



Beyond the Trees: Combining Ecology and History to Understand Human Impact on an Old-Growth Forest Landscape

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Abstract

Forest reserves in boreal Scandinavia are primarily established to protect biodiversity. However, they also serve as important reference areas for traditional land use by the indigenous Sami people, a factor often overlooked during reserve creation. In this study, we examined the role of Sami land use in shaping the forest structure of Tjieggelvas, a large forest reserve in northern Sweden that has not been affected by modern forestry. We collected field data on both forest structure and cultural objects—visible remains of human activity—at five sites and analyzed the data using Principal Component Analysis (PCA). The results revealed noticeable differences between sites, mainly due to human impact. However, there was no link between forest-structure variables associated with old-growth conditions and the density of cultural objects. To arrive at a better interpretation of our findings, we reviewed archival sources from the early eighteenth century onward and interpreted Sami place names. The combination of these data provided a detailed understanding of the cultural history and human influence on this ancient forest. We conclude that the management and designation of forest reserves should more thoroughly incorporate cultural history and values than they currently do. Recognizing cultural heritage enhances the overall value of protected areas, connects the present with the past, and honors the history of indigenous peoples.

Keywords Forest history · Forest ecology · Sápmi · Boreal forests · Indigenous land use · Historical ecology

Introduction

Boreal forest reserves and national parks in Scandinavia are generally established to protect ancient trees, pristine landscapes, and unique biodiversity. These areas are typically chosen because they have little to no influence from modern forestry or other large-scale human activities (Svensson et al., 2020). Beyond these protected zones, forests have been heavily logged and altered, leading to fragmentation and ecological decline (Svensson et al., 2020). Furthermore, modern forestry frequently damages cultural heritage by

logging old trees and performing mechanical soil scarification (Anon., 2020). Therefore, protected forest landscapes serve as vital repositories of traditional and indigenous land use and are crucial for conserving biodiversity (Bürgi et al., 2020; Fa et al., 2020; Watson et al., 2018; Cuerrier et al., 2015; Santoro & Piras, 2023; Turner et al., 2009).

However, the significance of old-growth forests for preserving cultural heritage is seldom considered when setting up or managing natural reserves or national parks (Östlund & Norstedt, 2021). In northern Fennoscandia, the indigenous Sami remained the majority into the 18th century and in some areas into the 20th century. Their traditional land use included hunting, fishing, reindeer herding, and plant gathering in various combinations (Fjellström, 2020; Itkonen, 1948). Because forests are time-lagged systems, the effects of past land use persist for a long time (Bürgi et al., 2017). For example, the impact of tree felling for firewood and construction around old Sami settlements on forest structure is still visible today (Josefsson et al., 2010b; Östlund et al., 2003), and the vegetation in reindeer corrals

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can differ from that of the surrounding areas centuries after they were abandoned (Aronsson, 1991).

On a landscape level, the impact of traditional land use is less obvious, but such land use can still significantly change forest floor vegetation and tree species composition if it occurs over long periods (Freschet et al., 2014; Josefsson et al., 2009). However, these effects are subtle and complex to distinguish from the influences of soil and climate factors. Additionally, it has been suggested that the loss of cultural memory and a prevailing view of forests as wilderness have led to a general lack of appreciation for the biological and cultural heritage within forests (Eriksson, 2018). One result is that the role of traditional land use is seldom considered in forest protection efforts (Lennartsson et al., 2023).

The overall goal of this study is to improve understanding of the long-term impacts of traditional indigenous land use and to expand the often limited discussion on this complex topic. We will use field data on both forest structure and cultural objects (i.e., visible remains from past human activities), and analyze all the data in a comprehensive, integrated way using Principal Component Analysis (PCA). Additionally, we will gather data from historical sources and utilize analyses of Sami toponyms (place names) provided by linguists. In this way, we will address the following specific questions:

1. How are variations in forest-structure characteristics in a large, protected landscape connected to historical land use?
2. Does the density of cultural objects indicate how heavily the site was used and how much the forest structure differs from old-growth conditions?

In this way, we aim to contribute to a more nuanced understanding of the complex long-term effects of low-impact human land use in a forest landscape that is also a historical cultural landscape primarily used by an indigenous people.

Data and Methods

Study Area

The study area is situated around the Arctic Circle in northern Sweden at 66°N, 17°E, within the Tjieggelvas Nature Reserve, one of the largest conserved old-growth forests in northern Europe. The reserve spans about 330 km² of forests, lakes, wetlands, and boulder fields, including the large Lake Tjieggelvas in the Pite River. Our study site is located east of the lake between 460 and 590 meters above sea level. The terrain is gently rolling with rocky hills and rises to the east, where the vegetation gradually shifts to subalpine

birch forest and then alpine mountain heaths. The soil ranges from mesic to dry and is generally poor in nutrients. The forest is mainly composed of Scots pine (*Pinus sylvestris*), with some downy birch (*Betula pubescens*), especially in the upland areas, and a very small proportion of Norway spruce (*Picea abies*). The ground layer mostly consists of dwarf-shrubs (*Vaccinium* spp., *Empetrum nigrum*), ground lichens of the genera *Cladonia* spp., *Cetraria* spp., and *Stereocaulon* spp., and mosses such as *Hylocomium splendens* and *Pleurozium schreberi*.

No roads lead to the study area, which has never been commercially logged except for a narrow strip by the lake or subjected to other types of large-scale resource extraction. Nevertheless, humans have long used the area. Throughout history, the area has always been important to the indigenous Sami. Several lakes serve as habitats for pike (*Esox lucius*), perch (*Perca fluviatilis*), grayling (*Thymallus thymallus*), brown trout (*Salmo trutta*), and whitefish (*Coregonus* spp.).

