dispersal by organisms’ movements), a structural perspective (i.e. the structural characteristics of the habitat networks) can enable a system-level analysis (e.g. analyses on how seeds may spread in the landscape and if there are certain groups of, and/or individual, habitat patches that may be more vulnerable than others to being left out from the flow of seeds due to their structural position).

Hence, structures can shape processes and their outcomes, but the opposite also holds true. Processes may create structures, which in turn may feedback upon the processes and so on. For example, Paper V shows that fishermen were more inclined to communicate with other fishermen using the same type of fishing gears than to others. This has resulted in fairly distinct social groups, and members of these groups may have started to develop a sense of belonging and a perception of “we versus them”, which in turn may have contributed to further strengthen the structure of distinct groups. Here it must, however, be clarified that we have not tested if the correlation between group structures and types of fishing gear is a consequence of fishermen being more interested in establishing relations with others using the same type of gear, or, if they have changed their gear preferences to match the preferences of the groups that they belonged to a priori. Either way, the above discussion on mutual feedbacks would be the same. Structure and process are continuously reflecting upon each other (Figure 2).

![Figure 2](image)

*Figure 2. The relation between structure and process*
Resilience and adaptability (adaptive capacity) are two major concepts that are crucial for sustainable management of coupled social and ecological systems (e.g. Berkes et al. 2003). In the following subsections, I will elaborate more explicitly, using the results from the thesis’ papers, on how the structural network perspective can enhance understanding of these concepts in relation to the structural characteristics of the systems under study. While the structure alone means nothing without any assumptions about the underlying and ongoing processes, with such knowledge and/or assumptions, the structural network perspective may enable enhanced understanding of system-level characteristics such as resilience and adaptability. It may do so because it can identify potential weaknesses and strengths of the system, provide hints of the key features and behaviors of the system, identify key components of the system; in so doing it can guide and inform research which may, in turn, be using completely different approaches and methodologies.

**NETWORK DENSITY**

Network density is defined as the ratio of the number of realized ties divided by the number of possible ties (e.g. Wasserman and Faust 1994). A high density implies a relatively high average number of links per node in a network. In many respects, this may be perceived as something highly desirable: it may seem to be a good thing to be well connected. For example, in studying the landscapes of scattered habitat patches of Papers II and III, it is obvious that a high network density leads to more opportunities for dispersion. It also implies a higher tolerance to the removal of some of the habitat patches; that this loss will not fragment/disconnect the landscape (however, see also the discussion on centrality further on). Thus, the resilience of the landscape in upholding species’ dispersal in the face of habitat destruction would be higher for landscapes with higher densities. As seen in Paper II, the landscape’s resilience seems low, i.e. continued removal of forest patches could rapidly decrease the level of connectivity in the landscape.

In social networks, a high network density can enhance the sharing of knowledge and information among actors, which in turn should enhance the overall level of knowledge (e.g. Reagans and McEvily 2003). Such exchanges of information can lead to significantly better management of natural resources as shown in Paper IV. Thus, high density also seems to be favorable in social networks. However, as Paper IV also shows, too high densities can actually reduce the diversity of the actors’ perceptions of ecosystem behaviors; this reduction in diversity can lead to a reduction in their collective ability to respond to change and surprise (i.e. loss of their adaptive capacity). Thus density seems to be of a double-edged nature, and in
Paper IV it is intermediate levels of density that gave the best results in terms of stable, reliable and high utility returns from the managed ecosystems. The double-edged nature of density also applies to landscapes of scattered habitat patches. For example, imagine the kind of dispersal that is under consideration is related to something undesirable, e.g. a virus. Then a high network density would enhance the spread of the contaminant. This leads to the following conclusions:

1. High density may be beneficial since it enhances the exchange of various desirables, such as good ideas, information, genetic material, etc., which can increase the system’s ability to respond to change and disturbance (adaptive capacity).

2. High density may enhance a system’s resilience in terms of reducing its vulnerability to the removal of individual components.

