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RESEARCH ARTICLE

People and pines 1555–1910: integrating ecology, history and archaeology to assess long-term resource use in northern Fennoscandia

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Abstract

Context Past human land use has received increasing attention as an important driver of ecosystem change also in seemingly natural landscapes. Quantification of historical land use is therefore critical for assessing the degree of human impact and requires integration of ecology, history and archaeology.

Objective This study aims to assess and compare levels of resource use by different actors during 355 years across a large landscape of northern Sweden.

Method Data on resource use derived from case studies were extrapolated using demographic data to estimate harvested resources at the landscape scale. Here, we examined the use of the key-specie Scots pine by native Sami peoples and farmers and through commercial logging, and reconstructed historical forest conditions in order to interpret harvest levels and sustainability.

Results We show that (1) the pre-industrial use of Scots pine resources in Pite Lappmark was sustainable from a landscape perspective, and (2) that the early commercial logging, in contrast, was not sustainable. Large and old Scots pine trees were logged at a very high rate, reaching up to 300 % of the annual ingrowth.

Conclusion We suggest that historical landscape studies should incorporate analysis at different spatial scales, as such an approach can mirror the overall use of resources. Only then can land use data be applied across larger spatial scales, function as reference values and be compared to those of other regions, time-periods and types of human impact.

Keywords Forest history · Human impact · Ecosystem change · Native Sami · Farmers · Commercial logging · Sustainability · *Pinus sylvestris* · Inner bark · Firewood

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Introduction

During the last two decades ecologists have increasingly acknowledged past human land use as an important driver of ecosystem change (Rhemtulla and Mladenoff 2007). Areas previously considered as 'natural' landscapes and completely devoid of human impacts have, in fact, shown clear traces of human activities, with prolonged ecosystem effects (Cronon 1983; Krech 1999; Foster et al. 2003; Josefsson 2009; Freschet et al. 2014). To increase our understanding of human–environment interactions, especially over the long term, the integration of ecology, history and archaeology has been identified as a way forward (Briggs et al. 2006; Bürgi et al. 2013; Goldewijk and Verburg 2013; Scharf 2014). Practical approaches on how to combine data from these diverse disciplines have not been covered in the literature to any great extent, and reconstruction methods based on multiple perspectives are still only in an exploratory stage (Gimmi and Bugmann 2013; Yang et al. 2014).

More than 60 years ago, Day (1953) suggested that studies of pre-industrial land use should focus on the extent and intensity of early human occupation to better understand humans' ecological roles and the effects of their actions on past and present environments. More specifically, he considered the following four factors: (1) duration of occupation, (2) population density, (3) population concentrations and movements and (4) local patterns of settlements or locations of villages. Information on these factors provides an unambiguous basis for understanding people's movement patterns in pre-industrial times and the resulting spatial pattern of their land use. However, interpreting information on pre-industrial human population density, territorial size and precise uses of diverse ecological resources is challenging (Goldewijk and Verburg 2013). Meeting the challenge requires not only a thorough understanding of studied ecosystems and human societies (Hayashida 2005), but also robust tools for extracting and integrating such information (Gimmi and Bugmann 2013). This is not straightforward because of the breadth of the ecological and social dimensions that must be considered, and the frequently fragmentary nature of historical records.

This paper presents a model for combining historical, ecological and archaeological data to assess the magnitude of regional pre-industrial land uses. Our approach is to extrapolate quantities of used natural resources, obtained from case studies, to a regional scale by using demographic data. This study is focused on native Sami and early farmers' resource use, which is contrasted with early commercial logging in Pite lappmark—a large area covering almost 21,000 km^2 situated in northern Fennoscandia. The study embraces a time period from 1555 until 1910. We focus on resources and ecosystem services derived from Scots pine (*Pinus sylvestris* L.), the most common tree species and a key natural resource for people in this region throughout history. The specific questions addressed are the following: (a) how has the population densities of native Sami and early farmers changed throughout the study period? (b) what quantities of various Scots pine resources were exploited by the different actors over time? and (c) was the use of Scots pine resources sustainable during the study period? The results then form the basis for discussions on overall land use and sustainability during the study period focusing on human impact and ecosystem change, Sami migratory patterns, and the advantages of combining and extrapolating different sets of data to quantify and interpret overall land use in the past.

Study area and historical background

Pite lappmark, northern Sweden (65–67°N, 15–20°E), encompasses 20,759 km^2 and today covers the Arjeplog and Arvidsjaur municipalities (Fig. 1). Of the total area, 11 % is covered by water, 8 % by open land and wetlands and 46 % by productive forest (National Forest Inventory (NFI) SLU 2008–2012). The remaining 35 % is mountain birch forest and mountain heath. About half of the productive forest land has been dominated by Scots pine since the late nineteenth century up until present day (Holmerz and Örtenblad 1886; National Forest Inventory (NFI) SLU 2008–2012).

