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Research, part of a Special Feature on Understanding Adaptive Capacity in Forest Governance

Interlocking panarchies in multi-use boreal forests in Sweden

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ABSTRACT. This paper uses northern Sweden as a case study of a multi-use social-ecological system, in which forestry and reindeer husbandry interact as different land use forms in the same area. We aim to describe the timeline of main events that have influenced resource use in northern Sweden, that is, to attempt a historical profiling of the system, and to discuss these trends in the system in terms of adaptive cycles and resilience. The study shows that key political decisions have created strong path dependencies and a situation in which forestry today is characterized by low flexibility and low resilience due to the highly optimized harvesting of tree resources. Since forestry is the overwhelmingly strongest actor, trends in forestry from the mid-19th century forward are, to a large part, driving dynamics in reindeer husbandry and environmental protection, resulting in a system of interlocking panarchies with large implications for the competing land uses.

Key Words: *adaptive cycles; boreal forests; conservation; forestry; historical profiling; panarchy; reindeer husbandry*

INTRODUCTION

A forest is a multifaceted, complex system that includes many natural resources, such as timber for forestry, grazing for reindeer husbandry, biodiversity, and recreational experiences. Any system dealing with natural resources can be seen as a coupled social–ecological system (SES) (Walker and Salt 2006). Such systems consist of many linkages and feedbacks, which may create responses and system behavior that are difficult to predict, including shifts to alternative states (Walker and Meyers 2004, Kinzig et al. 2006). The multiple use character of the forest means that many stakeholder groups may have different, and sometimes conflicting, goals for the management of the ecosystem, with subsequent challenges for balancing these different goals (Hyttönen 1995, Keskitalo 2008a). This creates a situation in which single goals cannot be optimized and the sustainable management of the system should incorporate management for resilience, in order for the system to be able to absorb disturbances and still retain its basic functions (Walker and Salt 2006). In addition, external forces, such as global markets and climate change, also affect the rules of the game. Coordination of the goals of multi use forest management thus requires both an understanding of the present forest system and policy and an understanding of how changes in conditions may affect these.

This study will treat social–ecological systems as characterized by periodic changes, or so called adaptive cycles, which have been used to study regional SESs in, for instance, Australia, Zimbabwe, and China (Allison and Hobbs 2004, Abel et al. 2006, Dearing 2008). The adaptive cycle can be described by four phases: a growth or exploitation phase (the r phase), a conservation or consolidation phase (the K phase), a collapse or release phase (the Ω phase), and a reorganization phase (the α phase) (Gunderson and Holling 2002, Walker and Salt 2006). The first two phases are sometimes called the foreloop, while the latter two phases are called the backloop. While not all systems go through the entire cycle during periods of change, the concept has been useful for identifying changes and emphasizing the dynamic nature of SESs (Cumming and Collier 2005, Abel et al. 2006).

Adaptive cycles for key system factors at different temporal and spatial scales make up every social–ecological system (Holling et al. 2002, Walker and

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Salt 2006). For instance, forest dynamics are governed by processes at different scales, ranging from an individual leaf to a tree to a forest stand and to a forested landscape, etc. Similar hierarchical scales and processes are found in social systems, ranging, for instance, from individuals to families to communities to nations. Each one of these levels in a SES may have its own adaptive cycle, which in turn may influence adaptive cycles at scales both above and below. For instance, a forest fire is dependent on an ignition event, the amount of fuel load, which depends on tree growth rates and tree mortalities, connections between landscape structures, and weather conditions (cf. Holling et al. 2002). All operate on different scales and it is the cross-scale interactions among the factors that converge on the conditions leading to a forest fire. Such a hierarchy of linked adaptive cycles is called a “panarchy” (Holling et al. 2002), in which different factors may interact with each other in ways that are difficult to foresee and may together drive the system.

The identification of the key factors that drive actions in the system can be based on critical events, corresponding to a method of assessing resilience called historical profiling (Carpenter et al. 2005). In historical profiling, distinct dynamic regimes in the SES are identified, and events taking place during transitions in each of these regimes, for instance, through changing land use patterns or changing legislation that impact land use, are analyzed. This paper will use northern Sweden as a case study of multi use systems in which different sectors use the same area for different purposes. In our case study, the purpose is to describe a timeline of important key events that have influenced resource use in northern Sweden, and to discuss these trends in terms of adaptive cycles and resilience. We use the concept of panarchies to attempt to reduce the complexities in the interactions within multi use boreal forests. We will treat the social–ecological system in terms of what can be termed its sub-systems: forestry, in which environmental protection will also be treated, and reindeer husbandry. As the governance of these sub-systems is strongly separated into different sectors (for instance, regulated by different ministries, governmental departments, and agencies, and with different interest organisations), we will study the internal dynamics within each sector and the interactions between these in order to assess effects on the system as a whole. The sectorial division of the system has resulted in an institutionalization of the conflict situation (Keskitalo 2008b), and events in the governance of each sub-system will have large implications on the development of adaptive cycles.