3. Too high density may, however, contribute to a homogenization of the system. It may reduce inherited variability and diversity (such as knowledge- and genetic variations), which would reduce the system’s ability to cope with changes, disturbances and surprises (i.e. reduces adaptive capacity).

This discussion of density is a good example of how the network approach helps to identify structural characteristics of a system that may be important in shaping the outcomes of different processes, whether those processes are knowledge transfer or seed dispersal. It also shows the need in combining structural analysis with assumptions about processes. Furthermore, the above conclusions do not define what would be an optimal level of density for any given system; rather they focus on how this structural characteristic may affect the system’s resilience and adaptability. Directing one’s attention to network density may then be useful for both researchers and managers since it can provide means to steer further scientific inquiries, or managing directives, in various real-world situations. This has, to my knowledge, rarely been done in natural resource management, although the impact of network density has received attention elsewhere, e.g. in the organizational research literature (e.g. Reagans and McEvily 2003). Network density can help to explain, and possibly predict, certain aspects of systems’ behaviors and it may guide discussions on ways of improving the system’s resilience. Paper IV presents an example of the latter. In an attempt to utilize the benefits of sharing experiences in a social network without running into the problem of homogenization, a special kind of network was constructed: a small set of pre-selected experimenters were protected from too much incoming information, hence providing for some degree of individual autonomy and thereby maintaining heterogeneity, whereas the remaining members
in the network could benefit from all of these experimenters’ diverse experiences. This particular network illustrates how structure can steer ongoing processes in a way to enhance desirable behaviors in the system.

**CENTRALITY AND INFLUENCE**

Network centrality can be defined and measured in numerous ways, although the general concept of centrality is about identifying potentially influential network positions. For example, degree centrality is defined as the number of links a node possesses, and in many cases one can argue that the more links a node has, the more influential it may be (e.g. Wasserman and Faust 1994). Another frequently used measure of centrality is the betweenness centrality index (Freeman 1979), a measure that tries to encapsulate the degree of “in-betweenness” for each and every individual node in the network. A node that is between many other nodes may exert influence by its potential to control and steer exchanges in the network.

Network centrality is closely related to the concept of key-stone species in ecology (see e.g. Paper I). In food-webs, species that have many links to others may exert more influence on ecosystem functioning compared to less centrally positioned species. A similar relationship is found in Paper III, but from a landscape perspective. Paper III shows the negative impact on overall network reachability (i.e. the number of nodes reachable by going through all possible links) that the removal of a relatively small but carefully selected set of habitat patches would have on a landscape of scattered habitat patches. This critical set of patches can be accurately identified using the betweenness centrality index (Freeman 1979) as shown in Paper III. Thus, the landscape’s potential to support dispersal over long distances is highly vulnerable (i.e. less resilient) to the removal of patches with high betweenness centrality. Consequently, focusing conservation efforts on these centrally-positioned patches would be a cost-efficient way to enhance the landscape’s resilience to fragmentation.

This also applies to social networks. For example, if there are some very centrally positioned actors in a community network, their impact would, for better and worse, be large and the community could become very dependent on these few actors. In other words, a social network with some very centrally positioned actors may also be less resilient. Furthermore, in Paper V, the most centrally positioned group of fishermen in the community network, and also the most knowledgeable in the studied community, was that represented by Deep Sea (and to some degree Seine net) fishermen. However, since this group of fishermen may lack appropriate incentives, they may not exploit their position to initiate collective action to deal
with the declining fish stocks. As such they may, in fact, act as barriers to collective action since highly motivated but less central actors have difficulty initiating action due to less favorable positions. Because these centrally positioned actors may limit possibilities for others to bring forward their knowledge and opinions etc., the diversity of information that is effectively accessible and that could be utilized in case of change and disturbance is reduced. That implies a reduction of the adaptive capacity.