Cultural objects indicating traditional land use are abundant and include “bark-peelings,” i.e., more or less healed rectangular scars on the trunks of Scots pine from harvesting bark for food (Rautio et al., 2014), remnants of storage platforms where gear and food were left between seasons (Rautio et al., 2014), stumps from cutting firewood or construction wood (Josefsson et al., 2010b), “lichen stumps,” i.e., tall stumps from trees felled to provide reindeer with arboreal lichens (Berg et al., 2011), fences used to control reindeer movements (Norstedt et al., 2017), tree blazes, i.e., marks on trunks created with an axe, and stones on larger rocks or stone piles indicating trails or traplines, i.e., series of traps for fowl or small mammals (Josefsson et al., 2010a), and hearths from Sami dwellings (Josefsson et al., 2009).

Before the first law on reindeer husbandry, which took effect in 1886, most forest land in the Sami districts (lappmarker in Swedish) was divided into taxlands—units owned and used by one or a few Sami families, who paid taxes to the Swedish Crown (Norstedt, 2018). Our study area was divided into three main taxlands, Mattme (now mostly called Vattme), Árvas, and Siebmer (Josefsson et al., 2010a).

In the late 19th century, many Sami established small farmsteads and became more or less sedentary. This also occurred in our study area, where the main settlement, Áhkábákte, was permanently occupied until the late 20th century, while two smaller farmsteads, Ligas and Muŋka (on the northern shore of Lake Muŋkajávrrre), were abandoned much earlier (Josefsson et al., 2009; Sjaggo, 2021). Such farmsteads usually had limited arable land, and the owners relied on hunting, fishing, and reindeer herding (Meschke, 1979).

Today, no one lives permanently in the study area, which the Luokta-Mávas reindeer-herding community uses for winter grazing. Recreational fishers often visit Lake

Tjieggelvas, but few venture into the forest. In contrast, the forest has been the subject of extensive research in forest history and has become an important reference area for Sami cultural landscapes.

Site Selection

We selected five sites that we presumed to differ in terms of land-use history (Fig. 1). Since we wanted each site to be as homogenous as possible with respect to the presumed land use, and also had to adjust to lakes, boulder fields, etc., sites were slightly different in size. The five sites are described with the survey year and area indicated in parentheses.

- **Ligas** (2017; 36 ha) is the place of a small former farmstead, located between the lakes Áhkájávrrre and Mähtjávrrre, close to the smaller lake Lijgásjávrrátj, 473 m.a.s.l. The farmstead is abandoned, the buildings have been demolished, and the natural vegetation is growing back. In both Áhkájávrrre and Mähtjávrrre there is pike, perch, whitefish, and grayling.
- **Plähkkájávrrre** (2016; 13 ha), a major fishing lake with the same species as in Áhkájávrrre and Mähtjávrrre, located in the northern part of the study area, about four kilometers from the Áhkábákte settlement. The study site is just north of the lake in a mostly flat area with pine forest, around 484 m.a.s.l.
- **Hålgåsjávrrre** (2016; 15 ha) is another major fishing lake south of lake Plähkkájávrrre, with the same fish species. The study site is located east of the lake, on a gentle slope with Scots pine forest, at around 475 m.a.s.l. This area has been carefully surveyed for cultural objects before because of a large concentration of bark-peelings (Rautio et al., 2014).
- **Rátkamjávrrátj** (2018; 20 ha) is a small lake on the slope above Hålgåsjávrrre, near the upper edge of the pine forest where birch becomes more common. The study site is just west of the lake, around 582 m.a.s.l. The lake has smaller brown trout, but lacks the species found in larger lakes.
- **Gállakvárre** (2019; 12 ha) is a mountain in the southern part of the study area. The study site is located in the pine forest east of the mountain, immediately east of a small lake called Ittkájávrrre, around 526 m.a.s.l. Just like in Rátkamjávrrátj, smaller brown trout are present in the lake.

Collection of Data on Forest Structure and Cultural Objects

The method used for collection of field data was based on the comprehensive field survey covering 2,700 hectares that

was conducted in 2006 by Josefsson et al. (2010b) in the core of the study area. In that study, data was gathered along parallel transects, 20 meters wide, spaced 500 meters apart. Within the transects, circular sample plots of 0.1 hectares were placed every 500 meters. Cultural objects were surveyed throughout the transects, and information on forest structure and tree age was collected from the sample plots. Here, the same method was used with some modifications. We laid out 20 m wide transects, 100 m apart, and placed circular sample plots of 0.1 ha every 100 m (Table 1). We collected data on forest structure and tree age in the sample plots, as well as on cultural objects along the entire transects.

The results of the previous study, which will henceforth be referred to as “Tjieggelvas large,” serve as a reference to our findings.

Forest structure

Following the methods developed by Josefsson et al. (2010b) for analysis of coniferous old-growth forests in Scandinavia, we measured basal area and height of trees, both conifers and broadleaves (almost exclusively Scots pines and birches), basal area of dead standing trees, and volume of coarse woody debris (CWD) in each sample plot. These parameters, in addition to the age-structure, provide data on key structural elements of this type of forest and give indications of natural and anthropogenic disturbance (Josefsson et al., 2010b). Specifically, the basal area of dead standing trees, CWD volume, and tree age are variables connected to old-growth forest conditions in this region.

In addition, we randomly selected up to five trees within each plot using a relascope and extracted cores with a 4.13 mm increment borer for age estimation. Cores were stabilized in the field and transported to the lab, where they were mounted and sanded following standard dendrochronological procedures. Distances between tree-rings were then measured using either a Lintab measuring table with the TSAPWin software or scanned and analyzed with Coorecorder and CDendro (version 9.3.1). Dead trees were dated using three master chronologies from northern Sweden: Tjieggelvas Nature Reserve (Gunnarson et al., 2012), Lycksele (unpublished data), and Torneträsk (Grudd et al., 2002). A relascope-weighted average age for each tree species was calculated for each plot.