The name *lappmark* implies that this was the *land* of the *Lapps* (i.e. the native Sami). Before the onset of permanent agrarian settlements, which spread north along the Bothnian coast and inland along the large rivers (Lassila 1972), northern Sweden was inhabited by Sami peoples (Hansen and Olsen 2006). The traditional Sami economy was based on hunting, fishing, gathering wild plants and keeping domesticated reindeer (*Rangifer tarandus* L.) (Fjellström 1985); these subsistence strategies required very large areas for survival, due to the northern location and generally low productivity of the ecosystems. Pite lappmark differs from other areas in northern Sweden in that permanent cultivation started rather late in this region, only after the mid-eighteenth century. The main reasons for this were the harsh climate, the high

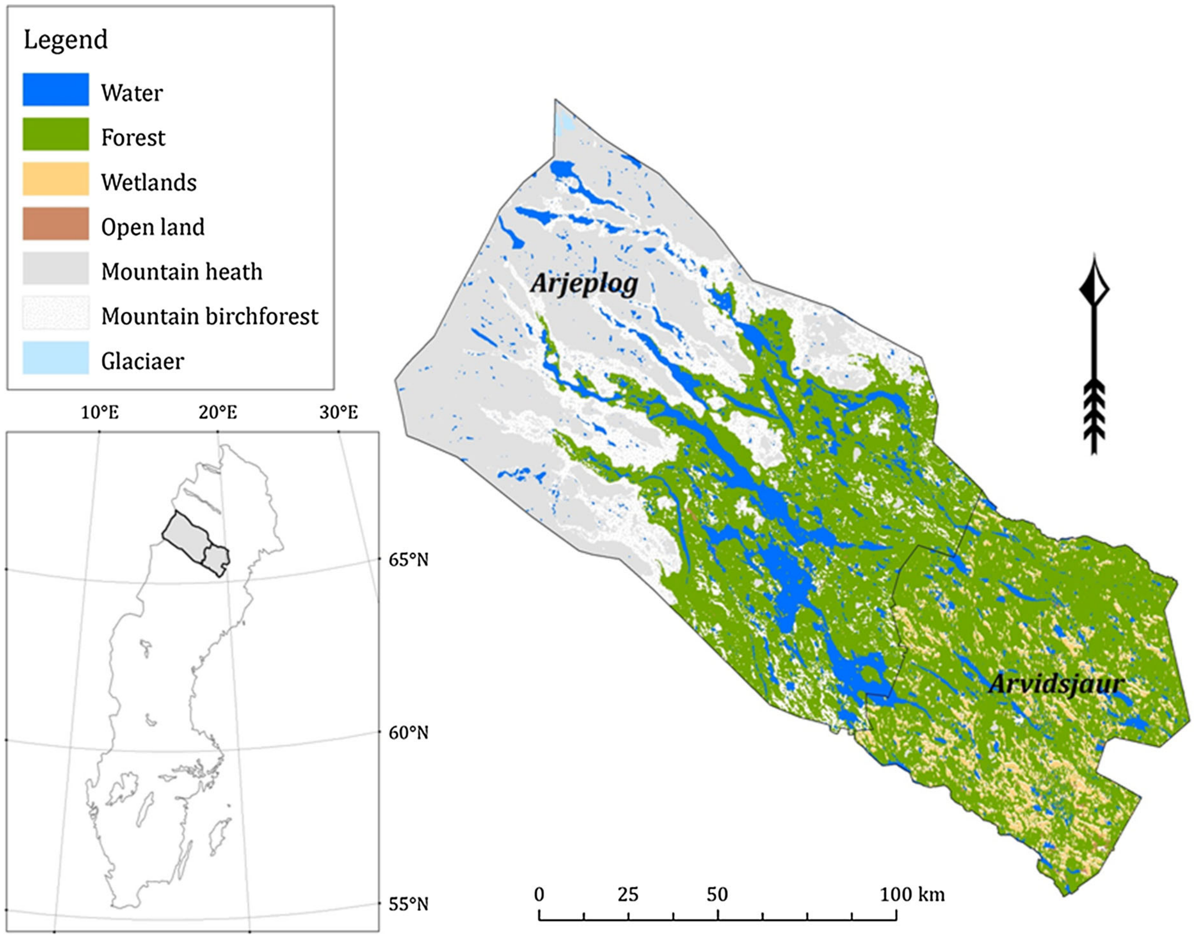

Fig. 1 Location and land cover map of Sweden, indicating the study area of Pite lappmark comprising of the municipalities of Arjeplog and Arvidsjaur. The entire study area comprises 20,759 km^2 and about half is forested. ©Lantmäteriet i2012/901

altitude and the difficulties both in travelling in the complex terrain and cultivating the predominantly coarse glacial till soils (Bylund 1956; Wistrand 1962).

Throughout history reindeer have played a central role in Sami subsistence and culture. The ways in which the Sami connected to and used the reindeer have changed over time. Very early on the Sami hunted wild reindeer, using both trapping pits and snares (Bergman 1997), but eventually they started domestication (Hansen and Olsen 2006). During the time frame of this study, reindeer herding changed from an intensive form of animal husbandry, where relatively few reindeer were tended on a daily basis and also milked, to an extensive form where larger herds were kept (Hultblad 1968); this has persisted on a large scale up until today.