Firstly, the paper will describe the case study area. Secondly, it will describe the adaptive cycle as can be seen in the meta-system of forestry, conservation, and reindeer husbandry. Finally, we will discuss interactions among the systems in terms of interlocking panarchies. Since this paper is based on an historical analysis, we wish to point out that these are our interpretations, which are based on varying amounts and qualities of data sources identified in the paper, for instance, in terms of historical information (see also Abel et al. 2006 for a similar discussion).

CASE STUDY BACKGROUND

The total forested area in Sweden covers some 23 million ha, the majority of which is used for forestry. About 50% of the area is owned by small-scale, non-industrial, private owners, large forest companies own about 40% of the land, and the rest is divided among other public owners. Approximately 1% of the productive forest is clear-cut annually. The total production value of forestry and forest products amounts to about 20,000 million Euros annually, with an export value of about 10% of all exported products from Sweden and about 4% of Sweden's GNP (Official Statistics of Sweden 2008). This makes forestry an important industrial sector in the country. However, forestry also has effects on other sectors, such as conservation. For instance, more than 50% of the red-listed species in Sweden are found in forests, but only about 3% of productive forests are protected; this figure reaches 8% if voluntary protection is included, but this lacks long-term guarantees.

In northern Sweden, boreal forests are of great importance for reindeer husbandry as grazing lands. The reindeer husbandry area covers about 40% of the country, and is divided into 51 herding districts, with the majority of the districts practicing a migratory herding system. Reindeer husbandry is a meat-producing industry that is under the exclusive rights of the indigenous Sami people. The total number of reindeer in Sweden is on average about 225,000 animals, counted as the size of the winter herds, and has remained so, albeit with considerable variations, for the last century (Fig. 1). Reindeer husbandry is dependent on large grazing grounds since only natural, low productive vegetation is used for forage. The semi-domesticated reindeer use alpine vegetation in the mountain range close to the Norwegian border during summer, while winter is spent on lichen-rich pine heaths in the boreal forest towards the Baltic Sea. Generally, winter resources are limiting, but a few herding districts have good winter grazing conditions and poor summer grazing conditions; descriptions of the Swedish reindeer husbandry may be found in Danell 2000 and Moen and Danell 2003. Grazing conditions related to weather and forage availability, together with access to land and disturbances from other land uses, are thus of prime concern for a sustainable industry (see e.g. Roturier and Roué 2009). Reindeer husbandry is of high cultural importance for the Sami people, but of lesser economic importance in Sweden nationally; in 2009/2010, the estimated total turnover was about 19 million Euros, or roughly 0.1% of the production value of forest products (Richard Doj, Sami Parliament, 2010, *personal communication*).

RESULTS

Forestry and effects on environmental conservation

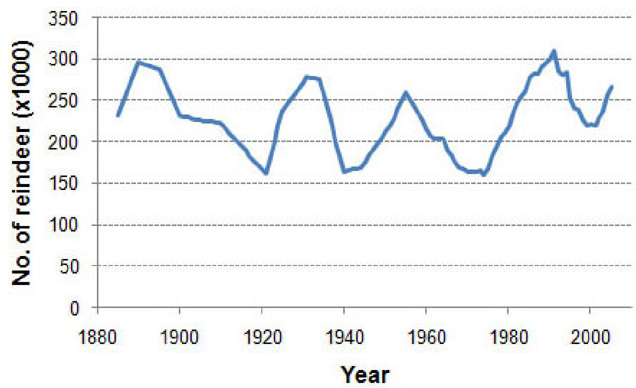
Before the mid-19th century, the boreal forest consisted of all-aged, multi-storied stands in a landscape mosaic (Östlund et al. 1997). The most important structuring processes were fires and storms. Mean fire intervals were in the range of 80-100 years (Zachrisson 1977, Engelmark 1984, Engelmark et al. 1994), but there were large variations at the landscape scale, for instance, due to the presence of mires (Hellberg et al. 2004). An estimated 1 % of the stands burned every year (Zachrisson 1977), and no human influences on the fire regime can be detected before the 18th century (Carcaillet et al. 2007). Dry pine-dominated stands, in particular, burned repeatedly through low-intensity fires, creating open all-aged stands that were important for creating and maintaining lichen cover on the ground (Östlund et al. 1997, Axelsson and Östlund 2001, Berg et al. 2008).