Cultural Objects

Cultural objects (COs) were surveyed along the transects. We classified and documented each CO and recorded its location using a handheld GPS device. Then, we calculated the CO density of each sample plot based on the number of COs within segments of transects measuring 25 m in both

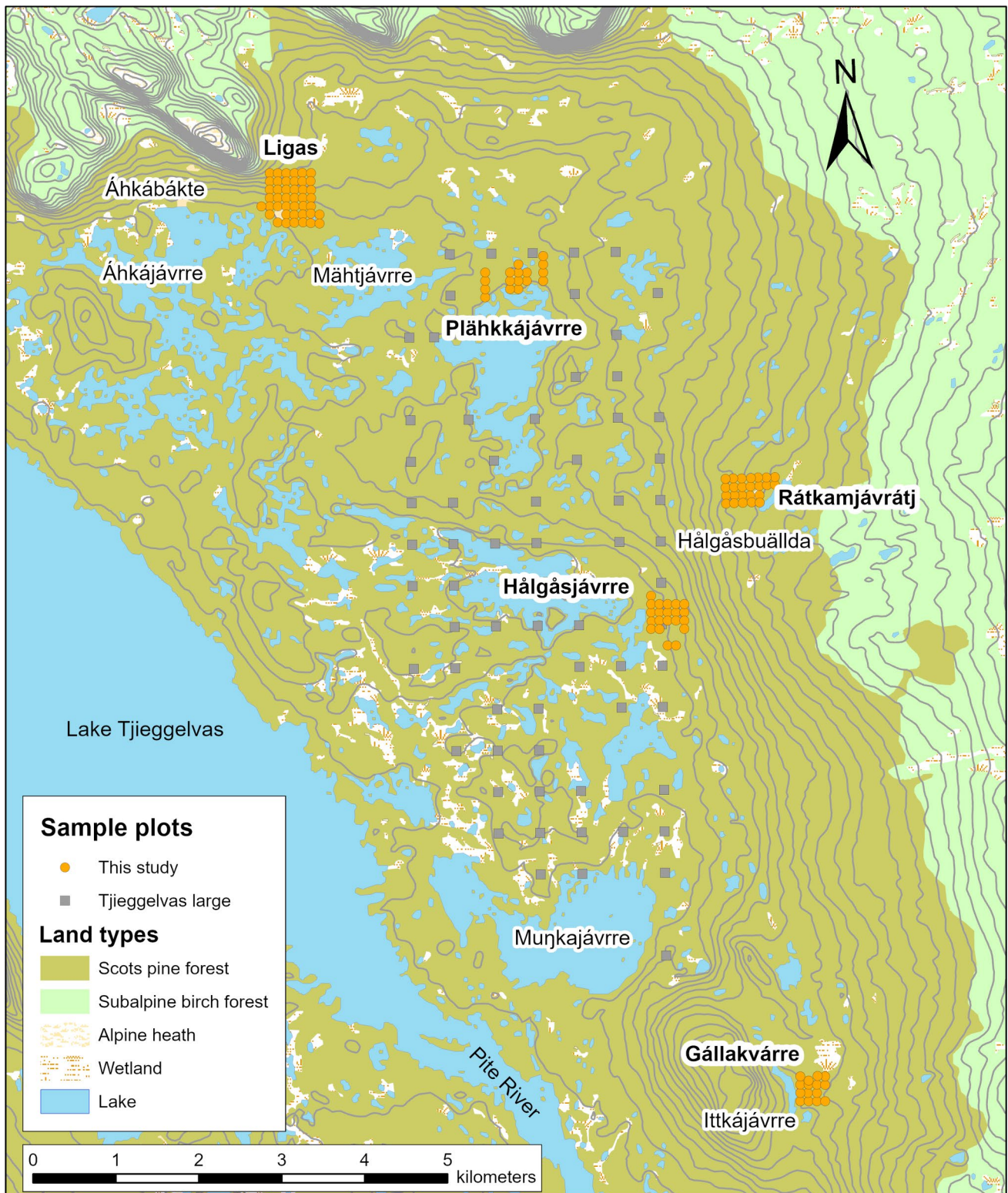


Fig. 1 Overview map of the study area, showing the five study sites, the plots of the previous study “Tjieggelvas large”, the former farmstead Áhkábákte (still inhabited seasonally) and some other placenames occurring in the text. Names of study sites are indicated in a bold typeface

Table 1 Overview of the transect areas and the number of sample plots surveyed on each study site

	Ligas	Plähhkájávrrre	Hålgásjávrrre	Rátkamjávrrátj	Gállakvárre	Sum
Transect area (ha)	7.2	2.6	3.0	4.0	2.4	19.2
Sample plots	43	17	21	24	15	120

directions from the center of each plot (0.1 ha), using ArcGIS software. For the Rátkamjávrrátj site, plot coordinates were lost, so we assigned a CO/ha value to each plot equal to the average of the relevant transect.

At the Rátkamjávrrátj site, we observed many clusters of birch stems that came from shoots growing from old stumps. These stumps might come from trees that were cut down for firewood or from trees that had died naturally, such as from heavy attacks by the Autumnal moth (*Epirrita autumnata*). Since we could not clearly identify them as human-made artifacts, they were not recorded as COs.

The Hålgásjávrrre site had previously been the subject of a study where all cultural traces of past Sami land use were documented in one part, and about 50% of the other part (Rautio et al., 2014). For the COs of this site, we used the GIS data from that earlier study, laid out transects in ArcGIS, and incorporated COs according to the same principles used during the field surveys.

