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REVIEW PAPER

Climate Change, Land Use Conflicts, Predation and Ecological Degradation as Challenges for Reindeer Husbandry in Northern Europe: What do We Really Know After Half a Century of Research?

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Abstract Reindeer grazing has been entitled as ecological keystone in arctic–alpine landscapes. In addition, reindeer husbandry is tightly connected to the identity of the indigenous Sámi people in northern Europe. Nowadays, reindeer husbandry is challenged in several ways, of which pasture degradation, climate change, conflicting land uses and predation are the most important. Research on reindeer-related topics has been conducted for more than half a century and this review illuminates whether or not research is capable to match these challenges. Despite its high quality, traditional reindeer-related research is functionally isolated within the various disciplines. The meshwork of ecology, socio-economy, culture and politics, however, in which reindeer husbandry is embedded by various interactions, will remain unclear and difficult to manage, if actors and relationships are kept separate. We propose some targets for new integrative research approaches that incorporate traditional knowledge and focus on the entire human-ecological system 'reindeer husbandry' to develop solutions for its challenges.

Keywords Socio-ecological system · Pasture management · Landscape ecology · Arctic–alpine environments

STATUS QUO OF REINDEER HUSBANDRY

Grazing of arctic–alpine ecosystems by reindeer (*Rangifer tarandus*) has been entitled as ecological keystone (Vors and Boyce 2009). Reindeer act as an ecosystem engineer affecting ecosystem structures and processes at broad spatial scales (e.g. Suominen and Olofsson 2000). In Fennoscandia, about 40% of the area is used as reindeer pasture (Fig. 1, Tyler et al. 2007; Moen 2008). Furthermore, reindeer husbandry is tightly connected to the socio-cultural identity of the indigenous Sámi people (Jernsletten and Klokov 2002) and provides an important economy. In the further context, we use 'reindeer husbandry' as a general term, including concrete actions with the herd (herding), the overall organization (management), and the livelihood of families having a close relationship to the animals (Jernsletten and Klokov 2002).

Reindeer husbandry depends on the diversity of accessible natural pastures (Reindriftsforvaltningen 2010), covering the seasonally different needs of the reindeer as summarized in Box 1.

Pastures have also been affected by human activity and the historical development of reindeer husbandry. Because of the long history of human–reindeer interactions and the gradual development of today's situation (Box 2) it is probably of little use to discuss previous pasture conditions (e.g. Suominen and Olofsson 2000; Staland et al. 2011). Instead, we will outline some basic aspects important for the understanding of the broad scale grazing system 'reindeer husbandry'.

Grazing by reindeer constitutes a natural component of arctic–alpine ecosystems in Fennoscandia (Oksanen et al. 1995): ecosystem development has been shaped by grazing and associated trampling since the last glacial epoch. Suominen and Olofsson (2000) provide a comprehensive review of impacts of semi-domesticated reindeer on structure of tundra and forest communities in Fennoscandia. For instance, vast expanses of mountain birch forest changed towards prevailing open land, interspersed with scattered single trees or tree groups (Oksanen et al. 1995, see also Fig. 2). However, especially with regard to treeline, a multitude of hypotheses to explain its structure and position have been proposed. Apart from other environmental factors (e.g. herbivory), they focus mainly on