The forests at this time went through repeated adaptive cycles whereby regeneration and growth led to a build-up of fuel, known as the foreloop. Ignition from lightning then led to a release and reorganization of the stand, that is, the back-loop. With the advent of large-scale forestry and fire suppression from the late 19th century onward, the boreal forest shifted into a new adaptive cycle that has yet to play out its full potential. We will attempt to describe some of the trends and key events.

At the end of the 19th century, new timber markets opened up and forests became an economically valuable resource. Sawmills were built on the Baltic coast, close to the river mouths of the major rivers. Forest stands were harvested and the timber was floated on the rivers down to the sawmills. In some places, this period can be characterized as ecological devastation of the forests with no consideration for regeneration or long-term sustainability. Old-growth pine stands were among the first to be harvested (Östlund et al. 1997). This continued until the 1903 Forestry Law, in which it was stated that over-harvesting must cease, and a law on regeneration measures after harvesting was passed (Ekelund and Hamilton 2001). Local clear-cutting eventually ceased, and, from the 1920s, most forests were harvested through repeated selective logging in which the largest trees were selected and the forest was left to regenerate naturally. This produced poor quality forest stands because of low growth rates and low forest regeneration. The Forestry Law of 1948 aimed at increasing timber production to provide a more steady supply of timber to saw- and pulpmills, with strong criteria related to profitability that should govern forestry. This, together with the development of the chain-saw and efficient forest harvesters, shifted harvesting methods from selective logging to clear-cutting, which produces even-aged, one-storied tree monocultures. Clear-cutting, coupled with regeneration criteria, was turned into law in the Forestry Law of 1979.

The increasing optimization of harvesting rate in the boreal forest has of course led to large changes in the landscape. For instance, studies from different parts of northern Sweden have shown decreases in old-growth stands (>150 years old) from 83 % in 1910 to 3 % in 1980 (Östlund et al. 1997). Similarly, mean patch sizes of old-growth forest decreased by an order of magnitude (Axelsson and Östlund 2001), and mean stand ages went down from 200 years to 74 years (Eriksson et al. 2000). Silvicultural measures to increase growth and regeneration were also introduced, such as herbicide treatment to reduce the proportion of deciduous trees, prescribed burning of clear-cuts, and soil scarification (Axelsson et al. 2002, Berg et al. 2008). The standing volume of timber was lowest in the 1940s

Fig. 1. Number of reindeer in the Swedish reindeer husbandry area. The number is given as the size of the winter herd. Data from Moen & Danell (2003) and the Sami Parliament official statistics (http://www.sametinget.se).