To gain a better understanding of each site, we examined the public database of the Swedish National Heritage Board (RAÄ, 2024) for archaeological data collected during previous surveys. This data was primarily available for the Plähhkájávrrre and Hålgásjávrrre sites. Around Rátkamjávrrátj and Gállakvárre, we conducted additional searches in the surrounding areas. These COs were not included in the dataset but were used for comparison and context.

Distance to the Nearest Major Fishing Lake

To assess the impact of recurrent stays for fishing, the distance of each plot to the nearest major fishing lake (Muñkájávrrre, Plähhkájávrrre, Hålgásjávrrre, and Áhkájávrrre) was measured afterward using ArcGIS software.

Productivity and Vegetation Type

To estimate the productivity of each plot and its potential to support certain land uses, a proxy was evaluated using vegetation data from the Swedish Environmental Protection Agency (NMD 2018). We created a six-step scale, ranging from the least ecologically productive (1) to the most ecologically productive (6), and assigned a value to each plot.

1. Pine forest with boulders
2. Pine forest of dwarf shrub-lichen type
3. Pine forest of dwarf shrub type

4. Pine forest with isolated birches
5. Mixed forest with nearly equal parts of pine and birch
6. Birch-dominated forest

Overview of Parameters

To summarize, these are the parameters related to forest structure and cultural objects that we measured or evaluated for each sample plot (the list includes the labels used in the data plots shown in the Results section):

- Basal area of conifers (BA_conif)
- Basal area of deciduous trees (BA_decid)
- Height of conifers (Height_conifer)
- Medium age of pines (Age_pine)
- Medium age of deciduous trees (Age_decid)
- Basal area of dead standing trees (BA_dead_standing)
- Volume of coarse woody debris (Vol_CWD)
- Density of cultural objects CO/ha (CO_ha)
- Distance to the nearest major fishing lake (Dist_lake)
- Productivity (Vegetation)

PCA Analysis

To identify which parameters contributed most to variation between sites, we performed a principal component analysis (PCA) in R (R Core Team, 2023). Before conducting the analysis, we standardized the data to prevent differences in units and scales from affecting the results.

Some data were missing due to minor disruptions in the fieldwork procedures, such as missing data on coarse woody debris from the Rátkamjávrrátj site, and plot-specific factors like plots lacking deciduous trees. When appropriate, missing data were replaced with null values. For site-related missing data, we followed recommendations for environmental PCA (Dray & Josse, 2015). This involved conducting multiple imputation of missing values using the R package Amelia (Honaker et al., 2011), which is a fast and robust method that combines an algorithm with a bootstrap approach. The reliability of this imputed data was verified. Besides Amelia, we used other R packages, including FactoMineR (Lê et al., 2008), factoextra (Kassambara & Mundt, 2016), and data.table (Barrett et al., 2024), missMDA (Josse & Husson, 2016), corrplot (Wei & Simko, 2021), and VIM (Kowarik & Templ, 2016).

Collection of Historical Data

We researched and analyzed historical data related to the study area overall and the specific study sites in both published works and unpublished primary sources.

The most important primary sources were district court records, which often contain detailed information about land use and landowners. Additionally, court records include descriptions of tax lands, mainly from the early nineteenth century, when competition over land increased and owners sought to have their lands legally described and defined. For Mattme, this was done in 1841 (ADCA. Records from ordinary court proceedings 1840–1844, p. 201); for Árvas, in 1819 and 1856 (ADCA. Records from ordinary court proceedings 1820–1824, p. 38; 1856–1859, p. 381); and for Siebmer, in 1819 and 1841 (ADCA. Records from ordinary court proceedings 1840–1844, p. 168; 1820–1824, p. 37). The records from these procedures contain valuable information about land and lake use.

Starting in 1900, the Swedish government began investigations to understand the situation of the Sami and reindeer herding. The 1912 *Reindeer Pastures Commission* included interviews conducted in 1913 with several reindeer herders in our study area. The 1930 *Sami Affairs Commission* included more interviews, and elders were asked to describe how reindeer herding was done in their youth, around 1900.

Toponyms in the local language, Pite Sami, were interpreted following Sjaggo (2021).

Results

Cultural Objects

The types of COs varied across the sites (see Table 2). Densities also changed, as explained in more detail for each location.

Ligas

The density of COs in Ligas was generally low. Although some sample plots had high densities of COs, we found none at all in more than 40% of the plots. The types of COs identified were mainly cut stumps, likely used for both construction wood and firewood. There were also a few Scots pine trees with bark-peeling scars.

Plähhkájávrrre

Although one of the sample plots at Plähhkájávrrre had the second highest density of COs in the study, with 70 COs/ha, about half of the plots had no COs at all, and the others ranged from 10 to 30. Most of the COs were bark peelings or cut stumps, but there were also some blazes on trees. In previous archaeological surveys, several traplines marked by stacked stones have been recorded in the surroundings, and there are hearths along the lakeshore (RAÄ, 2024).

Hålgåsjávrrre

The density of COs was higher at Hålgåsjávrrre than at any other site, primarily due to a concentration of Scots pines with bark-peeling scars. In a previous study, many of the bark-peelings were dated using dendrochronology, so we know the site was used repeatedly—almost every decade—for over 300 years. Additionally, remains of several storage platforms and hearths in the area suggest that the site served as a place where gear or food, such as dried inner bark, was stored between seasons (Rautio et al., 2014).

Rátkamjávrrátj

At Rátkamjávrrátj, the density of COs was relatively low. Two-thirds consisted of bark peelings, while the rest were stone markings, likely for traplines, aside from one hearth.