Similar to network density, centrality also has a double-edged nature. Although the above discussion highlights the possible drawbacks of having some very centrally positioned nodes in a network, this structural configuration can also be beneficial in natural resource management. Centrally positioned actors may use their favorable position to initiate action, coordinate resources, and bring together otherwise disconnected groups of actors (for an overview, see Gladwell 2002). This insight leads to the hypothesis that the benefits of having some very centrally positioned nodes depends on what phase a system is in. Having some very centrally positioned nodes could help enabling shifts into new regimes, which may be the initiation of a new management regime as has happened in Kristianstad Water Kingdom (Olsson et al. 2004, Hahn et al. In press) or in connecting various isolated habitat fragments of a landscape. However, to prevent a system in a desirable state from shifting into undesired regimes, and at the same time upholding the system’s adaptability, having some very centrally positioned nodes seems to be less favorable.

From the individual actor/node perspective, the benefits of centrality can be perceived quite differently. For example, assume that an actor in a social network would benefit from a high degree of centrality (as shown in Paper IV where agents with higher number of links performed better); then there would be an incentive for everyone to link up to as many others as possible. That would be fine if it led to a higher network density, although there are dangers associated with too high densities as previously discussed. However, the real benefit for the individuals lies in getting more and/or more strategic links than the others, i.e. they could end up trying to boost their own centrality at the detriment of others, which could lead to the reduction of resilience as explained earlier. In a sense it seems like individuals’ interests may be in conflict with the community’s benefits, i.e. a dilemma very similar to that of governing common-pool resources (cf. Ostrom 1990).

In summary, measures of network centrality can provide valuable insights on important system properties that influence management of natural resources. As emphasized earlier, when discussing the possible impacts of network centrality, the need to combine the structural analysis with assumptions about processes is
obvious. Furthermore, in comparison with network density, analyzing aspects of centrality is more oriented towards the study of individuals (whether they are humans or habitat patches), even though the focus would still (largely) be on outcomes at the systems level. No matter what specific questions are guiding scientific or managerial inquiries; nodes that are centrally situated in a network deserve high attention since they may have a large impact, and their particular individual properties may impinge upon the scale of the system.

**BONDING, BRIDGING, AND GROUPS**

A key structural characteristic of any network is its level of coherence (Wasserman and Faust 1994). A network that consists of just one distinguishable group, or of only one distinguishable core of centrally situated nodes surrounded by more or less peripheral others, is very different from a network where there are two or more distinguishable subgroups (or cores). In the case of networks consisting of several different subgroups, these groups could e.g. resemble occupational categories in a community (Paper V), or they could resemble groups of species that are more interrelated to other group members compared to non-members (Krause et al. 2003). In any case, the existence of subgroups implies that there are multiple centers/hubs in the network, and that the relational pattern both within and among these groups can be of importance.

Let us consider bonding. Herein, bonding refers to the tendency of actors to have more relations with other actors that are in some way similar or adjacent (McPherson et al. 2001), e.g. the tendency for species to interact more with other species in their immediate neighborhood (be it e.g. geographical neighborhood or nearby ecological niches). Bonding may then imply the existence of several subgroups in the network. Bridging, on the other hand, is different. Bridging refers to linkages between different subgroups in a network. A bridging tie would then be a bridge between different groups, and the actor(s) that hold the bridging ties are the brokers (see further in e.g. Gould and Fernandez 1989).