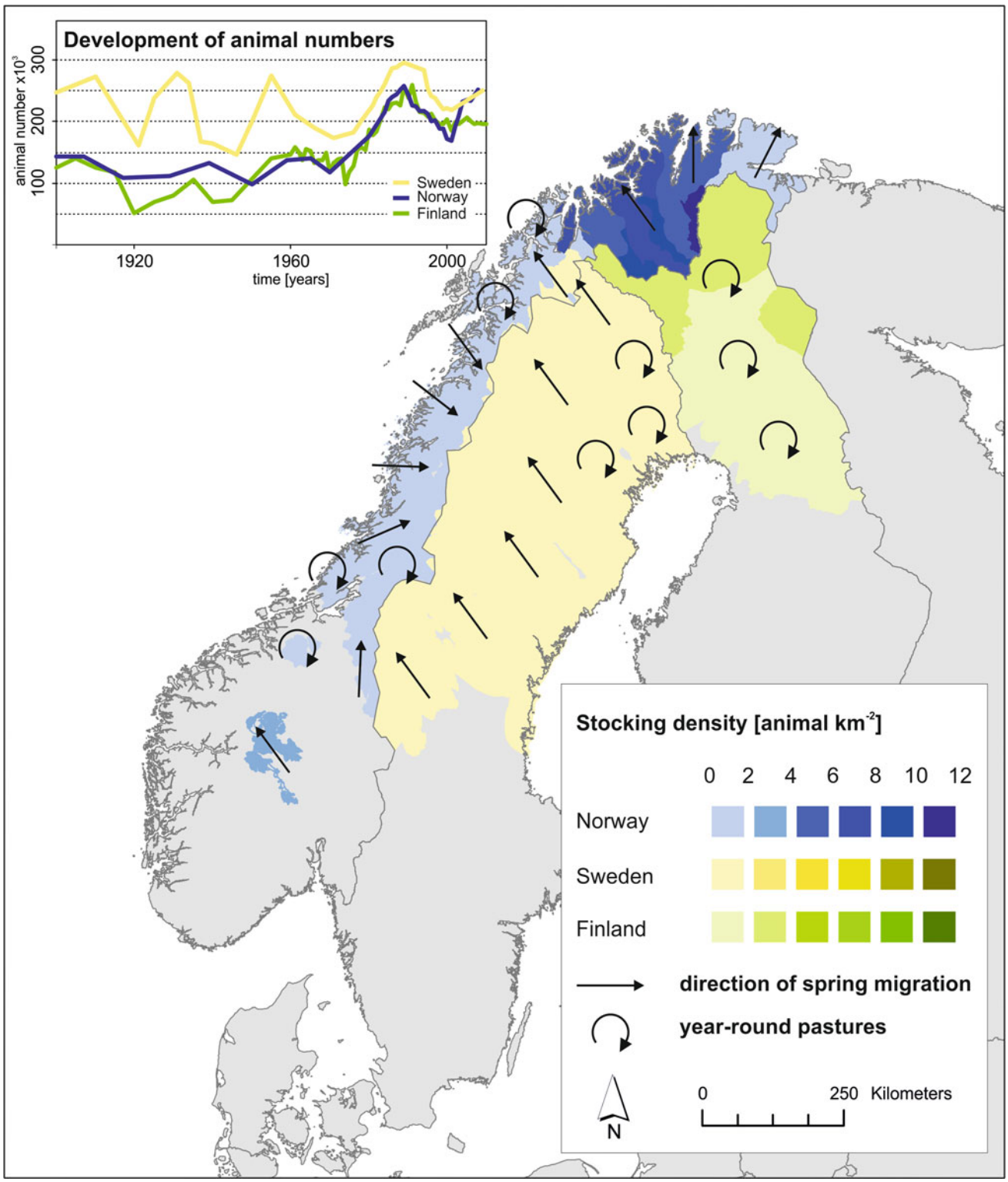

Fig. 1 Reindeer pastures in Norway, Sweden and Finland: Seasonal migrations of reindeer and historical development of reindeer numbers towards today's stocking densities are shown (based on data from Reindriftsforvaltningen, Sametinget and Paliskuntain Yhdistys)

climate (see Holtmeier and Broll 2005 for the review). Thus, pastures are not affected by reindeer grazing only, but also by climate and climatic change. Recently, van Bogaert et al. (2011) illustrated how complex these climate–vegetation–grazing interactions (which in case of reindeer husbandry are related to the human impact as

Box 1 The Reindeer—Adaptations to Pasture Conditions

The seasonal cycle in the reindeer's circumpolar distribution area is characterized by a short summer with good forage supply and limited forage quantity and quality during the rest of the year. The reindeer adapts to these conditions by seasonal cycles in its metabolism. Productivity and growth is limited to the summer season with access to high quality pastures at slopes and depressions (Danell et al. 1999a). During late spring and summer, the animals—in general opportunistic feeders with more than 200 species registered as forage plants (Gaare and Danell 1999)—feed on protein-rich herbs, grasses and leaves to support growth and lactation. Their energy demand sums up to 45 MJ day^{-1}, corresponding to the intake of 2.5–2.9 kg dry matter (Danell et al. 1999a). With withering of green pastures during autumn, metabolism switches towards maintenance (Gaare and Danell 1999). During winter, the energy demand drops to about 20 MJ day^{-1}. As reindeer have due to a specialized microbial flora in their rumen the unique ability to digest carbohydrate-rich lichens (Storeheier et al. 2002), this corresponds to the intake of 1.6–1.7 kg dry matter of lichens per day. Lichens dominate in areas with limited snow cover and are thus comparably easy accessible. Even if lichens constitute up to 80% of forage during winter, the reindeer does not depend solely on lichens—it might feed on accessible other phytomass as well (Gaare and Danell 1999). Due to the limited spatial extent (10–30% of the total grazing area) and their low productivity per unit area (10–30% compared to summer pastures), winter pastures are often described as the bottle-neck for reindeer husbandry as they determine the number of animals to be kept inside a grazing area (Gaare and Danell 1999; Jernsletten and Klokov 2002). To summarize, pasture usage by reindeer is naturally characterized by a seasonal migration between summer and winter pastures to meet the different seasonal needs—evidence for these natural migrations is provided by ancient trapping systems (e.g. Jordhøy 2008). Seasonal migrations in combination with marked differences between summer and winter diet secure an optimal utilization of the low primary production patterns in space and time. Due to migrations and feeding strategies, reindeer naturally affect their pastures to a much lesser extent than smaller herbivores (e.g. Olofsson et al. 2004a), like for instance the lemming (*Lemmus lemmus*).

Box 2 History of Reindeer Husbandry in Fennoscandia

Nowadays, reindeer are often used as emblematic for northern Europe and the culture of its indigenous people, the Sámi (Beach 1990). However, full and economically viable reindeer husbandry is a rather young phenomenon (Müller-Wille et al. 2006), in its present form shaped by external and internal forces (Lundmark 2007). Interactions between humans and reindeer in form of hunting date back to the late Pleistocene. Regarding the question when reindeer husbandry developed, there are two lines of argumentation (Bergman et al. 2008): Following the first, evolving fur trade and taxes during medieval times led to a sharp decrease in population size of wild reindeer. Hunting was during the sixteenth century subsequently replaced by intense nomadic herding of semi-domesticated reindeer through an expansion of small intensively managed herds already kept earlier (Müller-Wille et al. 2006; Lundmark 2007). According to the second line, the transition towards reindeer husbandry took place already much earlier, during the Iron Age (e.g. Andersen 2011). Regardless of which of these positions to be adopted, the small, intensively managed herds mark the first step towards present day's reindeer husbandry. During the nineteenth century, national border arrangements led to spatial interruption of migratory patterns between coastal summer pastures and continental winter pastures, often curtailing the access to previously used pastures (Müller-Wille et al. 2006; Lundmark 2007). In the late nineteenth century, the intensive herding of reindeer was succeeded by the more extensive large-scale herding still practiced today (Lundmark 2007). After World War II, Sámi life changed towards a gradual sedentarization. Market access increased, and during the 1960s reindeer husbandry was revolutionized through the introduction of snowmobiles and later all-terrain vehicles, further promoting the more extensive form of herding (Riseth and Vatn 2009). Due to differing economic development policies in Norway, Sweden and Finland, reindeer husbandry in these three countries was characterized by slightly different developments (Müller-Wille et al. 2006). Common in all three countries were several range restrictions that split pastures into many separate management districts, often delineated by natural obstacles or reindeer fences, as well as adjustments in herd composition and slaughter strategies to maximize production (Holand 2007). In general, private-owned reindeer graze on commonly managed pastures. In Norway and Sweden, reindeer husbandry is restricted by law to the Sámi people. In some smaller areas also non-Sámi may practice reindeer husbandry. Herd management primarily reflects the natural seasonal migrations (Fig. 1), which often involve both, arctic–alpine and subalpine/boreal grazing grounds. In Finland, both Sámi and Finnish people conduct reindeer husbandry, primarily in a more sedentary form in the boreal forest. Herd gathering and supplemental feeding during winter is quite common (Jernsletten and Klokov 2002). The number of reindeer in these three countries is quite comparable today, but shows a different historical development (Danell et al. 1999b; Jernsletten and Klokov 2002, see also Fig. 1). The recent development in reindeer husbandry strongly contrasts the general decline of livestock grazing in agriculture as shown for Norway by Austrheim et al. (2011). According to Oksanen and Riseth (2004), there are at least in Norway more people willing to participate than there is place, resulting in a constant pressure to expand the physical boundaries of the grazing system.