Table 2 Numbers of cultural objects of different types found at each site during transect surveys. The most common types at each site are marked with gray backgrounds, and the results of “Tjieggelvas large” are included as a reference

Site	blaze	bark peeling	cut stump	hearth	lichen stump	storage platform	stone marking	other	sum
Ligas	2	13	56	0	0	0	0	0	71
Plähhkájávrrre	5	8	8	0	0	0	0	0	21
Hålgåsjávrrre	0	43	0	1	0	1	0	0	45
Rátkamjávrrátj	0	14	0	1	0	0	3	0	18
Gállakvárre	1	8	0	0	7	0	8	0	24
Tjieggelvas large	15	136	49	4	141	7	17	5	374
Sum	23	222	113	6	148	8	28	5	553

Since no prior archaeological surveys had been done around the site, we also searched the surrounding areas for COs. Notably, we discovered three hearths near the uppermost part of the lake. The only recorded cut stump in the vicinity was found close to those hearths. Additionally, we found the remains of an old wooden boat.

Gállakvárre

The density of COs at Gállakvárre was the second highest of all sites. The objects were almost equally divided among bark peelings, stone markings, probably for traplines, and lichen stumps.

Since archaeologists had never surveyed the area, we searched for COs in the surroundings and found four hearths on the western side of Lake Ittkájávrré. Near one of the hearths, we discovered remains of two storage platforms and several low firewood stumps. North of the study site, we found nearly 30 stone markings, probably indicating traplines, along with two hearths, some clusters of lichen stumps, and some bark peelings.

PCA Analysis

The eigenvalues from the PCA analysis of the sample plots are quite low; 27.2% and 16.5% of the dataset's variance are explained by the first and second principal components, respectively.

Dimension 1 is mainly associated with variation in the distance to the nearest major fishing lake (Dist_lake) and the volume of CWD (Vol_CWD), which are strongly correlated (Fig. 2, Fig. 3). Pine age (Age_pine) and basal area of dead standing wood (BA_dead_standing) contribute as well, although to a lower degree. All of these parameters are positively correlated with the axis of dimension 1. By contrast, the density of COs (CO_ha) does not contribute to this dimension.

The basal area of deciduous trees (BA_decid) has the strongest loading on dimension 2 and is positively related to the axis. Vegetation also shows a positive correlation, but its contribution is smaller. The density of COs and the basal area of coniferous trees (BA_conif) are negatively related to the axis of dimension 2, but they have less influence. Additionally, the density of COs is negatively related to the basal area of deciduous trees and positively related to the basal area of coniferous trees along dimension 2.

When the sampling plots are grouped by site, some sites appear as more similar than others (Fig. 4). The key drivers of site separation and major contributors to the variation along dimension 1 are the distance to the nearest major

fishing lake (Dist_lake) and the volume of CWD (Vol_CWD). The results for each site are described in more detail below.

Ligas

The Ligas site represents one extreme in the PCA analysis. Its sample plots are clustered on the left, negative side of dimension 1, which is characterized by a short distance to the nearest major fishing lake, a small volume of CWD, a small basal area of dead standing wood, and, to some extent, a low age of Scots pines. At the same time, there is a strong influence of the parameters related to dimension 2, such as a large basal area of deciduous wood, a relatively low basal area of coniferous trees, and productive vegetation.

Plähkkájávrré

The Plähkkájávrré site shares many similarities with Ligas but is less affected by the factors related to dimension 2, particularly in areas with smaller basal areas of deciduous trees.

Hålgásjávrré

Hålgásjávrré largely overlaps with Plähkkájávrré but has more old-growth features, including greater amounts of CWD, larger basal area of dead standing wood, and older trees.

Rátkamjávrrátj

The Rátkamjávrrátj site is notably different from the previously mentioned sites regarding parameters related to dimension 1, though it slightly overlaps with Hålgásjávrré. It features a location far from major fishing lakes, a tree layer with old pines and birches, a large number of dead standing trees and CWD, and generally low-productivity vegetation. It exhibits characteristics of a genuinely old-growth forest. In contrast, it somewhat resembles Ligas in relation to dimension 2, primarily due to its relatively large basal area of deciduous trees.

Gállakvárre

The Gállakvárre site largely overlaps with the Rátkamjávrrátj site and thus exhibits characteristics of an old-growth forest. Regarding parameters related to dimension 2, it more closely resembles Plähkkájávrré and Hålgásjávrré than Ligas, with a small basal area of deciduous trees.