The first farmers moving into the region were dependent on hunting and fishing in addition to farming, because of the harsh climate (Campbell 1948). The Swedish authorities wanted permanent settlements in the north and applied constant pressure to the farmers to also cultivate the land (Staël von Holstein 1809). Cattle husbandry remained far more important than growing crops, and limitations on the ability to collect winter fodder and access to summer grazing sites in the forest were the primary constraints on the development of a thriving livestock industry (Campbell 1948). As a result, northern Sweden has largely remained a forested landscape up until the present day.

Scots pine forests, and Scots pine trees in particular, provided important ecosystem services for both the

Sami people and the early farmers. In early spring, the Sami collected inner bark to eat from mature trees (but without killing the trees) (Östlund et al. 2009) as this was a highly valued nutritional food resource, mainly due to its starch and mineral contents (Rautio et al. 2013). At the Sami winter campsites at lower elevations, standing dead Scots pines provided valuable firewood (Östlund et al. 2013). During winters when heavy snow crusts prevented the reindeer from digging to access the ground lichens, thin Scots pine and Norway spruce (*Picea abies* (L.) Karst) trees with abundant arboreal lichens were felled to feed the reindeer (Berg et al. 2011). The farmers used the Scots pine primarily as firewood but also for tar production and as construction material for buildings, equipment and tools (Östlund et al. 2002).

With industrialization during the mid-nineteenth century the demand for sawn timber increased dramatically in Western Europe (Björklund 1984), and as a result large-scale exploitation of the Swedish forests began (Arpi 1959). Large diameter Scots pine trees were selectively logged as a "timber frontier" swept across northern Sweden from the coast to the inland areas (Östlund et al. 1997). The interior parts of Pite lappmark, however, were not affected by this early phase of commercial logging until the end of the nineteenth century (Andersson et al. 2005).

Scots pine trees were clearly an important and well-used resource by both people inhabiting this region over a very long time period and the first commercial forest actors. Today, a large part of the forests of Pite lappmark is still being managed for timber production and the industry makes a significant contribution to the national economy. Therefore the use of specifically Scots pine resources provides excellent opportunities to understand ecosystem changes in this particular landscape.

Methods

In this study we used quantitative data on resource use derived from specific case studies, which we extrapolated using demographic data, to estimate harvested quantities at the landscape scale. These case-studies provide data on forest structure and historical land use. The ecological provisions we examined include firewood, lichen-rich trees felled to feed the reindeer with arboreal lichen, inner bark used as a food resource, and timber removed in early commercial logging (for exact definitions of these resources see Supporting Material). The time frame we choose for our study is 1555–1910: this 355-year period covered the three predominant kinds of land use practiced by the Sami, farmers and early commercial loggers, and both historical and archaeological archives on resource use are available. Finally, we used a reconstruction of the pre-industrial Scots pine forest in order to interpret harvest levels and sustainability.

Demographic data

To estimate human population numbers and density we used demographic data extracted from taxation records and cameral records from the years 1555, 1600, 1661, 1699 and 1759 (see Supporting Material). These are the earliest accounts of the Sami population in Sweden and are truly unique from an international perspective. All of these records list the heads of the households (i.e. fathers) and the tax they paid, but the records of 1759 are exceptional in that they also contain information on every individual in each household. To estimate total population numbers for the years 1555–1699, we multiplied the number of taxpayers (Swedish; *Mantal*) with a correction factor (i.e. the number of persons included in a household) of 4.9, which is in line with previous estimates of this factor (for example 5.0 according to Hoppe 1945 and Tegengren 1952). The correction factor was derived from the 1759 taxation record by dividing the total number of people (1005) with the number of taxpayers (205). To approximate the population number for every year between dates of our tax record-based data (1555, 1600, 1661, 1699, 1759, 1810 and 1850) we used linear interpolation between every pair of data points. We choose this approach because the population number during a certain year is more likely to be correlated with nearby years rather than distant times (for equations used see Supporting Material). Population records for Sami practicing traditional land use and farmers were also retrieved from the first systematic population censuses in Sweden carried out in 1810 and 1850.

Quantification of resource use

To quantify the use of Scots pine by Sami and farmers we extrapolated detailed localized data on resource use by households in the entire study area using our estimates of historical population numbers (see Supporting Material).

Data on Sami firewood consumption were extracted from an experimental case study by Östlund et al. (2013) (conducted within Pite lappmark), who found that the annual use of standing dead Scots pine trees per family amounted to c. 42 m^3 (based on that c. 4.9 persons resided in one tent hut, i.e. one household). The information on farmers' consumption of firewood was derived from early twentieth century ethnographic studies (Anonymous 1924), suggesting an annual consumption of c. 3.4 m^3 per person. The data on inner bark harvesting and felling of lichen-rich trees were acquired from two case studies in unlogged old forests situated in the Tjeggelvas nature reserve in Arjeplog parish, Pite lappmark, published by Josefsson et al. (2010a) and Berg et al. (2011) respectively. From Josefsson et al. (2010b) we obtained local demographic data which we correlated to the quantities of both inner-bark harvesting and felling of lichen-rich trees (see Supporting Material for correlations and regression models). Numbers of trees and harvested volumes of timber during the first commercial logging period were retrieved and compiled from the statistical yearbooks of the Swedish Forest Service (1870–1910). The three most common assortments harvested in early commercial logging were: (1) Timber trees (Swedish: *Sågtimmer träd*) from which one or more sawn logs could be obtained; (2) Dry wood (Swedish: *Torrträd*) including standing dead trees suitable as fuel wood for industrial purposes; and (3) Beams (Swedish: *Bjälkar*) which was timber that was square-cut and used for construction (see Cnattingius and Eriksson 2010). Timber trees remained the most important assortment throughout the study period but with increasing proportions of dry wood and beams over time.