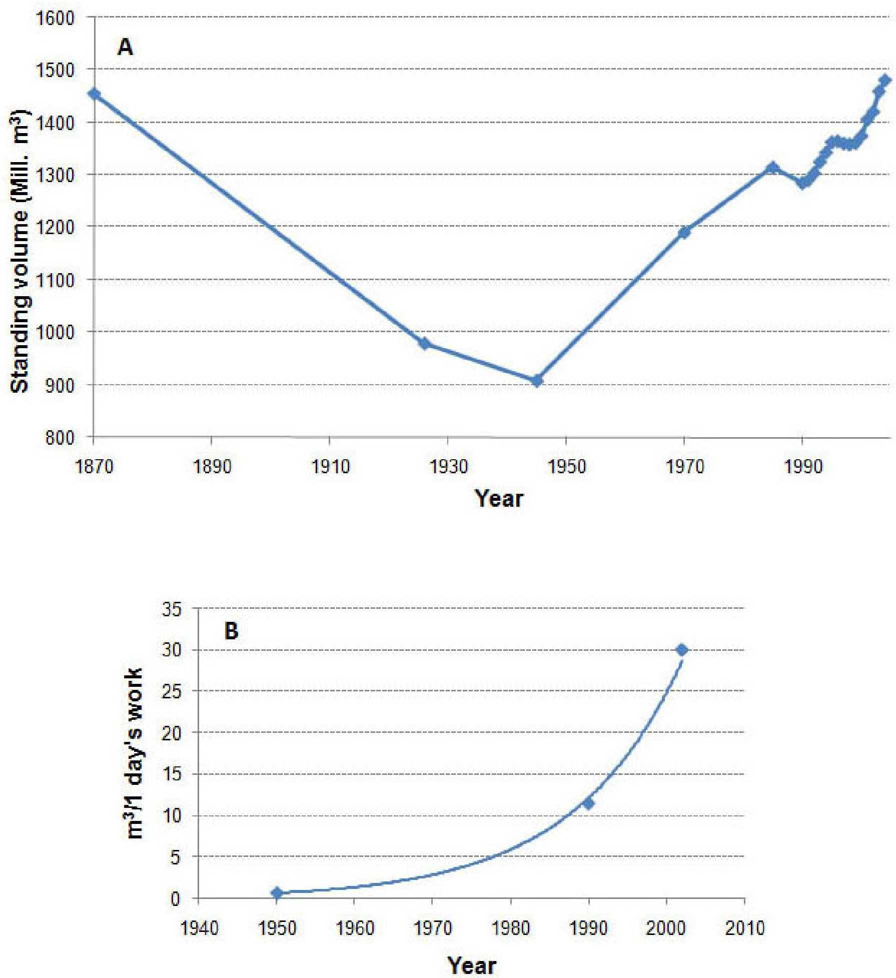


due to selective logging and did not recover to the level of 1870 until the turn of the 21st century (Fig. 2a). However, today the forests are dominated by young, dense stands in comparison with the open, old-age stands 150 years ago.

The trend toward more intensified silviculture during the 20th century can be seen as the increased optimization of forest resource harvesting, i.e., moving up the foreloop. To illustrate, in 1950 it took one man one day to produce one cubic meter of wood. In 1990, one man in one day produced 11.5 times as much, and the efficiency is now over 30 times as high as in 1950 (Holmberg 2005, Fig. 2b). The number employed in forestry has decreased by at least one order of magnitude since WWII (Holmberg 2005), and site productivity has increased due to more efficient silviculture (Berg et al. 2008). The development of forest-related industries has also become more strongly connected to the resource itself. For instance, in 1976, a bill was passed that states that new investments in forest industries must be linked to the secure production of timber or pulp (Holmberg 2005). This has led to even stronger optimization such that, for instance, it is considered impossible to convert to continuous-canopy forestry, which may have advantages for biodiversity, as that would result in a 20% reduction in timber production, which, in turn, would have strong negative economic effects for the saw- and pulpmill industries (Karlsson and Lönnstedt 2006).

The development of industrial forestry has also had strong impacts on the ecosystem, particularly through the removal of natural disturbance regimes, such as fires (Kuuluvainen 2002) and resulting structures, such as dead wood (Fridman and Walheim 2000), and through fragmentation of remaining old-growth patches (Mladenoff et al. 1993, Komonen et al. 2000). Even though the first forest reserves (known as *Domänreservat* in Swedish) were established in 1909 in Sweden, forestry could continue virtually without consideration of any environmental concerns up to the 1960s (Ekelund and Hamilton 2001), and protection of biodiversity was not given equal weight to timber production until the Forestry Law of 1993. This is reflected in the number of protected areas in northern Sweden, where the majority of the areas were established after 1990 (Moen and Eckerberg, *unpublished manuscript*). Today, about 3% of the productive forest in Sweden is protected, while Angelstam (in Ekelund and Hamilton 2001) has suggested that at least 9-16% of the forested area needs to be protected in order to conserve biodiversity. Many of the red-listed species in boreal forests are associated with structures or processes that are scarce today, such as burned areas, dead and decaying wood, deciduous trees, gaps, and stands with long canopy continuity (Esseen et al. 1997). The majority of stands where red-listed species occur, outside of protected areas, are small with a median size of 1.4 ha (Aune et al. 2005), and likely to exhibit an extinction debt (sensu Tilman et al.

Fig. 2. A. Changes in the standing volume of timber summed over the five northernmost counties in Sweden. Data from 1870 from Linder and Östlund (1992), other data from the Swedish National Forest Inventory (SOU 2001:101). The data before 1990 are averages, while the data after 1990 are moving 5-year averages.
B. Estimated harvesting efficiency, measured as cubic-meters of wood produced by one man in one day. Data from Holmberg (2005)



1994), and may thus currently be going through a release and reorganization phase (Berglund and Jonsson 2008).