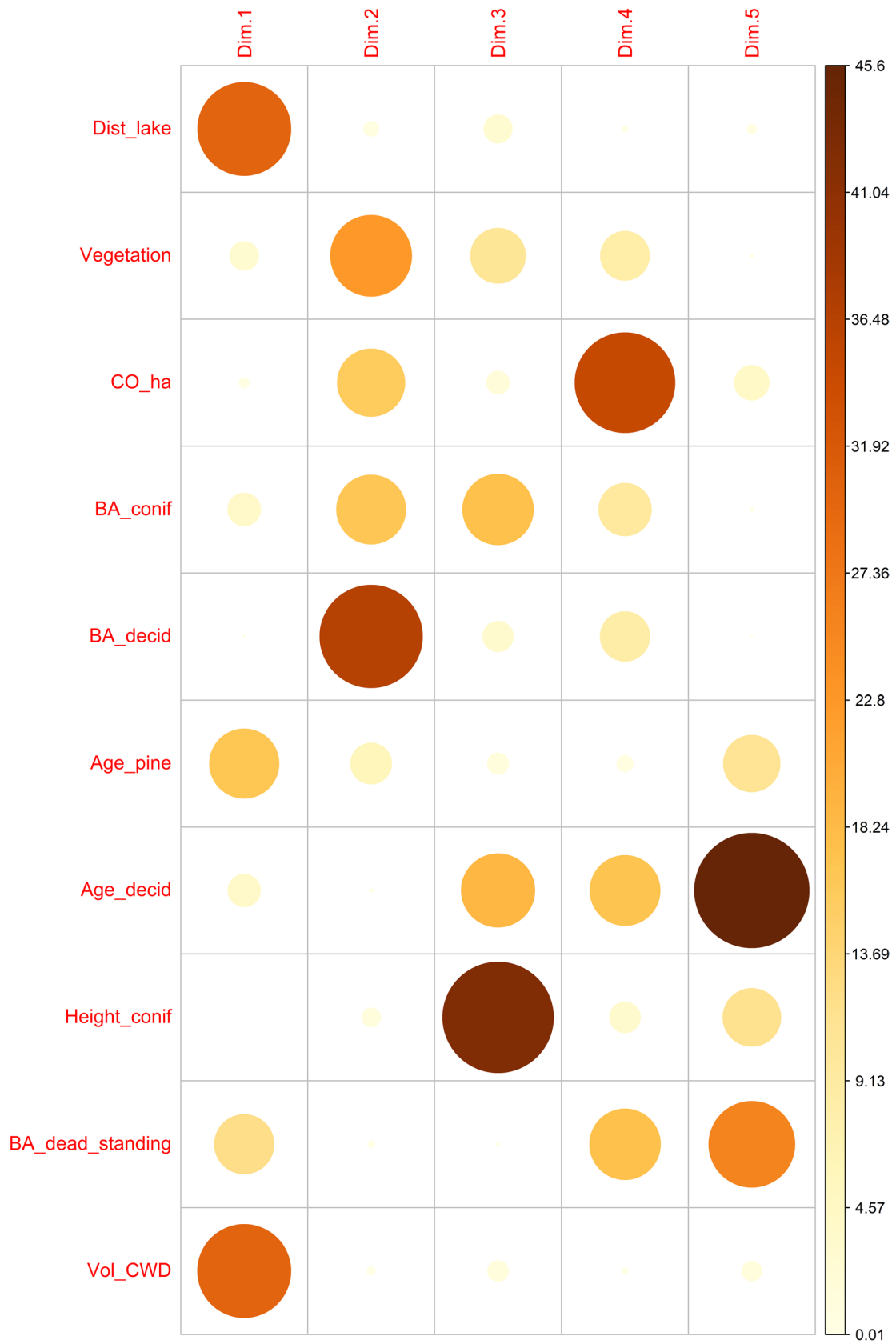


Fig. 2 Contributions of variables ($n=10$) to the first five principal components (Dim. 1–5). The color scale indicates each variable’s contribution (in %) to the variance of each component