Forest structure 1555–1910

To enable analysis of the sustainability of the different forms of resource use we needed data on forest conditions and dynamics in a pre-logging setting. The National Forest Inventory from 1926 (NFI, Swedish *Riksskogstaxeringen*) constitutes the earliest available data on forest structure and dynamics in our region; however, to reconstruct the pre-logging condition we needed to complement this data. We chose regional data from Dalarna county (a region in central Sweden with similar physiogeography and climate as Pite lappmark) to adjust for the lack of large trees (i.e. trees >30 cm DBH) from our data set, which were logged during the period from 1870 to the first decades of the twentieth century (see Supporting Material for detailed information on this procedure). This procedure resulted in the best possible estimation of the overall forest structure in Pite lappmark prior to late nineteenth century forest exploitation and modern forestry impacts.

Results

Demography in Pite lappmark 1555–1850

In 1555, the taxation record lists the names of 70 taxpaying men, all of Sami origin. This corresponds to a total human population of 343 persons (Fig. 2), (assuming an average of 4.9 family members per taxpayer) or 0.017 persons/km^2 implying that every Sami family could on average use an area of c. 300 km^2 land and water. The Sami population increased thereafter, and at the end of the 1600s it had more than doubled to 745 persons. In 1759, a total of 1005 persons or 0.048 persons/km^2 were present in the study area. On average, every household had 1.8 children less than 10 years old, and 0.6 older children. In addition, 8 % of the households included one or two older members and 0.4 maids or farmhands. In 1810,

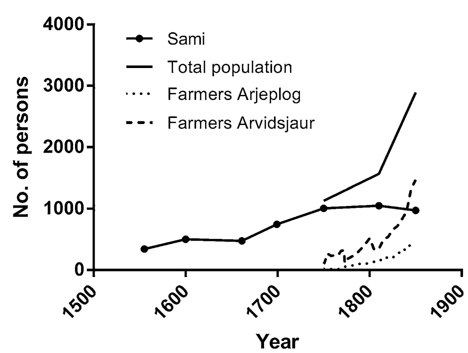

Fig. 2 Numbers of Sami people—and farmers inhabiting Pite lappmark from 1555 until 1850 (total population and taxpayers), according to taxation records and population censuses. The data show that the first farmers moved into Arjeplog parish in the mid-eighteenth century, but the farming population did not increase rapidly until the early nineteenth century, mainly in Arvidsjaur parish

the Sami population peaked at 1048 persons but then dropped to 973 in the 1850s. In 1850, each Sami family in the study area could use c. 100 km^2 of land and water.

In 1760, the first farmers arrived from outside the study area, although a few Sami families even before then had changed subsistence mode and become farmers themselves (Bylund 1956). The total number of farmers rose from 517 persons in 1810 to 1920 people in 1850 (Fig. 2). The farmsteads were mainly concentrated in the eastern part of the study area, at lower elevations.

Harvest of seasoned Scots pine firewood

The Sami population used c. 3000 m^3 of firewood annually in 1555, rising to c. 9000 m^3 in 1810 and then declining to 8300 m^3 in 1850, which is equivalent to 5–17 % of the annual production (i.e. tree mortality) of this resource (Table 1; Fig. 3a). The farmers used 1758 m^3 of firewood annually in the 1810s, rising to 6500 m^3 in 1850, equivalent to 0.8–12.4 % of the annual production (i.e. mortality) of this resource (Table 1; Fig. 3a).

Sami felling of lichen-rich Scots pine trees

About 7000 thin Scots pine trees (DBH 10–20 cm) were felled annually to acquire lichen during the 300-year study period, amounting to over two million trees in total (Table 1). The estimated annual and total volumes harvested are 650. These quantities correspond to only 0.42 % of the annual volume ingrowth of the resource (Table 1). In total, 195,000 m^3 Scots pine trees were felled during the entire period, corresponding to 2.7 lichen-rich trees ha^{-1} or 0.009 ha^{-1} year^{-1}, on average.

Sami harvest of Scots pine inner bark

The annual numbers of Scots pine trees used to harvest inner bark rose from c. 1400 in 1555 to c. 4400 in the early 1800s, and then declined to 4000 in 1850 (Table 1). These quantities correspond to 0.002 % of the available stock of suitable trees (DBH, 15–25 cm) in 1555 and 0.007 % of such trees in 1810 (Table 1). In total, more than 900,000 Scots pine trees were harvested during the entire period, corresponding to 1.15 bark-peeled trees ha^{-1} or less than 0.004 ha^{-1} year^{-1}, on average.