well) actually are: altitudinal shifts in tree line positions in the Abisko area in Sweden during the twentieth century has been strongly correlated regionally to reindeer numbers and not to climate change, even though temperature has increased by 2.5 K during that time.

In accordance with the pasture conditions, the numbers of reindeer have never been stable. Instead, they fluctuated widely with a period of 20–30 years in Sweden and at least until the 1970s less pronounced in Finland and Norway (Fig. 1). This behaviour reflects one of the basic mechanisms in population ecology, density dependence. Dependency on depletable resources, such as pastures creates alternating cycles of low and high population densities (e.g. Tveraa et al. 2007). However, ecological mechanisms alone fail to explain the development of reindeer numbers from the 1970s towards the highest peak ever in Norway

Fig. 2 Scattered single trees and tree groups above present forest line due to grazing near Kokelv, northern Norway (photo by R. Pape, 2010)

and Finland. Consequently, Oksanen and Riseth (2004) as well as Helle and Kojola (2006) argue that these cycles are not driven by ecological factors only, but also by an interaction of ecological and socio-economical factors. From an ecological point of view, winter conditions were favourable to reindeer from the mid 1970s to the late 1980s, dampening the bottle-neck effect of the winter pastures on herd size (Helle and Kojola 2006). Regarding the socio-economic factors, the combination of collective land use and private ownership of reindeer might add instability to the system (tragedy of the commons; Hardin 1968), even if this topic is controversially discussed especially in Norway: individual herders try to increase herd size, e.g. as insurance against potential population crashes and as social status (e.g. Johannesen and Skonhoft 2010). Furthermore, it seems likely that access to external money due to subsidies (enabling supplemental feeding in Finland, decreasing the need to slaughter in Norway) and the technological revolution of herding techniques (c.f. Box 2) contributed to the height of the latest peak (Moen and Danell 2003; Helle and Kojola 2006). In Sweden, this peak did not differ from the previous ones and a more sophisticated look on the situation in Norway and Finland reveals only the northern parts of the reindeer herding area to be responsible for the peaks. Riseth and Vatn (2009) discuss differences in natural conditions, ethnic relations and capacity building between southern and northern reindeer herding to be responsible for the differences, at least in Norway. A more detailed evaluation of explanations for the observed population trends is provided by Helle and Kojola (2006).

According to Oksanen and Riseth (2004), laws and administrative borders constitute another factor aggravating the inherent ecological instability of reindeer husbandry. Especially, winter pastures are sensitive to grazing and trampling (Väre et al. 1996), prompting for rational use. However, due to border arrangements and subsequent border closures between Norway, Sweden and Finland (c.f. Box 2), some Swedish districts have very restricted access to their traditional summer ranges in Norway, whereas Finnish and Norwegian Sámi have totally lost their grazing rights in the other country. Moreover, the delineation of districts in Finland is quite schematic with less reference to pasture conditions, and Finnish laws entitle the herders to have their reindeer wherever within the district they find it most convenient (Oksanen and Riseth 2004).

Based on this outline about the status quo of reindeer husbandry, its multi-facetted ecological, economical and social aspects become evident, highlighting the complexity of this grazing system. This background seems necessary to understand the challenges reindeer husbandry is facing today. Based on a review of relevant topics—out of a plethora of issues related to reindeer and reindeer husbandry published so far—we will examine whether research is capable to match current challenges of reindeer husbandry.