It seems that most social and ecological systems would benefit from both bonding and bridging. The process behind connectivity and density may be attributed to the, perhaps inevitable, tendency of individual actors to interact with similar actors (cf. McPherson et al. 2001). This tendency was observed in the fishing community where fishermen showed a propensity to form links with other fishermen using the
same type of fishing gear (Paper V). Bonding may, therefore, bring similar actors together in a social network, which could then make them perform better (Paper IV), and/or develop similar knowledge (Paper V). Bridging, on the other hand, implies ties between separate groups of nodes, and bringing these groups together could help prevent the development of an undesired “we and them thinking”, which can hinder collective action (cf. Ostrom 2005), but bridging would also (indirectly) reduce the structural characteristics of distinguishable groups in the network. Thus, it appears that a mix of bonding and bridging is desired (see also Oh et al. 2004, Newman and Dale 2005). Bonding provides for density and help e.g. similar actors to develop understanding of issues that are common amongst them, (e.g. Reagans and McEvily 2003), and bridging provides e.g. for long-range dispersal of species (Paper II and III) and/or the spread and accessibility of ideas and information in social networks (cf. Granovetter 1973). Bridges make it possible to utilize diversity present in the network by providing access to distant sources, in so doing they enlarge the repertoire of knowledge (Olsson et al. 2004) and/or the genetic material available in case of disturbance, which in turn enhances adaptive capacity. Bonding, on the other hand, helps develop specific knowledge (or specific adaptations to local conditions), i.e. it provides efficiency and within-group coordination (see e.g. Borgatti and Foster 2003 and references therein) while still providing diversity at an inter-group level.

Groups are structural features. As repeatedly stated, structure and process go hand in hand. Analyzing groups’ structures and their relations (bridges) in a network may reveal underlying processes; it may also help in explaining and predicting systems’ behavior. Such analyses are common in various scientific fields such as organizational research (Borgatti and Foster 2003) and food-web studies (e.g. Krause et al. 2003, Luczkovich et al. 2003), and this thesis shows that this approach is also applicable within the field of natural resource management.

THE NETWORK APPROACH AND TRANSDISCIPLINARY RESEARCH

Given the great complexity of ecosystems and the challenges humanity is faced with when managing these, integrated research approaches that consider both ecological and social aspects of reality are needed. Accordingly, one of this thesis’ objectives was to use the network structural perspective as a means of studying both ecological and social aspects of natural resource management. Throughout the work presented in this thesis, the network approach has indeed provided a common systems perspective and a common methodology in as disparate issues as species
dispersal in fragmented landscapes and communication and learning among small-scale fishermen. Based on these experiences, I argue that the network approach of viewing systems as sets of components with patterns of interactions can create bridges across different scientific disciplines and facilitate integrated research approaches. Transdisciplinary research has a lot to benefit from utilizing common patterns of abstraction, methods, and analytical toolboxes. Furthermore, there are already many firmly established theories, based on network approaches, in separate disciplines. The recent gain in interest from various scientific disciplines in the network approach (Freeman 2004) has also created considerable momentum with new analytic toolboxes, insights and theories on networked systems continuously being developed.

**CHALLENGES FOR THE FUTURE**

Since the network approach carries a number of advantages when studying both social and ecological systems, it seems natural to move beyond the scope of this thesis where social and ecological system properties were mostly considered separately and instead consider the possibility of merging social and ecological components and relations into integrated abstractions of coupled social-ecological networks. Such truly integrative approaches have been suggested to better encapsulate, and make explicit, the inevitable interrelation between natural and social systems (Janssen et al. In press). Although an interesting and promising suggestion, such integrative approaches require the researcher to simultaneously compare very different kinds of relations (e.g. comparisons of predator-prey interactions with friendship among human actors); issues that need to be solved before such approaches become truly useful (see further discussion in Janssen et al. In press).

An overall objective with this thesis was to increase understanding of the connection between network structure and function. Network analysis can uncover numerous structural characteristics in any network, but how these characteristics relate to matters of importance in natural resource management is not always straightforward. For example, several functional (social) properties such as adaptability, learning and ability for self-organization are often put forward as instrumental. However, these properties often benefit from a number of distinct network structural characteristics, as this thesis has shown, thus there may be inherent juxtapositions between different structural characteristics that need to be balanced in what we envision to be social network structures conducive to natural resources management (cf. Bodin et al. In review). The same argumentation applies to different types of ecological networks.
Networks of any kind are rarely static, i.e. they constantly change and develop over time. People change and adapt and, accordingly, their ties with others change as well. Species invasions, evolution, and climate change induce changes in food-webs, and changing land-use patterns and human population growth often cause habitat fragmentation and changes in landscape connectivity. Thus, it is important to understand consequences of changes in networks, as well as to understand the drivers behind these changes. Much of the network-oriented research has focused on static network analysis, although there are several ongoing research initiatives that take on a more dynamic approach (see e.g. Breiger et al. 2003 and references therein). In natural resource management, change and dynamic are of considerable interest (see e.g. Gunderson and Holling 2002, Berkes et al. 2003), hence a major challenge for the future is to better understand causes and consequences of change in both social and ecological networks.