Early commercial logging of large diameter Scots pine trees

Early commercial logging (1870–1910) in Pite lappmark focused on trees with large diameters (>30 cm) and included cutting of timber trees, beams and standing dead trees. The logged volumes rose from c. 23,000 m^3 in 1870 to c. 340,000 m^3 in 1898, then stabilized at c. 200,000 m^3 annually (Fig. 3b). The logging exceeded the annual volume ingrowth of trees >30 cm (DBH) for timber trees during this period by 180–240 % (Table 2; Fig. 4).

Discussion

This study provides data on human population numbers, quantities of various harvested Scots pine resources, and forest conditions in pre-industrial times. The study is rare since it covers land use over a very long time-period (i.e. more than 350 years) and a large landscape (21,000 km^2). Our results contribute to the understanding of how the use of the pine forest differed between actors and how this use changed over time. Based on the results of this study we will discuss the effects of historical human land use on the ecosystem and how people moved over the landscape in order to retrieve critical resources. Finally we will make some concluding remarks on the advantages of using a method that combines studies at different spatial scales.

Quantitative comparisons and sustainability

Our analysis shows that the total human population in Pite lappmark increased rapidly between 1555 and 1850, albeit from very low initial numbers. This was mostly due to rapid growth in the numbers of farmers (both settlers from areas further south in Sweden and Sami people changing their mode of subsistence) from the 1750s onwards. Despite this dramatic increase the population density never exceeded 0.2 persons per km^2. Thus, Pite lappmark—like other similar regions in northernmost Fennoscandia (Hicks 1976; Sjögren and Kirchhefer 2012)—remained a marginal area in

Table 1 Scots pine resources harvested by Sami and farmers during the study period. Because population numbers were important factors for scaling our resource use the outtake was highest at the end of the study period. However, pre-industrial land-uses did not exceed the volume increment (harvests of seasoned firewood or lichen stumps) or number of trees in a suitable diameter class (harvest of Scots pine inner bark) at any point in time

Ecosystem service	Year 1555	1600	1661	1699	1759	1810	1850	Acc	ha^{-1}
Sami harvest of inner bark									
Trees harvested (no.)	1434	2089	1987	3114	4199	4381	4068	910,406	1.15
Part of the standing no of trees (%)	0.0024	0.0035	0.0033	0.0052	0.0070	0.0073	0.0067		
Sami felling of lichen-rich trees									
Trees harvested (no.)								2,148,357	2.7
Volume harvested (m^3)	651	651	651	651	651	651	651	195,296	
Part of the yearly volume ingrowth of resource (%)	0.42	0.42	0.42	0.42	0.42	0.42	0.42		
Sami harvest of firewood									
Volume harvested (m^3)	2940	4284	4074	6384	8610	8988	8358	1,866,673	
Part of the standing volume (%)	0.33	0.48	0.45	0.71	0.96	1.0	0.93		
Part of the annual volume ingrowth of dead wood (%)	5.6	8.1	7.7	12.1	16.3	17.0	15.8		
Farmers harvest of fire wood									
Volume harvested (m^3)					418	1758	6528		
Part of the existing volume of dead wood (%)					0.05	0.19	0.72		
Part of the yearly formation of dead wood (%)					0.8	3.3	12.4		
Overlap firewood (sami + farmers use)									
Volume harvested (m^3)					8701	10,741	14,868		
Part of the existing volume of dead wood (%)					1.0	1.2	1.6		
Part of the annual formation of dead wood (%)					16.5	20.3	28.2		

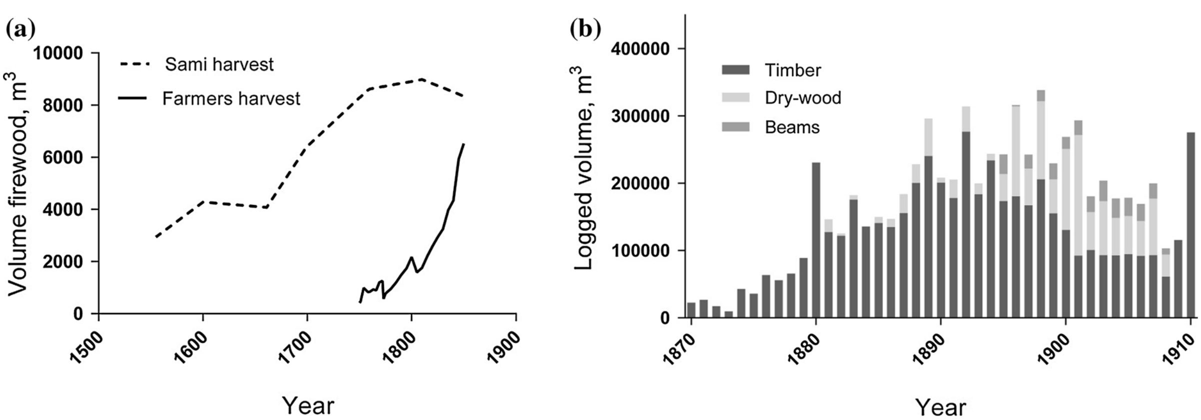

Fig. 3 **a** Sami and farmers' harvests of seasoned Scots pine firewood during the study period (1555–1850). Despite the larger population of farmers in the end of the study period, the Sami used much more firewood. **b** Total volumes of large diameter Scots pine trees logged during the first commercial logging era (1870–1910) in Pite lappmark. Volumes ranged from 0.029 m^3/ha in 1870 to 0.35 m^3/ha in 1910. Timber trees were the most commonly harvested assortment throughout the study period, but proportions of beams and dry wood harvested increased with time