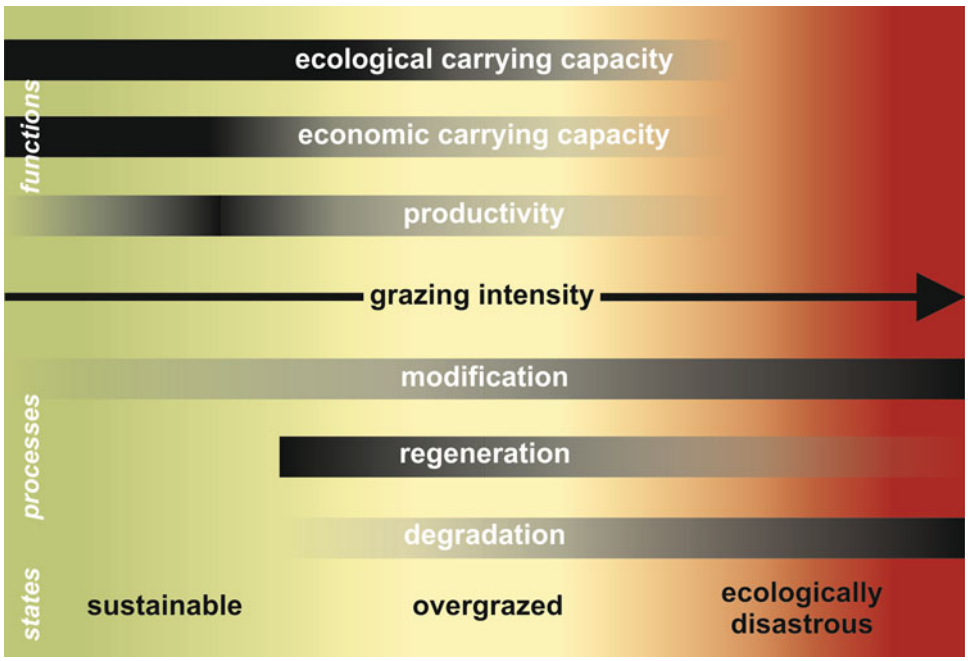

Fig. 3 Functions, processes and states of an ecosystem triggered by grazing intensity (based on Löffler 2004). Grazing implies a modification of the ecosystem, corresponding to degradation if the ecological carrying capacity is exceeded. Around this point of exceedance, the former sustainable system is transformed to an overgrazed system, characterized by a decline in productivity and an imbalance between degradation and regeneration which leads to a decline in carrying capacity as well. Under constant or even further increased grazing pressure, this process continues leading to zero production of the herd and diminished regeneration, perceived as ecological disaster

CHALLENGES FOR REINDEER HUSBANDRY

Throughout reports and articles, reindeer husbandry is described to face challenges, sometimes even called threats. But what are these challenges? Four of the most mentioned will be reviewed in the following.

Reindeer Husbandry and Ecosystems—From Keystone to Disaster?

Due to the reindeer population trends since 1970s (Fig. 1), a subsequent heavy use especially of winter pastures has been documented both in Finland and Norway. A similar trend has been obvious for some areas in Sweden, too (Moen and Danell 2003). As a consequence, a resulting dramatic decline in the cover of lichen heaths important as winter grazing grounds from about 30 to 1% in Finnmark (northern Norway) has been reported by Johansen and Karlsen (2005). Moreover, also a deterioration of summer pastures due to changes in plant species composition and soil erosion has been described at least for one district in Finnmark (Johansen et al. 2007). According to Löffler (2000), the combined effects on vegetation and soils have even led to a broad-scale depression of the altitudinal zonation. A decrease in body weight of reindeer, higher mortality and lower reproduction as clear signs of density dependency were reported in northern Finnish Lapland (e.g. Kumpula et al. 1998) and parts of Norway (Fauchald et al. 2004; Tveraa et al. 2007).

Facing this situation and fuelled by the media, a discussion of so-called 'overgrazing' developed during the last few decades, wherein reindeer have been accused to cause 'diminishing' of the pastures (e.g. Torp 1999). Moreover, herders have been stigmatized as eco-criminals as they transform the mountains into 'rocky areas' (Beach 2000). The well-publicized situation in northern Fennoscandia has generated the overriding view of reindeer grazing to be synonymous with 'habitat degradation' or even 'ecological disaster', intimately related to concerns about the sustainability of reindeer husbandry (Moen and Danell 2003; van der Wal 2006).

But may we judge the observed development as 'degradation' and 'overgrazing' (Löffler 2000), or even as 'ecological disaster' (Moen and Danell 2003)? Or have we just failed to accept alternative states of the pastures? Following van der Wal (2006), the reported changes in the state of pastures are merely a transition between different alternative states of an ecosystem, triggered by a change in grazing pressure. This view adopts the keystone herbivore hypothesis of Zimov et al. (1995): grazers manipulate their own food supply by forcing vegetation change from one state to another, enhancing ecosystem processes like nutrient turnover and primary productivity. The hypothesis is supported by results of Olofsson et al. (2004b) from different sites along reindeer fences in northern Norway. Also Forbes et al. (2009) proved for Yamal peninsula a shift in vegetation towards graminoids and increased primary productivity in areas heavily grazed by reindeer. Löffler (2007) detected changes in phytodiversity towards a homogenization of stands due to increased grazing pressure. However, such changes in plant species composition do not refer to overgrazing (sensu Wilson and MacLeod

Table 1 Selected aspects and important findings of reindeer-related research

	Key findings	References
Pasture ecology	Reindeer as 'ecosystem engineer': grazing-induced dominance shifts between plant species results in alterations of phytodiversity, nutrient cycling and primary productivity	e.g. Löffler and Pape (2008), Pajunen et al. (2008)
Animal ecology	Pronounced differentiation in food and habitat choice depending on environmental conditions and disturbance	e.g. Vistnes and Nellemann (2007), Skarin et al. (2008)
Productivity	Climatic conditions, state of the pastures and management practices control productivity	e.g. Tveraa et al. (2007), Lundqvist et al. (2009)
Management	Development of management strategies requires an integrative and detailed assessment of the seasonal pastures	e.g. Moxnes et al. (2001), Riseth et al. (2004)

1991), at least as long as these changes are not accompanied by a decrease in productivity. But facing exact this decrease in productivity in form of reduced reproduction and body weight in some high-density grazing districts in Norway (Fauchald et al. 2004; Bråthen et al. 2007), one needs to agree upon overgrazing to be a problem in reindeer husbandry at least in some parts of northern Europe. According to Mysterud (2006), overgrazing implies a decline in carrying capacity due to unfavourable effects on vegetation and soils. This deterioration of the environment is defined as 'degradation', whilst the term 'disaster' refers to the social component of this process, if environmental and associated economic losses exceed the ability of the affected community to cope using its own level of resources (UN/ISDR 2004). Figure 3 illustrates the different states of the grazing system, triggered by grazing pressure.

Apart from the emotionally afflicted and less-constructive debate whether reindeer husbandry is facing an ecological disaster or not: we need to be aware of unfavourable effects for ecosystems and reindeer husbandry in general due to intense grazing at least in some areas. In contrast, management strategies for large herbivores normally seek to balance harvesting yields with the preservation of the ecosystems these yields are based on. Thus, the identification of (and knowledge about) both the triggering factors of substantial changes within the ecological system (i.e. grazing pressure) and the exact governing conditions under which these changes occur (i.e. ecological and socio-economical settings) is a prerequisite for sound pasture management (Gordon et al. 2004)—but also forms the actual scientific challenge (Bråthen et al. 2007).