Scale-issues are important to consider but are rarely well understood. Many network studies focus on relatively small and limited-scale systems such as relations among villagers in one village (e.g. Paper V) or predator-prey relations in one bay area (Krause et al. 2003). Other studies focus on very large, coarse-grained systems, e.g. the pattern of relationships between countries or cities around the globe (e.g. Nemeth and Smith 1985). To better understand how networks on such different scales interact and relate to each other remains a major challenge for the future although such research exists, see for example (Polis et al. 2004).

Network studies are often “data-greedy”, i.e. much effort must go into collecting large quantities of network data (Marsden 1990, Breiger et al. 2003). This has obviously slowed progress in the field since empirical data is essential in developing validated knowledge. New technologies could, however, be of much help. For example, studying species dispersal in the field is normally very time-consuming. But innovative use of e.g. GPS technology, remote sensors and miniature radio transmitters could greatly reduce the burden of such data collection. In studying social networks, easy-to-use software programs are being developed that use the internet to provide interactive electronic questionnaires that simplify the relational data collection process (although it is limited to studies where the respondents have access to computers).

Finally, although this thesis argues for the benefits of the structural network approach to better understand the intrinsic complexities in natural resource management and ecosystems, it is desirable to apply several (both quantitative and qualitative) different research approaches (cf. Lubchenco 1998). Enhanced knowledge of complex systems, and relations between structures and processes, calls for multiple perspectives.
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Denna avhandlingen syftar till att bidra med kunskap om de problem och möjligheter som relaterar till uthållig förvaltning av naturresurser i sammankopplade, och synnerligen komplexa, sociala och ekologiska system. Den övergripande angreppssättet som använts har varit att betrakta och modellera omvärlden som bestående av enskilda sociala och/eller ekologiska komponenter och deras inbördes relationer, det vill säga som nätverk. Detta sätt att abstrahera omvärlden har den fördelen att det (1) lyfter fram och synliggör de komplicerade mönster av interaktioner som föreligger mellan de i systemen ingående delarna och (2) möjliggör för forskaren att analysera dessa mönster vilka sedermera förhoppningsvis kan bidra till att förklara specifika egenskaper och beteenden hos systemen. Avhandlingen har således ytterst syftat till att undersöka hur olika sociala och/eller ekologiska nätverks strukturella (topologiska) egenskaper kan påverka systemegenskaper som inom ovan nämnd naturresursforskningen har funnits vara viktiga för uthållig naturresursförvaltning. Till dessa systemegenskaper hör bland annat förmåga till anpassning och lärande (adaptiv kapacitet) och återhämtningsförmåga (resiliens, enkelt uttryckt systemets förmåga att återhämta sig till sin ursprungliga huvudsakliga konfiguration efter en störning i någon form). De nätverksspecifika strukturella egenskaperna som studerats är bland annat densitet (länktäthet), centralitet, gruppbildning och gruppöverbryggning. Övergripande resultat och analys, utfört inom ramen för denna avhandling, visar att det, i många fall, finns ett klart samband mellan nätverksstrukturen och systemets egenskaper, och att nätverkens struktur, för både ekologiska och sociala system, kan spela en avgörande roll för systemens adaptionsförmåga och resiliens. Vidare diskuteras också att det kan finnas motsättning-
ar mellan vissa nätverksstrukturella egenskaper och olika önskvärda systemegen-
skaper. Exempelvis kan en hög centralitet i ett informations- och
kommunikationsnätverk mellan olika förvaltare/brukare bidra till en effektivare
förvaltning då koordinering underlättas. Detta kan dock samtidigt även bidra till
en minskad anpassningsförmåga då ett fåtal individer blir väldigt tongivande och
andra kunskaper, vilka kan vara av avgörande betydelse för att till exempel
hantera en ovanlig yttre störning, får svårare att få genomslagskraft.