Table 2 Volumes of timber removed in the first commercial logging in the region, from 1870 to 1910. Harvest levels greatly exceeded the annual volume increment

Ecosystem service	Year 1870	1880	1890	1900	1910
Early commercial logging					
Volume harvested m^3/ha	0.029	0.29	0.26	0.34	0.35
Part of the annual ingrowth of trees (%)	20	200	181	233	239

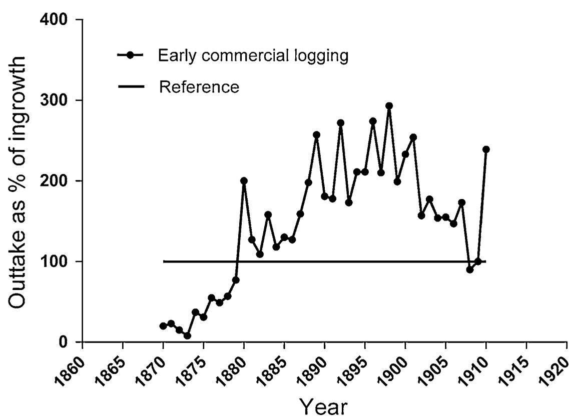

Fig. 4 Volumes of Scots pine removed during early commercial logging as a percentage of the annual increment in volume of the resource. A reference line, illustrating 100 procent outtake of the increment, has been added to show that this resource use was unsustainable from approximately the 1880s onwards

Europe from a demographic, as well as a geographic point of view, throughout the studied time period.

In quantitative terms, firewood was the most important Scots pine resource for both the Sami practicing traditional land uses and the farming community (Table 1). Nevertheless, even in the 1850s, when population numbers were highest, only 28 % of the annual production of suitable dead Scots pine trees was used by these two groups. Thus, this resource use was clearly sustainable during the time frame of our study (Table 1). Interestingly, the annual Sami harvest exceeded those of the farmers; in the 1850s, when the Sami population was far lower (Fig. 3a), the Sami still used almost three times as much firewood per person (9.3 m^3) compared to the farmers (3.4 m^3) (Table 1). This was probably because heating tent huts consumed much more fuel than heating log farmhouses and because of differences in heating practices. Generally, fires were continuously maintained in the tent huts, but not in the farmhouses (cf. Östlund et al. 2013). Our estimates take into account the best firewood available (dry Scots pine wood), and people certainly also used other types of wood for heating and cooking (Liedgren and Östlund 2011).

According to our analysis a substantial number of lichen-rich Scots pine trees were felled—more than two million over a time period of 300 years. This is clearly an underestimate since the figure is derived from present day densities of stumps related to this activity, and, naturally, many of the stumps have vanished due to decay. Trees with bark-peelings can remain standing for many centuries (either dead or alive), due to high contents of resin. Thus, at a conservative estimate, at least four million trees were used for this purpose during our study period.

Our quantitative estimations of the Sami use of Scots pine inner bark indicate that the annual harvest levels were low, ranging from c. 1400 to 4400 peeled trees per year (Table 1). This is a small proportion of the total number of trees in the preferred diameter class, based on the estimated annual ingrowth of trees in this diameter class in the study region. Clearly, trees suitable for inner-bark harvesting were not a limited resource at any point during the time frame of the study, and the acquisition of this resource had a negligible impact on the forest as the trees were not felled or killed. Over the 300 years of this study, we estimate that less than one million Scots pine trees were used in this manner.

Whereas the Sami and farmers' use of harvested resources was clearly sustainable, the annual levels of commercially logged trees rapidly decreased the density of large diameter trees. In fact, this resource use was two to three times higher than the annual formation of Scots pine trees >30 cm in DBH (Table 2; Fig. 4). Considering pure volumes, it far exceeded both the Sami's and farmers' firewood consumption, and was the only Scots pine use investigated in this study which was not sustainable.

Human impact and ecosystem change

Our results show that the spatially broad but low intense Sami land use gradually increased during the studied period. There was no overexploitation of the Scots pine resources, but rather a limited outtake of the natural regeneration and renewal of them. This way of land use, developed over millennia, successively created a domesticated landscape with clear gradients, including smaller intensively used hotspots, areas of intermediate use and large low-impact areas (Hicks 1976; Ericsson 2001; Berg 2010). The main drivers for shaping this landscape were the seasonality of resource availability and the local ecological context—just as elsewhere throughout the northern hemisphere (cf. Nelson 1980; Cronon 1983; Vitebsky 2005). Similarly, pre-industrial anthropogenic landscapes in Eastern United States, display heterogeneous land-use patterns of habited and seemingly uninhabited land (Hammett 1992; Delcourt and Delcourt 2004; Munoz et al. 2014). Our findings are also consistent with the demonstrated importance of firewood for people in diverse prehistoric contexts globally (Day 1953; Hastorf et al. 2005), while contrasting sharply with the unsustainable historical use of firewood in other ecosystems, e.g. in the more heavily populated areas of Europe (Kaplan et al. 2009; Ludemann 2010) and elsewhere (Lev-Yadun et al. 2010).