Five decades of intensive research and a multitude of resultant publications regarding various aspects of reindeer–pasture interactions yield undoubtedly important insights (c.f. Table 1 for a rough overview), but they do not necessarily solve this challenge. Nevertheless, out of these aspects productivity seems to be the most promising point of departure: primary production as integral of the environmental settings constitutes the basis for reindeer husbandry and determines its upper limit of use intensity. Secondary production by reindeer is an important measure in reindeer husbandry, reflecting pasture conditions, management practices and climatic conditions (Tveraa et al. 2007; Lundqvist et al. 2009). But due to a multitude of parameters across different trophic levels involved in the control of secondary productivity, it is difficult to qualify and quantify its determinants (Lundqvist et al. 2009). Thus, investigations on the determinants of secondary productivity were hitherto mostly restricted to mono-causal approaches focusing on climate (e. g. Helle and Kojola 2008), or, if multi-causal, restricted to small samples (Fauchald et al. 2004, but see Tveraa et al. 2007). Lundqvist et al. (2009) provided such a multicausality-based approach where all Swedish grazing districts have been investigated. However, parameters commonly considered as important, as for instance the quality of the pastures, did not show significant effects, maybe due to statistical intercorrelations. A mostly static view of the independent variables derived at a coarse spatial resolution only (Lundqvist et al. 2009) might add to this problem, emphasizing the need to consider productivity in general as dynamic system. Nevertheless, profound knowledge of primary productivity of reindeer pastures is inevitable for a sustainable management and thus the prevention of unfavourable effects caused by the overexploitation of resources. In this productivity context, winter pastures are often regarded as the bottle neck (c.f. Box 1) which led to a strong research focus on winter pastures and their lichen resources. However, this happened at the expense of an appreciation and understanding of summer pastures (Forbes 2006), which are important for calf growth and overall herd production (Danell et al. 1999a). Moreover, in some areas it is even the summer pasture that is regarded to be the limiting resource (Moen and Danell 2003). Thus, for an accurate evaluation of productivity, both seasonal pastures as well as their interrelation need to be considered.

Reindeer Husbandry and Other Forms of Land Use—Coexistence or Conflict?

Due to the space dependence of reindeer husbandry, conducted nowadays on ~40% of the total land cover in northern Europe, interactions with other forms of land use are inevitable. Northernmost Fennoscandia, in contrast to much of the boreal zone in Russia and North America, is subject to extensive and often intensive land use and ecosystem fragmentation. Boreal forests and forestry are an important source of economic wealth in Fennoscandia and highly managed (Forbes 2006). In addition to forestry, further diverse and overlapping forms of land use, like infrastructure development, hydropower, mining and recreation, caused already a pasture loss of 25% in the Barents region during the last 50 years (Jernsletten and Klokov 2002). This loss still continues in some areas with a magnitude of 300 km^2 $year^{-1}$ (Reindriftsforvaltningen 2010).

Instead of solely blaming the reindeer herders for the 'overgrazing' phenomenon, a decade ago the impact of these developments on reindeer husbandry came into consideration (e.g. Müller-Wille 1999): the loss of pastures, being direct (i.e. physical) or indirect (i.e. functional), increases the pressure from trampling and grazing on the remaining pastures, contributing to their deterioration (Forbes 2006; Kitti et al. 2006).

The specific effects of forestry on reindeer husbandry were recently investigated by Berg et al. (2008) and reviewed by Kivinen et al. (2010). The boreal forest provides the winter pastures for most reindeer districts in Norway and Sweden, although some districts and most of the districts in Finland practice reindeer husbandry in the forest all year round (Kivinen et al. 2010). Investigations by Kumpula et al. (2007) revealed the importance especially of old-growth forests for winter survival of reindeer. However, intense forestry management since 1950s aimed at a high productivity and based on clear cuts, often followed by soil scarification, fertilization and planting, does not support the requirements of reindeer husbandry, namely relatively undisturbed lichen-rich forests. Instead, it adversely affects the lichen resources required for reindeer husbandry in several ways (Berg et al. 2008; Kivinen et al. 2010). In Sweden, about 50% of the lichen-rich winter grazing grounds may have already been lost due to forestry since 1950s (Sandström et al. 2006). Consequently, Moen and Keskitalo (2010) describe trends in forestry as the driving dynamics in reindeer husbandry. According to Kivinen et al. (2010) and Moen and Keskitalo (2010), the challenges to mitigate the effects of forestry on reindeer husbandry are due to (a) the incongruence of spatial and temporal scales on which these two industries operate (e.g. forest stand vs. landscape perspective) and (b) the necessity to understand both the internal dynamics within each industry and the interactions amongst these industries to assess the sustainability of the entire system. Being forestry the overwhelming actor, it is according to Moen and Keskitalo (2010) especially important to understand trends in the drivers affecting forestry, even if they lie far beyond the local systems (e.g. changes in the international market). Moreover, Moen and Keskitalo (2010) stress the importance of increased and improved coordination amongst both sectors at the local level, although an evaluation of participatory management in Finland revealed a large potential for improvement (Ponnikas et al. 2008).

Human impact on reindeer husbandry is not restricted to forestry. Wolfe et al. (2000) provide a review of more than 90 studies about the response of reindeer to human activities, concluding that reindeer tend to avoid disturbed areas and increases both, activity and energy expenditure due to disturbance. According to Vistnes et al. (2004), 95% of studies dealing with effects of local and direct disturbance (e.g. causing flight) found minor and short-term effects on reindeer. However, continuous or permanent disturbance for instance by roads, power lines and cabins were found to decrease pasture use by semi-domesticated reindeer inside a corridor (or radius) of up to 4 km, dependent on disturbance type and terrain (Vistnes et al. 2004). Despite ongoing research, the call of Wolfe et al. (2000) for a cumulative effect assessment at annual, population and regional scales for future advances in understanding the implications of human disturbance to reindeer is still up to date. The statement of Danell (2005) and Beach et al. (2005) shed new light on this topic: most single impacts are restricted to a small area, but the cumulative effect of these encroachments will be substantial. Apart from the area loss itself, pastures will become more and more fragmented, isolated, and difficult to use (Danell 2005). If this development continues, it is argued by Beach et al. (2005) that reindeer husbandry, and with it also Sámi culture, may collapse.