Reindeer husbandry

Sami land use has a long history in northern Sweden. The first people colonized the Scandinavian peninsula after the deglaciation some 10,000 years ago. Early land use was focused on hunting and fishing. For instance, Sami villages in the 1500s had a round shape typical of hunter and gatherer communities (Lundmark 1998). During this time, each family had a few reindeer for milking, as draught animals, and as decoys when hunting wild reindeer. In 1602, a new tax decree was issued, which forced the Sami to pay tax to the Swedish state in reindeer meat to feed the large Swedish armies at the time, rather than in the squirrel and marten pelts that had been the rule earlier. This caused an increase in hunting for wild reindeer followed by a strong reduction in wild reindeer populations, which in turn led to an increase in domestic herds (Lundmark 1998). The change from a predominantly hunting community into a predominantly herding community that evolved during the 17th and 18th centuries constitutes an important process that led Sami land use in a new direction, and that has strong ramifications for the situation today. This can be seen as an example of path dependency in the development of new institutions regulating Sami land use (Thelen 1999). Path dependency in this context refers to the deterministic properties of institutional development, whereby “initial social outcomes concerning institutional, organizational, or policy design, even suboptimal ones, can become self-reinforcing over time” (Pierson 2002:372). Or put slightly differently: choices made restrict future options.

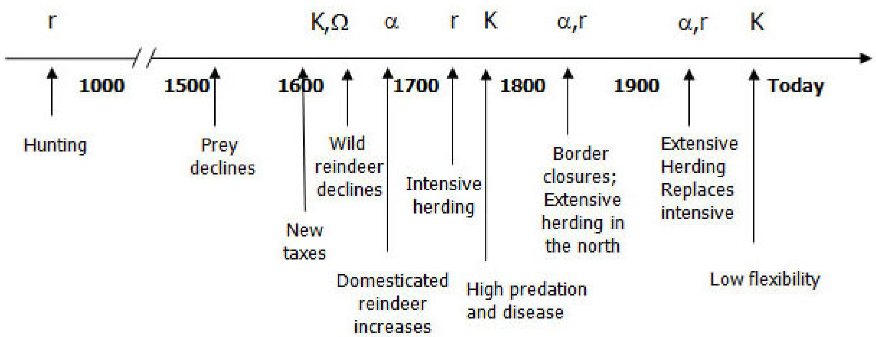
The earlier form of reindeer husbandry that developed, which is usually described as the intensive form, consisted of small reindeer herds that were watched on a day-to-day basis. The primary production was cheese made from reindeer milk (Lundmark 1998). The focus on milking made it necessary to keep reindeer herds close together during summer and as the herd size increased, diseases could easily spread (Lundmark 2006). During the 18th and 19th centuries, several crises affected reindeer husbandry, including high predation pressures, disease outbreaks, and competition from Swedish colonizers; the latter was a process that started in the late 17th century, but gathered momentum in the mid- to late 18th century (Lundmark 1998). The crises resulted in many Sami abandoning reindeer husbandry.

A significant event in the development of Sami land use was the closure of the borders between Norway, Finland (then Russia), and Sweden. In 1852, Russia closed the borders between Finland and northern Norway, forcing many Sami to move to Sweden since it was still possible to access their traditional winter grazing grounds in Finland from the Swedish side. In 1889, Russia closed the borders between Finland and Sweden, effectively cutting the Sami off on the Swedish side (Lundmark 1998). This led to a high density of reindeer close to the border and a lack of grazing grounds to support them (Lantto 2009). This, together with a convention with Norway that reduced the possibility of interborder migration (Lantto 2003, Pedersen 2009), resulted in the more-or-less forced migration of both Sami and their reindeer towards the South of the reindeer herding area in Sweden. The form of reindeer herding practiced by these Sami, usually referred to as the extensive form, differed from the intensive form. Reindeer herds were bigger and production focused on meat production. Herds were left unattended for extended periods during the summer since it was not necessary to keep them together for milking. These two forms of reindeer husbandry were not compatible, and where they met the large free-ranging herds assimilated the reindeer from the smaller herds. Eventually the intensive form was not possible to maintain, and in 1937 one of the Sami leaders, Gustav Park, stated at a meeting that the extensive form of reindeer husbandry had become totally dominating and had to be accepted (Lundmark 2006).

These changes in Sami land use over time can be seen as a series of adaptive cycles in which external forces have led to several reorganizations of land use patterns (see Figure 3). The first is the change from resource use based predominantly on hunting to resource use based on intensive reindeer husbandry; in this respect, one important event was the change in taxation which increased the hunting pressure on wild reindeer. This in turn reduced the wild reindeer populations and precipitated a change to domestication and milk production. One way of describing this is that hunting efficiency increased, moving up the foreloop of the adaptive cycle, until a decrease in the resource base forced a reorganization. The second step involves the transition from intensive to extensive reindeer husbandry as a response to geopolitical changes, that is, border closures, and to changed regulations, that is, the grazing convention with Norway. However, aspects of increased efficiency were also present, such as increased predation pressure and high disease incidence as a result of dense reindeer herds.