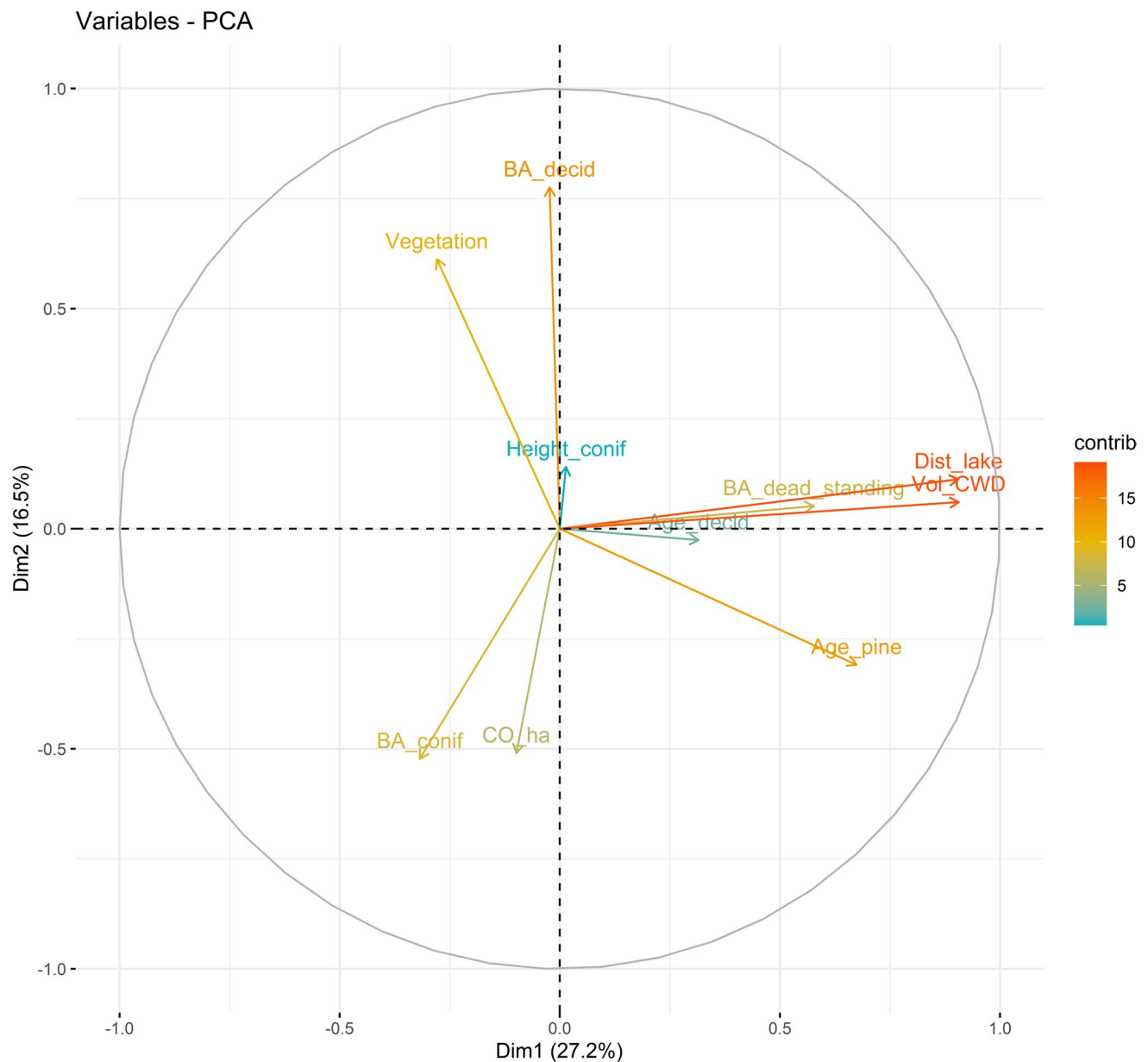


Fig. 3 Contributions of the 10 variables to dimensions 1 and 2. Arrows represent the direction and strength of each variable's influence. The color gradient indicates the contribution (in %) of each variable to the total variance explained by the two dimensions

Historical Data and Toponyms

Ligas

There are two maps over the area from 1888, one of the neighboring Áhkábákte and the other of the surrounding so-called crown land, but none of them indicate any settlement at Ligas (Ulfhjelm, 1888). As far as we know, the first known settler was Lars Nilsson Sjaggo (Sjaggo, 2021). In interviews with neighboring Sami in 1913, it was reported that Sjaggo intended “to settle on the land

of Áhkábákte,” which was owned by one of his cousins (Kaddik, *Reindeer Pastures Commission* 1913, p. 67), and that he “owns a settlement and is preparing to start farming” (Pavval, *Reindeer Pastures Commission* 1913, p. 53). The establishment of the settlement can thus be dated fairly precisely to 1913. Between 1930 and 1960, another family lived here after being forcibly dislocated from northernmost Sweden (Sjaggo, 2021, p. 167). An aerial photo from the 1950s shows about one hectare of arable land, which was probably cultivated until the family left in the 1960s.

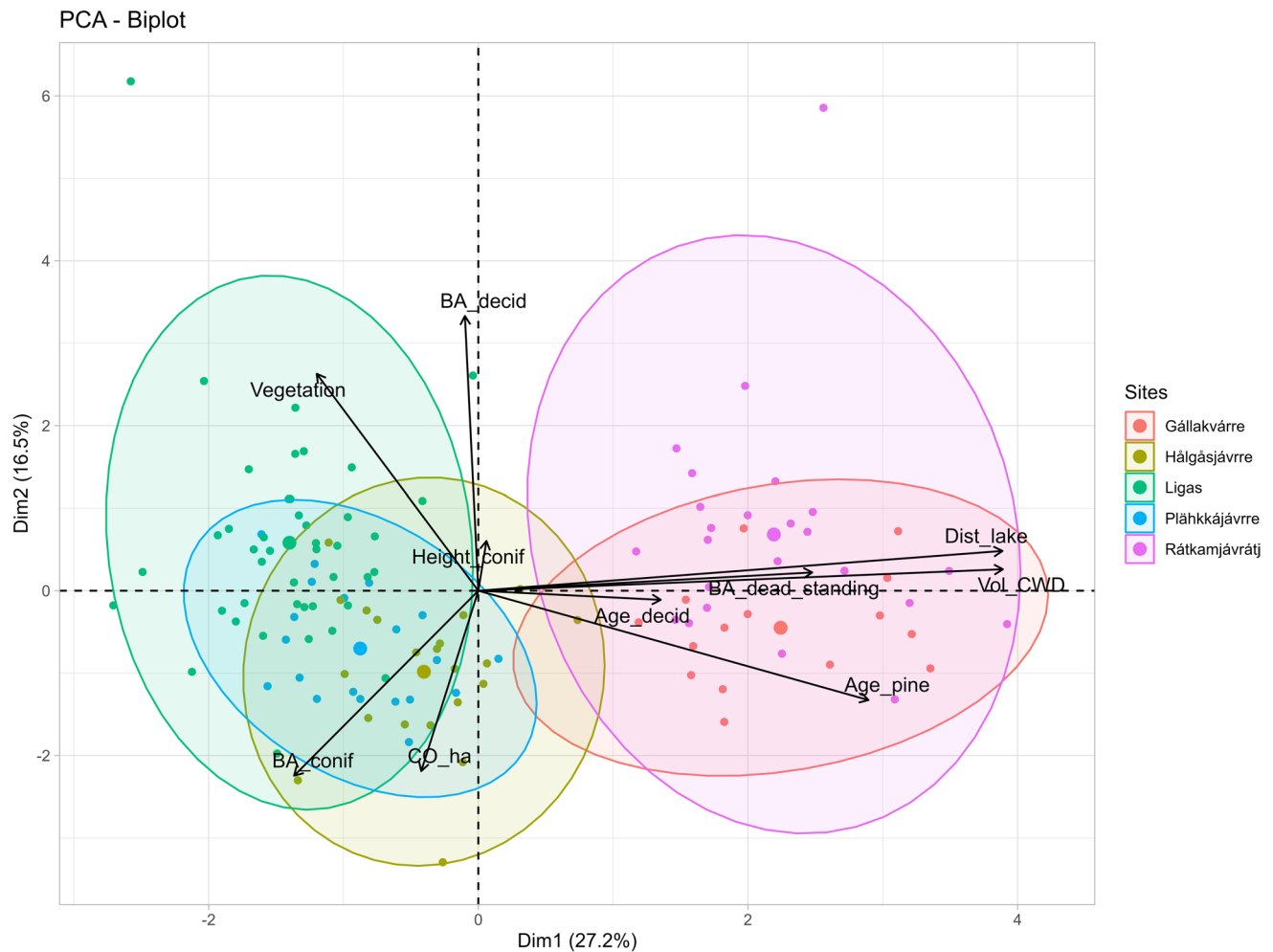


Fig. 4 PCA biplot of the individuals (i.e., sampling plots) and explanatory variables ($n = 10$) of the first (Dim1) and second (Dim2) principal components. Each point represents one sampling plot, colored by site