Reindeer Husbandry and Large Carnivores—Negotiating Wilderness?

Northern Europe falls within the range of five large carnivore species: wolf (*Canis lupus*), wolverine (*Gulo gulo*), brown bear (*Ursus arctos*), lynx (*Lynx lynx*) and golden eagle (*Aquila chrysaetos*). Previously subject to lethal control, the official policy being extermination, the role of state intervention in managing large carnivores has changed dramatically towards conservation policies during the later part of the twentieth century (Ermala 2003), aiming at preserving biodiversity and establishing viable populations. As a consequence, populations of all species increased in size and distribution (Swenson and Andrén 2005).

Often regarded as representatives of wilderness, the presence of predatory animals (in the form of large carnivores) in a cultural landscape often conflicts with the traditions, practices and land-use priorities of local communities (Heikkinen et al. 2011). Depredation on farm livestock and reindeer are the most important of these conflicts. Nowadays, the wild large predator populations in northern Europe have domesticated animals as key preys, whereof the semi-domesticated reindeer is the calculated main prey (e.g. Danell 2005; Andrén et al. 2011): assessments of the extent of depredation indicate direct yearly losses of 450 00–500 00 reindeer in Sweden, ~20 000 in Norway and about 10 000 in Finland, corresponding to about 20, 8 and 5% of the total winter stock in these three countries, respectively (Danell 2009). It is argued that the losses may locally be as large as the harvest (Andrén et al. 2011).

Apart from these direct losses which are more or less compensated by different national compensation schemes (Swenson and Andrén 2005; Heikkinen et al. 2011), Danell (2009) mentioned further effects, resulting depredation in his opinion to be the 'single largest threat' to reindeer husbandry in Sweden: the presence of predators alters the grazing behaviour of reindeer, resulting in a worsen body condition, lower production and less efficient management and use of pastures. Consequences of depredation for productivity and economy of the reindeer industry in Sweden were projected with different harvest strategies by Danell et al. (2009), concluding reindeer industry to be very close to a collapse both biologically and economically with the current depredation pressure. According to Danell et al. (2009) and Heikkinen et al. (2011), the system of predator governance urgently needs to be reformed. The missing knowledge how to deal with the currently sectored, rather independent research and marginal realms of ecologies, economics, socio-cultural and political spheres is stated by Heikkinen et al. (2011) to be part of the problem for resolving predator-related contradictions.

Reindeer Husbandry and Climate Change—Resilient or Vulnerable?

A strong dependency on natural pasture resources and the functioning and productivity of the ecosystems is according to Reindriftsforvaltningen (2010) inhered in reindeer husbandry. These pastures in the arctic–alpine and boreal have been, and will be, exposed to climate variability and climate change which already caused major changes in the physical environment (ACIA 2004; Callaghan et al. 2011): Throughout Fennoscandia, albeit regionally and seasonally different, a governing trend of rising temperatures during the last decades has been detected, most pronounced during winter (e.g. Lie et al. 2008; Callaghan et al. 2010; Tietäväinen et al. 2010) and this trend is also likely to continue in future (e.g. IPCC 2007). In congruence with winter warming which leads to an increase of freeze–thaw cycles and rain-on-snow events, Johansson et al. (2011) described changes in snow characteristics towards very hard snow layers in sub-arctic Sweden, whilst a general decline of winter snow and ice cover was shown by Andrews et al. (2011). When regarding the biotic effects commonly ascribed to climate change, it is important to notice that they need not to be related solely to climate change, but also to human activities (e.g. Aune et al. 2011; van Bogaert et al. 2011). Such biotic effects consist of a prolonged growing season over large parts of Fennoscandia (Karlsen et al. 2009) and a 'greening' due to increased shrub and tree growth and cover (e.g. Bär et al. 2008; Rundqvist et al. 2011). For a more thorough and detailed synthesis of this topic, the reader is referred to reviews provided by Callaghan et al. (2011) and Löffler et al. (2011).

Reindeer husbandry is affected by climate change both directly and indirectly through a large number of effects. These effects display complex patterns of interactions and are argued to be sometimes uncertain and contradictory (Riseth et al. 2009). O'Brien et al. (2004) recognized possible limitations in forage availability due to changes in vegetation. In accordance with Tyler et al. (2007) and Turunen et al. (2009) "an urgent need to discuss possible outcomes […] if reindeer husbandry is to be able to adapt to changes in its resource base" was stated (Moen 2008, p. 304).

A closer look on these changes in the resource base reveals the following (see also Table 2): the temperature increase resulting in higher rates of mineralization is predicted to increase primary production, but possibly at the expense of protein content and nutritive value of the vegetation (Turunen et al. 2009). The common hypothesis of altered plant species composition and habitat loss due to higher temperatures was recently questioned by Wundram et al. (2010) and Scherrer and Körner (2011), due to the buffering effect of topographically controlled thermal-habitat differentiation. Undoubted is the effect of higher summer temperatures, however, on increasing insect harassments which can only be avoided at the expense of food intake, resulting in lower productivity of the herds (Moen 2008). Warmer winters in combination with more precipitation intensify the risk of starvation due to pastures locked by ice crusts, but this effect might also be levelled off by the elongation of the snow-free period (Moen 2008). Especially, the forward displacement of the vegetation period in spring harbours the risk of a trophic mismatch with unfavourable effects for reindeer husbandry (Post and Forchhammer 2008): the seasonal migration of reindeer, primary controlled by day length, might no longer match the thermally controlled phenological development of the vegetation.