Reindeer husbandry has always been dependent on large grazing grounds since only natural, low productive vegetation is used for forage. During winter, the reindeer are dependent on ground lichens that they dig up through the snow, and on arboreal lichens during periods with difficult snow conditions. Today, forestry affects reindeer husbandry in many ways and on many scales (Danell 2005, Kivinen et al. 2010). For instance, forested landscapes become fragmented (Berg 2010), forest age structure changes (Berg et al.

Fig. 3. Examples of adaptive cycles in Swedish reindeer husbandry. The symbols above the timeline refer to the different phases of the adaptive cycle: the growth or exploitation phase (the r phase), the conservation or consolidation phase (the K phase), the collapse or release phase (the Ω phase), and the reorganization phase (the α phase). The data is adapted from Danell (2004, Fjällen i Fokus Conference, Umeå University, Sweden, *unpublished data*) and from the references in this paper.



2008), and infrastructure, such as roads, increase. Clear-cutting results in a loss of arboreal lichens (Esseen et al. 1996), and the short rotation time in current forestry reduces the time for recolonization (Dettki and Esseen 2003). Logging residues restrict access to ground lichens because they interfere with snow digging (Helle et al. 1990), and soil scarification to increase tree seedling establishment destroys ground lichens (Roturier and Bergsten 2006). The young regenerating forest stands are dense, which reduces the amount of light reaching the ground and thus lichen growth (Cabrajic et al. 2010). Other silvicultural measures to increase tree growth, such as fertilization, will also generally be negative for lichen growth (Olsson and Kellner 2006, Makkonen et al. 2007). These effects and trends are not specific to Sweden; conflicts between reindeer husbandry and forestry are also pronounced in Finland (Keskitalo 2008a, Raitio 2008).

DISCUSSION

Adaptive cycles in forestry, biodiversity, and reindeer husbandry

A number of characteristics with relevance to adaptive cycles can be identified. In general, increased optimization in forestry will lead to lower levels of resilience in the SES, i.e., a lesser capacity to cope with disturbances (Walker and Salt 2006). In terms of the adaptive cycle, we see forestry developments as moving up the foreloop into a strong conservation phase. It seems that periods of weak economies within forestry have led to harvesting regimes that overharvest forest production, and new methods have been taken into large-scale use without being tested (Ekelund and Hamilton 2001). Any disturbance, such as climate change, market failures, or financial crises, may cause a release and reorganization of the current forestry system in Sweden, and perhaps elsewhere. However, the system is also difficult to predict given its large dependence on external market conditions, something Ekelund and Hamilton (2001:3; our translation) note, for instance, in their history of forest policy in Sweden: “When establishing a new forest stand, it has so far not been possible to predict the main market at harvesting some 100 years in the future. This is likely to be equally difficult today”.

As a result of developments in forestry, biodiversity has probably already entered a release and reorganization phase as the few remaining protected areas are small and isolated. Unfortunately, the release phase may also lead to a loss of species, that is, a leakage out of the system, as indicated by the high number of endangered species in the forest. It remains to be seen if the current rate of conservation is sufficient to reduce the loss of biodiversity. There is also a strong concern within the forestry sector in

Sweden that changes in climate may result in increased damage by pathogens and insects (SOU 2007:60). At the same time, climate change is expected to lead to increased forest productivity in Sweden (SOU 2006:81), which has prompted the Swedish government to propose a bill for intensified forestry, including increased fertilization and thinning, a higher harvesting rate of biofuels, and the use of more fast-growing proveniences and species (Swedish Ministry of Agriculture 2007). These silvicultural techniques will increase forestry efficiency even more and thus lower resilience, and will, most likely, have strong negative impacts on biodiversity.