Nätverksperspektivet är ett gränsöverskridande abstraktionssätt så till vida att
ingående komponenter och interaktioner kan, till exempel, utgöras av arter och
deras predationsmönster (såkallade födovävar) men de kan även utgöras av
människor (individer) och deras vänskapsrelationer. På grund av denna generalitet
så har avhandlingen även syftat till att undersöka och presentera hur nätverkspers-
pektivet kan bidra till den transdisciplinära forskningen.

Avhandlingen är uppdelad i två större block, ett i huvudsak ekologiskt- och ett i
huvudsak socialt orienterat block (artikel II, III respektive IV, V). En övergripande
introduktion till nätverksperspektivet i sociala och ekologiska system ges i artikel I.
Både kvalitativa och kvantitativa metoder som till exempel konceptuell modelle-
ing, matematisk modellering, datorbaserad simulering, geografisk informationsbe-
handling och till viss del statistisk databehandling har använts i de olika artiklarna
liksom även enkäter, fältobservationer och intervjuer. Dock har nätverksperspekti-
vet varit den övergripande abstraktionsformen.

I det ekologiskt orienterade blocket används ett nätverksperspektiv för att studera
hur fröspridning påverkas av landskapsfragmentering. Även förutsättningar för
pollinering studeras, dock inte från ett nätverksperspektiv. Studieområdet är ett
jordbruksområde i södra Madagaskar. Landskapet består mestadels av jordbruks-
mark, men det finns även ett större antal utspridda ”öar” av mindre skogsdungar
(<0,5-95 ha). Dessa skogsdungar skyddas från avverkning och annan mänsklig
påverkan, i varierande grad, av lokalbefolkningen genom tabun och verkar ha
funnits under lång tid. Skogsdungarna härbärgerar ett stort antal arter som i sin tur
utför flera viktiga ekologiska funktioner/tjänster, till exempel pollinering och
fröspridning. I syfte att studera hur arter/individer lokalisera i de olika geogra-
fiskt separerade skogsdungarna kan röra sig i landskapet genom att förflytta sig
emellan dem, det vill säga hur ”ihopkopplade” de många små skogsdungarna är i
landskapet, så har ett nätverksperspektiv applicerats. Moderna i nätverket represen-
teras då av de enskilda skogsdungarna och länkarna representeras av möjligheten
för förflyttning (dispersion) mellan de olika skogsdungarna. På så sätt genereras ett
antal olika landsknapsnätverk; ett för varje art då olika arter besitter en varierande
förmåga att kunna röra sig i landskapet mellan skogsdungarna. Här så har en specifik lemurart (*Lemur catta*) studerats då dessa lemurer är viktiga fröspridare i detta landskap.

Den första artikeln i det ekologiska blocket (artikel II) fokuserar på hur väl nuvarande fragmenterade landskap möjliggör för lemurers fröspridning samt hur väl det möjliggör för pollinering utförd av bin. Vad gäller pollinering så utgicks från att skogsdungarna utgör boplats för bin, och att dessa bin endast kan pollinera växter inom en viss radie från skogsdungarna. Vidare så studerades effekterna av en möjligt scenario där de minsta skogsdungarna avlägsnats. Detta scenario skulle kunna bli verklighet om tabusystemet som upprätthåller skyddet för skogsdungarna tillåts erodera, vilket det idag finns vissa indikationer på att det gör. Resultaten visar att dagens fragmenterade landskap möjliggör för en ytmässigt omfattande fröspridning och pollinering. Samtidigt demonstreras att effekterna av ett borttagande av de mindre skogsdungarna kan bli mycket omfattande och att dessa försämringar kan ske i abrupt i etapper; detta trots att den totala skogsarealen reduceras förhållandevis lite. En av slutsatserna blir då att inte bara ytan av habitat är viktig för att upprätthålla viktiga ekosystemtjänster i landskapet, utan kanske är dess geografiska konfiguration av minst lika stor vikt. Detta är något som tyvärr ganska sällan uppmärksammas vid utformningen av till exempel naturreservat. Slutligen är det intressant att notera att det tabu som omgärdar skogsdungarna tycks ha bidragit till att upprätthålla de studerade ekosystemtjänsterna.