Table 2 Climate change effects on reindeer pastures and resulting consequences (after Moen 2008, Riseth et al. 2009)

Pasture	Change	Effect	Consequence
Summer	Prolonged growing season and higher temperatures	Increased plant productivity	Positive: more forage available
		Changed nutrient quality in plants	Ambiguous
		Changes in vegetation	Ambiguous
		Trophic mismatch	Negative: less forage available
		Increased insect harassments	Negative: higher energy expenditure
		Changed balance between summer and winter pastures	Ambiguous
Winter	Higher temperatures and increase in freeze–thaw cycles, increase in precipitation	Decrease in overall snow cover	Positive: more forage available
		Increased probability of locked pastures	Negative: less forage available
		Risk of lichens being out-competed	Ambiguous

In contrast to the propagated general vulnerability of arctic–alpine landscapes towards climate change, reindeer husbandry has only been paid subordinate attention in this context (Tyler et al. 2007). For an assessment of its vulnerability, three aspects need to be considered (Turner et al. 2003): the impacts exerted on the system, the ability of the system to cope with or to adapt to these impacts, and the extent to which this coping capacity might be constrained by environmental or societal conditions.

- *Impacts* The direct impacts of climate change have already been mentioned, affecting primarily the pastures. It is important, however, to consider also the other challenges, i.e. pasture degradation, conflicting land uses and depredation as well as their interaction with climate change. These cumulative impacts may be felt most immediately by the sector with the smallest existing margins for their activities, such as reindeer husbandry (Keskitalo 2010; Prno et al. 2011).
- *Adaptation capacity* Climate variability and change are not a new phenomenon for reindeer husbandry. During the last century, reindeer husbandry has in fact survived climate change events even greater than those predicted (Tyler et al. 2007), illustrating a large capacity to cope and/or to adapt to such changes (c.f. Lie et al. 2008; Forbes et al. 2009). The adaptation capacity so far was primarily based on the reindeer's behaviour and physiology (c.f. Box 1) and herd management, i.e. traditional knowledge how to cope with different situations (Tyler et al. 2007).
- *Constraints* According to Tyler et al. (2007) and Brännlund and Axelsson (2011), constraints of the coping capacity are primarily formed by the loss of the herder's authority over the land, resulting from decreasing pastures areas and the socio-economic and political environment.

As reindeer husbandry is challenged by multiple exposure sensitivities (as shown above), it is argued by Prno et al. (2011) that effective adaptation to climate change requires also the consideration or, even better, the resolution of socio-economic and other issues in reindeer husbandry. This is also illustrated by Rees et al. (2008), concerning future vulnerability of European reindeer husbandry to climate change. Albeit their study revealed primarily unfavourable effects for reindeer husbandry, resulting in a likely change in reindeer numbers between −60% in Norway and +10% in Russia, they concluded that the vulnerability of reindeer husbandry to projected climate change appears to be rather small compared to the potential effect of changing socio-economic factors. Thus, the net effect of climatic and socio-economic changes on reindeer husbandry remains still rather vague and difficult to estimate due to the seasonal and temporal variability of effects and the complexity of the involved environmental and socio-economic processes (Rees et al. 2008).

REINDEER HUSBANDRY AND RESEARCH—THE NEED FOR A CLOSER INTEGRATION OF IDEAS

A simple *Google scholar*-based search, including both papers in refereed journals and grey literature, reveals the history of reindeer-related research (Fig. 4). Until 1970s, research focused mainly on biological aspects including nutrition, feeding and animal health issues (c.f. Danell 2000). Since then, research on ecological effects of reindeer herbivory and the associated degradation debate evolved. In accordance with the general climate change debate, this topic came in the 1990s on the research agenda, getting in the last decade as important as the degradation topic. Regarding inter-annual trends, the climate change topic is characterized by the strongest increase in publication number, exceeding 16% of the publications in 2010, whereas the degradation topic stagnates around 10.5% since 2002. Albeit a broadened view (from pure biological aspects towards ecological interactions), interdisciplinary approaches to assess the system 'reindeer husbandry' as a whole remain scarce. During the last decade, a rather constant proportion of <5% out of nearly 27 000 publications deal with that topic.

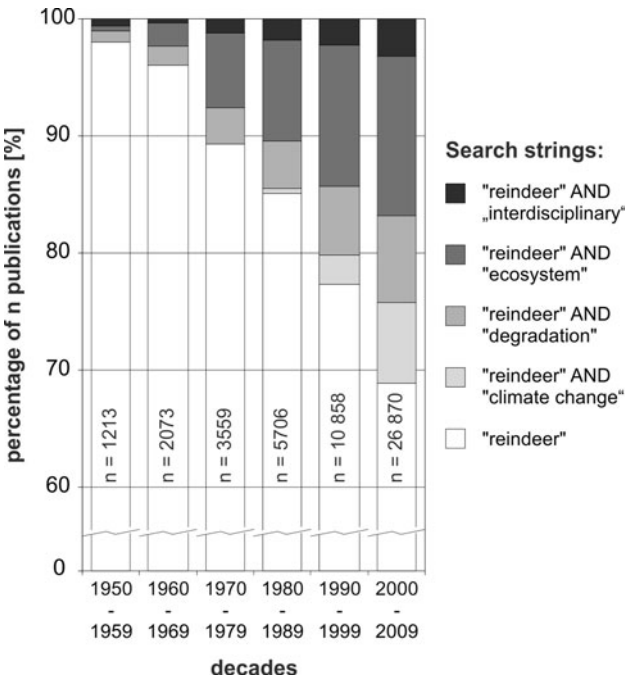

Fig. 4 Development of the number of publications on reindeer in general, and percent of publications related to interdisciplinary approaches, ecosystem, degradation and climate change, respectively. *Google scholar* search, 2-05-2011

Traditional reindeer-related research is notwithstanding of high quality, but functionally isolated within the various disciplines (Forbes 2006). However, it should have become evident from our review of current challenges in reindeer husbandry that the meshwork of ecology, socio-economy, culture and politics, in which reindeer husbandry is embedded by various interactions, will remain unclear and difficult to manage if actors and relationships are kept separate. Adapting systems, like e.g. reindeer husbandry, to climate change is an emerging topic in science (Opdam et al. 2009). In terms of knowledge building, this adaptation calls for integrative approaches, crossing economic, social and environmental borderlines (Opdam et al. 2009). Moreover, instead of a reductionist, analytical approach aimed at identifying impacts, a synthetic, design-orientated approach is needed (Meinke et al. 2006), aimed at generating solutions for challenges evolving from intensified land use and climate change.