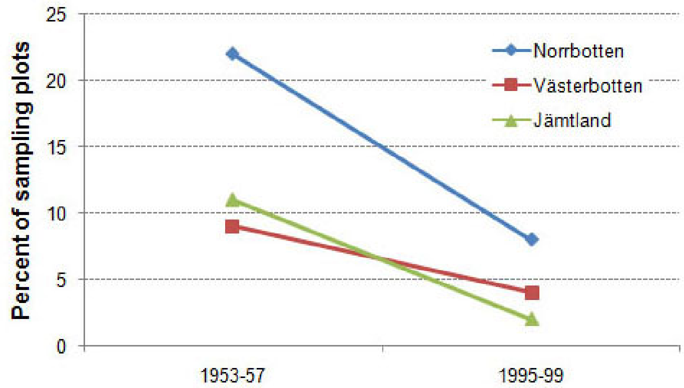
Reindeer husbandry has been shown to be very resilient to change in the past, as Sami land use has adapted to several different external influences (Fig. 3). Today, the situation may be seen as close to reorganization, due to its extensive land use needs, coupled with the existing fragmentation of areas and high degree of rationalization (Beach 2004). The industry is suffering from the cumulative impact of small incremental changes imposed by other land users. For instance, an individual forest stand that is logged, an area covered by a mine, or a new railroad may occur in only a very small portion of the herding district. However, taken together these encroachments will have a substantial impact on the amount and availability of grazing grounds. The gradual loss of land also has ramifications beyond that of the area loss itself; as the landscape becomes more and more fragmented and remaining grazing areas smaller and more isolated, use becomes much more difficult, and resilience is lost from the system (Danell 2005). It is likely that the level of conflict with other land users has increased over time, especially after the introduction of clear-cutting as the main silvicultural method for forest harvesting and regeneration in the 1950s. For instance, data from the National Forest Inventory suggests that roughly 50% of lichen-rich forest types have been lost, probably because silvicultural measures have resulted in decreased lichen cover so that areas have been classified as another forest type (Fig. 4; Sandström et al. 2006). It is also likely that the level of conflict will increase even further in the future as the burden of small incremental changes increases. This has caused some researchers to caution that reindeer husbandry, and with it the Sami culture, may collapse within a generation (Beach et al. 2005).

Interlocking panarchies

Our case study has illustrated path dependencies in forest landscape use in terms of the way in which increasingly intensive resource use systems are developed. These processes are determined by interactions on a number of different scales. For instance, forestry operates on, and is dependent on processes at scales from the stand to the international level. On the ecosystem side, the smallest scale that is managed is the stand, which is a relatively homogenous part of the forest, and silvicultural measures at the stand level create a forested landscape with a certain mosaic. On the governance side, forestry is strongly impacted by both economic and political factors. In a market context, forestry is driven by processes operating on scales ranging from individual companies to international markets. Political processes constitute priority systems that have large effects on the possibilities for adaptation in different sectors. This includes processes from the international level through to state regulations and to regional and local implementation and considerations. Conservation and reindeer husbandry also have their own internal dynamics that act on different scales, i.e., panarchies. Biodiversity patterns in an ecological time-scale depend on individual and species interactions, population, community and food web dynamics, and dispersal. All of these processes are, in turn, affected by abiotic factors and landscape properties, among other aspects. Reindeer husbandry is, on the other hand, affected by reindeer reproduction and mortality rates, amount and availability of forage, weather, and the balance between summer and winter grazing.

Each sector may thus be seen as a panarchy of linked adaptive cycles. These panarchies also affect each other, creating a system of interlocking panarchies connected by interactions among silvicultural measures and subsequent effects on biodiversity or reindeer grazing (Fig. 5). Our historical profiling shows that key political decisions have created strong path dependencies in this social–ecological system. These decisions range from border closures and tax systems established hundreds of years ago to more recent changes in management systems. An historical understanding is necessary to comprehend current resource use and lines of conflict. Further, we suggest that forestry today is characterized by low flexibility and low resilience due to the highly optimized harvesting of tree resources. We have already given several examples of interactions

Fig. 4. Percentage of sampling plots in the three northernmost counties in Sweden classified as lichen-type, i.e., containing >50% cover of lichens (Swedish National Forest Inventory data in SOU 2001:101)