Although our data suggest that Sami pre-industrial land uses had very weak effects on the availability of specific resources from a landscape perspective, specific case-studies have detected long—lasting local ecosystem effects, such as vegetation changes due to cutting of firewood (Josefsson et al. 2010a; Staland et al. 2011; Östlund et al. 2015) and both above- and below-ground feedback effects of trampling and organic matter transfer (Freschet et al. 2014). In addition, case studies have also detected strong cultural imprints in local hotspots (Berg et al. 2011; Sjögren and Kirchhefer 2012; Rautio et al. 2014). However, the extrapolation of such case studies provides a biased picture of historical land use and human impact if looked upon from a landscape perspective. This highlights the need for studies of large landscapes and encompassing long time-periods (Rhemtulla et al. 2007).

In contrast to the Sami pre-industrial land-use, the early commercial logging (1870–1910) in Fennoscandia had a very strong impact on the presence of old trees and on the forest structure (cf. Linder and Östlund 1998; Aasetre and Bele 2009). In Pite lappmark, the cutting of large-diameter timber trees reached up to 300 % of the annual ingrowth of such trees, and the cutting of these trees had a comparatively large impact on forest structure and productivity as well as biodiversity (cf. Axelsson et al. 2002; Ericsson et al. 2005; Jönsson et al. 2009; Josefsson et al. 2010c; Lie et al. 2012). The momentum of the early commercial logging and its effects on ecosystems are very similar to the early logging era in eastern North America (Boucher et al. 2009; Flatley et al. 2013; Boucher et al. 2014). In both cases, the early logging is foreboding the large scale landscape transformation due to modern forestry in the twentieth century (Östlund et al. 1997).

Sami migratory patterns

The approach used in this study enabled us to estimate the overall use of Scots pine resources in the studied region. However, pre-industrial land use was not a uniform process affecting all parts of a landscape in a similar fashion. Previous studies by Rautio et al. (2014), Berg et al. (2011) and Östlund et al. (2013) have shown that harvest levels in some areas exceeded far those in the surrounding landscape. Similarly, Munoz et al. (2014), who studied native subsistence strategies in temperate forests of eastern North America, suggested that typical land use patterns resulted in patchworks of managed and unmanaged ecosystems.

To facilitate our understanding of the mechanisms underlying the spatial pattern of preindustrial resource use we propose that the resources can be divided into two main categories: *continuously harvested* and *seasonally harvested*. The former includes resources that had to be accessed on a daily basis, such as firewood and grazing ground for reindeers. In contrast, *seasonally harvested* resources were those acquired at specific times and locations when and where they were abundant and/or readily available. Some plant resources were extracted during the entire vegetative period, while others were only gathered during certain times and at specific locations where they thrived and formed dense stands. Annual migrations of the Sami have often been described as cyclic, involving long distance journeys between three main areas: the summer, winter and spring/autumn 'lands' (Manker

1947). Once people reached these lands they are believed to have been more stationary (Manker 1947; Collinder 1953), especially in the spring/autumn lands that were occupied for the longest periods, i.e. 1 to 2 months at a time (Manker and Pehrson 1953).

Based on our knowledge of the local place and the landscape, the scale of the harvests, their seasonal availability and the interrelated acquisition strategies, we present a conceptual model of Sami migratory patterns during the study period (Fig. 5). The migratory patterns were of course much more complex in reality, but here we illustrate them as two circles adjoining at the spring/autumn campsite, which was an important locus for storing resources acquired during both winter and summer (Manker and Pehrson 1953). This implies that Sami knowledge of the land must have been extremely detailed, and included a thorough understanding of inter-annual resource dynamics in order to make informed decisions about when and where to go. To avoid depleting resources in favoured areas the Sami used a number of annual migration routes, revisiting the same locale intermittently. A