For future research, we propose a combination of traditional, sectoral in-depth studies on various topics as baseline for true inter- or, even better, transdisciplinary research projects aimed at resolving the entire system 'reindeer husbandry' (Fig. 5). Thereby, special focus should be lain on retrospective studies (e.g. Lie et al. 2008; Staland et al. 2011; Brännlund and Axelsson 2011), as historical understanding is necessary to comprehend past impact on alpine ecosystems, current resource use and lines of conflict. Furthermore, because much of the previous adaptation capacity of reindeer husbandry was based on traditional knowledge (e.g. Tyler et al. 2007), it is necessary to include traditional knowledge in scientific research. The potential of such an approach has already been shown by Riseth et al. (2011). Critics may say that it was these herders who have let their animals to degenerate the ecosystems in the first place, but one should keep in mind that it was primarily the socio-economic and political conditions that forced reindeer husbandry to its today's extreme level (Riseth and Vatn 2009).

More specifically, our review revealed the following topics for future research:

- Sustainable reindeer husbandry through adapted pasture use. Data about the quantity and quality of pastures and their productive capacity are needed as well as data on density, structure, management and productivity of reindeer stock, both in space and time, to reveal the optimal use of pasture resources. In addition, also the governing ecological and socio-economical conditions need to be considered.
- Mitigation of conflicts resulting from competing land uses and predators. Due to several overlapping land uses in the area of reindeer husbandry, research urgently needs to focus on their cumulative effects rather than depicting single effects. How is pasture use constraint in space and time due to various forms of land use? This aspect forms also an important component of the above-mentioned topic 'sustainable reindeer husbandry'. The management of both, competing land uses and predators in relation to reindeer husbandry requires important knowledge in the respective fields that needs to be communicated—participatory management seems inevitable.
- Mitigation and adaptation with respect to climate change. The lack of knowledge about the net effect of climate change on reindeer husbandry needs to be bridged to facilitate mitigation and adaptation. Due to the complexity of the involved environmental and socio-economic processes, a true transdisciplinary approach is needed.

With respect to past and recent research, RENMAN was the first multi-disciplinary research project that meets some of the criteria outlined above, aimed at the development of new tools and models of participatory research and planning in reindeer management (Forbes et al. 2006). Its outcomes, however, were rather vague. In the line of multi- or interdisciplinary research projects, EALÁT needs to be considered as its successor. This ongoing interdisciplinary project focuses on the examination of the adaptive capacity of reindeer husbandry to climate variability and change based on the explicit integration of reindeer herders' knowledge (Oskal et al. 2009)—overall results being curiously awaited.

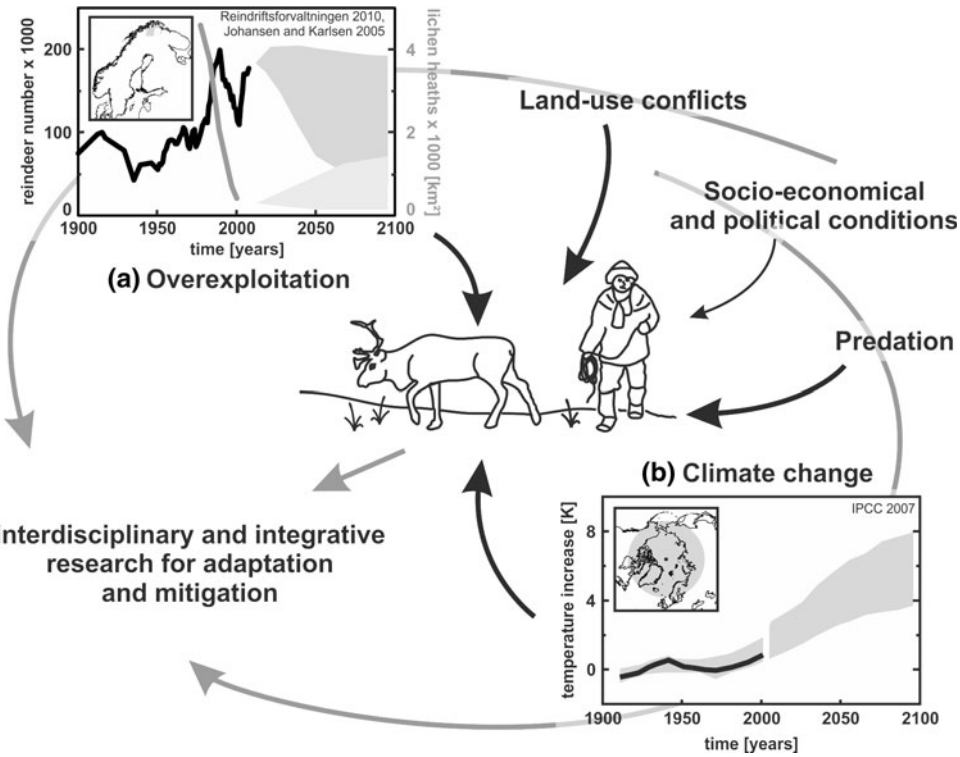

Fig. 5 Impacts and challenges related to reindeer husbandry (*fine* and *thick black arrows*, respectively) and proposed direction of future research (*grey arrows*). The graphs indicate (**a**), historic and projected future development of reindeer numbers and area covered by lichen heaths in Finnmark (Norway) and (**b**), historic and projected future change in mean temperatures in the Arctic

Today's challenges of reindeer husbandry reveal the necessity to integrate research across different spatio-temporal scales within an interdisciplinary and multidisciplinary framework for the understanding and adaptation of socio-ecological systems, but this seems still to be one of the most important methodological challenges for future research in general.

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