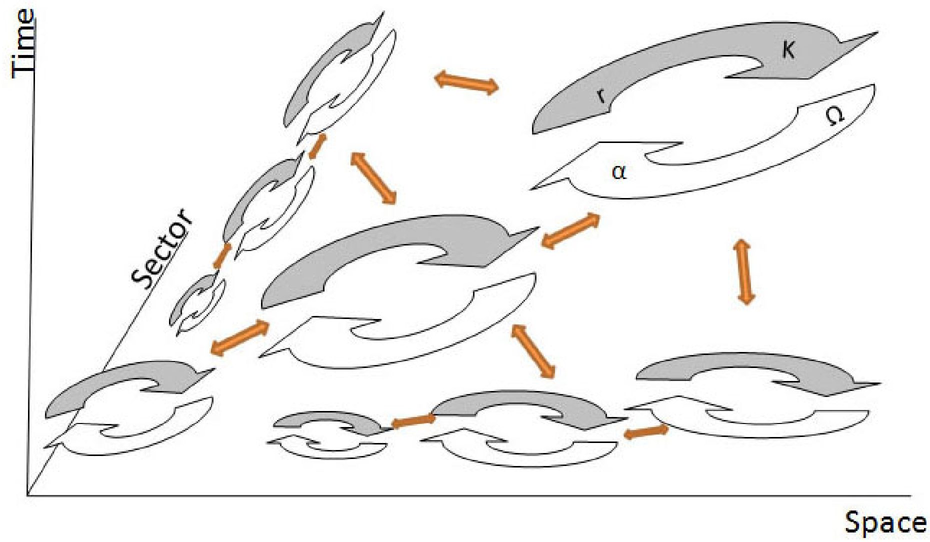


among silvicultural measures and the large effects on biodiversity or reindeer grazing. All of these examples can be seen as illustrations of connections among the panarchies. There are also other examples. For instance, reindeer grazing, which is linked to the reduction of lichens and in turn affects soil temperature and moisture, has been suggested to have positive effects on seed regeneration (Nilsson and Wardle 2005) and on tree growth (Fauria et al. 2008). On the other hand, grazing, trampling, and antler rubbing may cause damage to young tree saplings (Helle and Moilanen 1993). High biodiversity is generally thought to be necessary for maintaining both ecosystem services (Hassan et al. 2005) and resilience (Norberg et al. 2008). The way in which governance is functionally steering actions within forestry and reindeer husbandry can also be seen as related both to the political sphere, including formal laws and rights, and the economic sphere based on market demands, to which individual actors need to relate.

One reason for the large effects of forestry on reindeer husbandry, in particular, is the incongruence between management scales, and this may be a very clear example of connections between the panarchies. The management scale of a large forest company is that of their land holdings within a region. Within this region, they have a database of forest stands, varying from <10 ha to a few hundred hectares, which are planned to undergo silvicultural actions, such as clear-cutting or thinning. These stands are more or less interchangeable as long as the felling quota of the company is filled. On the other hand, the management scale of one reindeer herding district involves the landscape used by a winter herding group during perhaps a decade (in the order of several tens of thousand hectares), and may include many different forest owners and effects from other land uses, such as mines, tourism, energy production, and infrastructure. The landscape perspective is important for reindeer husbandry as it allows for a rotational use of grazing lands in relation to the dynamics of the lichen resource and to variations in weather. Without a landscape perspective, the herding groups will lose the buffering capacity that maintains resilience in their natural resource use (Sandström et al. 2003, Danell 2005).

A major problem in managing for increased resilience in the SES is that the governance of the sub-systems is totally separated into different sectors. We must thus understand both the internal dynamics within each sector and the interactions among the sectors to assess the sustainability of the system as a whole. Since forestry is the overwhelmingly strongest actor in the system, any change to forest management, be it increasing optimization as suggested in the recent government bill, or release and reorganization due to external disturbances, will have large implications for both conservation and reindeer husbandry. To discuss the future of the system, it is imperative to understand trends in the drivers affecting forestry. These drivers

Fig. 5. A schematic illustration of interlocking panarchies. Each set of linked adaptive cycles form a panarchy, representative of forestry, environmental conservation, and reindeer husbandry respectively. Processes in an adaptive cycle at a certain scale may affect both other adaptive cycles in the same panarchy, and adaptive cycles in other panarchies, creating a system with numerous interactions at many scales. See text for further details and examples.



may include, for instance, changes in the international market and demand for forest products, and large global trends that lie far beyond the local system in which the disturbances manifest themselves. It is also important to discuss the ways in which coordination among sectors can be increased, and develop further incentive structures for coordination at the local level where conflicts arise.

Possibilities for modifications of the state legislation have been assessed by a number of governmental committees, among other aspects with regard to Sweden's potential ratification of the ILO Convention No. 169 on indigenous people's rights to land. However, ratifying ILO 169, for example, would be politically difficult because of the current distribution of ownership and user rights, and because of the conflict of interest between the economically strong forestry interests and the reindeer husbandry sector, which is significantly weaker economically. While this may limit the potential for legislative changes that would actually shift power relations between the sectors, private and voluntary regulations such as forest certification, which extends the requirements for consultations beyond that of legislative demands, may serve to institutionalize new requirements to some extent (see Keskitalo et al. 2009). While these problems may seem sector-specific, the forestry–reindeer husbandry relationship is an example of the general problem of integration across sectorial limits, such as divisions between ministeries, departments and agencies. If the main practical possibility for improving the relationship between forestry and reindeer husbandry is through increased communication rather than legislation, such integration will be necessary.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/vol15/iss3/art17/responses/

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