I artikel III så vidareutvecklas nätverksperspektivet genom att flera olika nätverksorienterade metoder, mått och modeller som utvecklats inom andra forskningsfält (till exempel social nätverksanalys) appliceras på tidigare beskrivna landskapsnätverk. Med hjälp av dessa metoder så kan dels (1) internt sammanhängande grupper av ”habitatöar” (grupper av skogsdunger i Madagaskarfallet) identifieras, dels kan (2) enskilda habitatöar, vilka jämfört med andra bidrar betydligt mer till att upprätthålla kontakten (graden av ihopkoppling) i landskapet, identifieras. Sådana analyser kan vara lämpliga för att studera metapopulationsfenomen och/eller olika inom-artsliga fördelningsmönster (till exempel geografiska kön- och åldersfördelningar), eller för att identifiera enskilda habitatöar lämpliga för skyddsåtgärder. De föreslagna metoderna appliceras på det lemurbaserade landskapsnätverk i södra Madagaskar som togs fram i artikel II, och de resultat som erhållos med de föreslagna metoderna jämförs med resultaten av vad användandet av redan befintliga analysmetoder genererar. Denna jämförelse indikerar att de föreslagna metoderna verkar vara speciellt lämpade för att studera landskap där nivån av fragmentering är intermediär, det vill säga inte så kraftig att landskapet upplevs som helt splittrat, men inte heller som helt sammanhängande. Slutligen så introducerar artikeln ett datorprogram som utvecklats för att kunna genomföra de ovannämnda analyserna.
Det i huvudsak socialt orienterade blocket behandlar hur olika sociala nätverk mellan individer, till exempel jordbrukare, kan påverka förutsättningarna för en uthållig förvaltning av naturresurser. Utgångspunkten är att sociala processer/fenomen som till exempel lärande, kommunikation, påverkan/inflytande etc. kan ha en avgörande betydelse för olika samhällens/gruppers förmåga att hantera komplexa ekosystem. Detta är speciellt viktigt vid användarnära förvaltning då mindre grupper av brukare/nyttjare ges mandat att själva förvalta vissa naturresurser, en förvaltningsform som ofta förordas då till exempel närheten till naturresursen skapar möjlighet för dels snabba återkopplingar och dels genererandet av starka incitament för en långsiktig uthållig förvaltning.

Den första artikeln i det socialt orienterade blocket (artikel IV) utgår från en konceptuell modell över en förvaltningssituation där ett antal brukare är åsatta att efter bästa förmåga maximera avkastningen från varsin egen individuell naturresurs. Den modellteknik som används är såkallad agent-baserad simulering där ett antal virtuella datorbaserad agenter (i detta fall brukarna) programeras att agera och interagera efter ett antal i förväg specificerade regler. Simuleringen ”körs” och genererar därmed data som sedan analyseras, det vill säga modellen blir ett sätt att genomföra experiment.

I modellen så tillåts brukarna (agenterna) att utbyta erfarenheter i ett nätverk för att därigenom förbättra sina möjligheter för att lära sig hur naturresursen fungerar, och därmed ge dem möjlighet till en bättre avkastning. Den huvudsakliga forskningsfrågan som modellen försöker besvara är hur strukturen på det sociala nätverket påverkar den samlade avkastningen, det vill säga summan av alla brukares enskilda avkastningar. I detalj, den strukturella nätverksegenskap som studeras är densiteten (länktättheten) i det sociala nätverket.