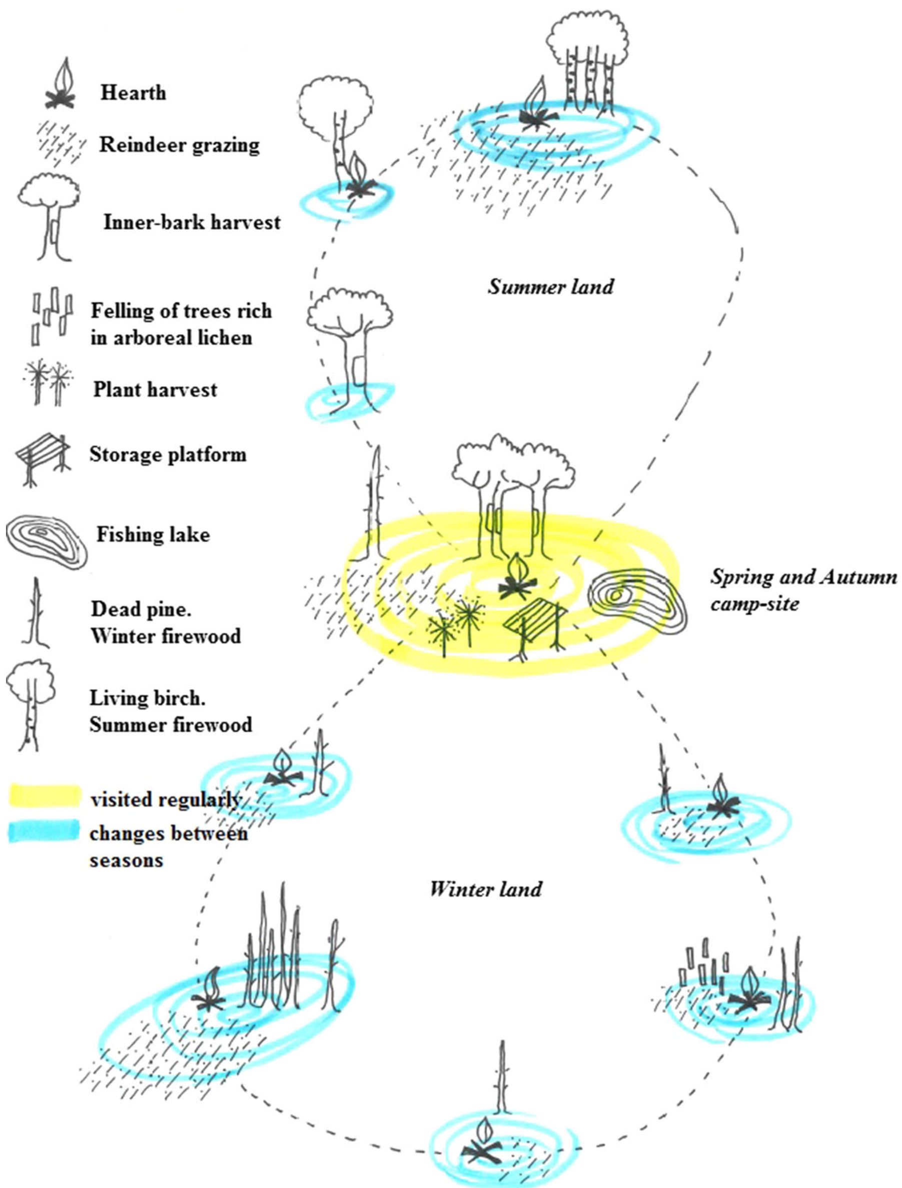

Fig. 5 Conceptual model of the Sami annual migratory pattern and the resources harvested annually, depicted as *two circles* adjoining in the spring/autumn campsite

similar reasoning have been put forward by Smith and McNees (1999) who studied pre-historic land-use patterns in south-west Wyoming, USA. Based on archaeological evidence they argue that prehistoric hunter-gatherers reused some resource locales on periodic basis over periods as long as 500 years and reoccupied some locales containing such facilities over a period of 2000 years.

Methodological approach

Here we present a model which combines data from two spatial levels with long-term demographic data, thus revealing the resource use over large landscapes and across centuries. A way forward is to more precisely estimate resource use on a per person basis, as models depending on population data then can, and will, provide very exact results on human impact. This is particularly important in regions where human impact cannot be generalized between groups of people, because different modes of subsistence have required varying amounts of resources per person. Our model can be applied to other landscapes and other periods to allow for comparative studies of, for example, pre-industrial resource use by native peoples in boreal and subarctic regions. Such information is crucial not only for an informed assessment of 'naturalness' in protected areas (Josefsson 2009) and restoration targets, but also for advanced interpretations of cultural landscapes in the past (Terrell et al. 2003).

Conclusion

Our study shows that it is possible to quantify historical land use over very long time-periods and across large landscapes. This can be achieved by extrapolating data on resource use from local case studies with regional human demographic data and a reconstructed pre-industrial forest landscape. The pre-industrial use of Scots pine resources, on a regional level and during a 300 year period, never exceeded the ingrowth of the resource and therefore can be considered sustainable from a landscape perspective. The early commercial logging, in contrast, was not sustainable. Large and old Scots pine trees were extracted at a very high rate, reaching up to 300 % of the annual ingrowth. This indicates that such trees were severely reduced over large areas.

Case studies in land use history are often focused on high-impact 'interesting areas'. Therefore, and in addition to the conclusion reached by Day (1953), we suggest that historical landscape studies should incorporate analysis at different spatial scales, as such an approach can mirror the overall use of resources. Only then can land use data be applied across larger spatial scales, function as reference values and be compared to those of other regions, time-periods and other types of human impact. We argue that historical landscape studies should not only consider land-cover change but also incorporate quantitative analysis of human resource use. This will deepen the understanding of the long-term human role in ecosystem change.

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