Resultaten visar att bäst avkastning erhålls vid intermediära densitet, det vill säga någonstans mitt emellan maximal densitet (där alla är ihoplänkade med alla andra) och inga länkar alls. Dock så ger även låg densitet avsevärd förbättring jämfört med inga länkar alls. Vid hög densitet så beter sig dock alla agenter väldigt lika (med andra ord synkroniserat), vilket visar sig ge upphov till sporadiska kollaps där samtliga agenter simulerar misslyckas med sin förvaltning; den samlade avkastningen faller då dramatiskt. Detta beteende förklaras med att den stora densiteten av länkar leder till att alla får tillgång till alla andra erfarenheter, vilket i sin tur leder till att alla tenderar att fatta samma beslut. Detta leder följaktligen till att alla kommer att generera väldigt liknande erfarenheter. Denna reduktion i erfarenhetsbasen gör systemet av brukare såbart för oväntade förändringar, och det är förklaringen till att samtliga brukare ibland simultant driver sina naturresurser till
en kollaps. Översatt till verkligheten skulle detta kunna få stora negativa konse-
venser då hela samhällen av brukare i så fall samtidigt skulle fallerar in sin
förvaltning och den samlade avkastningen skulle därmed i ett sådant scenario
nästan helt uteblå.

Den andra artikeln i det socialt orienterade blocket utgår från en fallstudie av en
mindre kustby i östra Afrika (Kenya) där fiske utgör den huvudsakliga inkomstklä-
llan. Det förhållandevis höga fisketrycket på denna kuststräcka har lett till reduce-
rade fiskebestånd. Detta har dock inte föranlett de lokala fiskarna i studieområdet
att vidta några kollektiva åtgärder som till exempel att begränsa sina fiskeuttag.
Fallstudien syftar delvis till att förklara varför så inte skett, och utgångspunkten är
att söka förklaringar i byns sociala nätverksstrukturer. Studien syftar också till att
söka efter underliggande attribut/egenskaper hos byborna som korrelerar med
deras sociala tillhörighet/gruppstillhörighet. Huruvida strukturen i det sociala
nätverket, som omfattar informations- och kunskapsöverföring relaterande till hur
naturen fungerar, bidrar till olika kunskaper hos olika grupper av individer har
också studerats.

Resultaten visar att tydliga grupperingar finns i byn, och att när det gäller utbyte av
ekologisk kunskap och information så korrelerar dessa grupper med individernas
yrkestillhörighet, till exempel så kommunicerar fiskare främst med andra fiskare.
Mer specifik för just fiskare så korrelerar grupptillhörigheten med den typ av
fiskeutrustning de använder. Vidare, en jämförelse mellan olika gruppars olika
ekologiska kunskaper och de sociala relationerna indikerar att strukturen på det
sociala nätverket delvis sammanfaller med kunskapsfördelningen. Då tidigare
forskning visat att gemensam förståelse av hur underliggande ekosystem fungerar
är av stor betydelse för att förmå olika brukare och intressenter att kollektivt enas
om uttagsbegränsningar så framläggs hypotesen att nätverkets struktur, med dess
påverkan på informationsutbytet och kunskapsfördelningen, delvis kan förklara de
uteblivna initiativen vad gäller uttagsbegränsningar i studieområdet.

Den nätverksstrukturella analysen av de sociala nätverken visar också att den
specifika grupp fiskare som fiskar från kanoter ute på reven besitter en central
position. Dessa fiskare är tack vare sin fiskemetod relativt mobila och kan kompen-
sera för en nedgång av de lokala fiskebestånden med att fiska längre bort. Med
andra ord, incitamenten för att genomdriva gemensamma begränsningar i fiskeut-
taggen kan antas vara lägre för dem än för andra grupper av fiskare. Följaktligen så
utnyttjar de inte sin fördelaktiga sociala position för denna typ av initiativ. Andra
grupper av fiskare som skulle ha mer att tjäna på denna typ av initiativ, men som
inte besitter samma fördelaktiga centrala position, blir samtidigt undanträngda och
kan därmed få svårare att få gehör för sina intressen.