Plähkkájávrrre

This site has been part of the historic Mattme taxland (Josefsson et al., 2010a). When the district court in 1749 made an inventory of available winter-grazing lands for reindeer, Mattme was one of the areas mentioned. It was reported that three Sami families owned Mattme, and that there was still space for a couple of reindeer herders during autumn and winter (ADCA. Records from court proceedings on January 27, 1749). However, in 1774, the owners of Mattme no longer allowed other reindeer herders to pass through their land (ADCA. Records from court proceedings on January 28, 1774). The most likely explanation for this change is that the owners of Mattme had expanded their own reindeer herding.

In 1841, when Mattme was described and registered as a taxland, Plähkkájávrrre was listed as one of the fishing lakes. The same document mentions the forest land *Pläcka*

muotki, undoubtedly related to the lake (ADCA. Records from ordinary court proceedings 1840–1844, p. 201). In Pite Sami, *plähkka* means shallow, and *muätke* is a piece of land located between two lakes, where boats have to be carried (Sjaggo, 2021). *Pläcka muotki* could indicate the land between Plähkkájávrrre and the lake Mähtjávrrre, which is not far from the study area. When an area was mentioned as a “forest land” in a land description, it usually meant that it was an area suitable for reindeer grazing.

More detailed information can be found in later sources. Around 1900, the reindeer-herding winter group, consisting of four households with a shared herd of about 1,000 reindeer and customary rights to the area, employed two main winter strategies depending on weather and snow conditions. They either migrated with the herd roughly 100 km further east or spent the entire winter in Mattme, where they lived in peat huts “by lake Bläcka” (Ruong, *Sami Affairs Commission* 1930, p. 692b). The remains of such a hut have been

discovered on the southwest shore of the lake (Liedgren et al., 2009). Near the hut, two lichen stumps have been dated to AD 1888 and 1895. A boy was born in the hut in January 1905 (APA, *Birth and baptism record 1895–1909*, p. 125; Liedgren et al., 2009).

After the establishment of the Áhkábákte settlement, Plähhkájávrrre was used as a fishing lake by the inhabitants (Sjaggo, 2021).

Hålgåsjávrrre

Just like Plähhkájávrrre, Hålgåsjávrrre belonged to the tax land Mattme and was listed among the fishing lakes in 1841 (ADCA. Records from ordinary court proceedings 1840–1844, p. 201). However, in a later registration of the neighboring tax land Árvas, “Hållkásjaur” was mentioned as one of the fishing spots of that land (ADCA. Records from ordinary court proceedings 1856–1859, p. 381). Clearly, it was an attractive fishing lake.

According to current reindeer herders of the Luokta-Mávas community, the traditional migratory route from the lowlands to the mountains ran along the northern side of Lake Hålgåsjávrrre. Migration occurred in spring and early summer, during the bark harvest season.

Rátkamjávrrátj

The lake is located in an area called Hålgåsbuäldda (*buäldda* means slope), a forested region that stretches from Lake Hålgåsjávrrre to the subalpine birch zone. When the Árvas taxland was described in 1819, Hålgåsbuäldda was noted as one of the key reindeer grazing areas (ADCA. Records from court proceedings 1820–1824, p. 38). The name of the lake includes the Pite Sami word *rátkam*, which means separation of reindeer herds (Sjaggo, 2021). Such herd separations have been conducted for various reasons. Historically, it was common to separate reindeer cows from bulls in the spring, just before calving. Cows were then guided to the best locations, not far from the summer pastures, so that newborn calves would not have to travel far (Kuhmunen, 2000). Evidence suggests this practice continued in the study area until around 1900 (Spaut, *Sami Affairs Commission 1930*, p. 690b). In autumn, separations often occurred “to separate bulls from cows” just before Michaelmas (September 29), “after migration from the mountain down into the forest” (ADCA. Records from court proceedings on January 26, 1792). Michaelmas was seen as the approximate start of the rut. Castration, for maintaining bulls' slaughter weight or producing tame reindeer for transportation, had to be done before the rut (Fjellström, 1986, p. 170), which likely explains the timing of these separations.

During the rut, the reindeer were released and formed larger herds. When the rut ended in October, reindeer belonging to different owners had to be separated into smaller groups, usually one family or a few families, who planned to stay together during winter. At the same time, buyers would come to purchase slaughtered animals (ADCA. Records from court proceedings, February 7, 1895).

Before the 1920s, no corrals were used for separations in this area (Ruong, 1945). This was because reindeer were accustomed to being handled by people (Steggo, *Sami Affairs Commission 1930*, p. 712).

Gállakvárre

We have found only one mention of Gállakvárre in historical sources. It appears in a description of the Siebmer taxland from 1819, where Gállakvárre was listed among its “forest mountains” (ADCA. Records from ordinary court proceedings 1820–1824, p. 37). Most of those mountains are classified as either good or poor reindeer grazing land, most likely based on the amount of reindeer lichen. Regarding Gállakvárre, no such classification is given, but it seems reasonable to assume it was used as grazing land like the other “forest mountains.”

Discussion

The PCA analysis indicates that distance to major fishing lakes and volume of CWD are the primary variables contributing to differences among sites. The strong correlation between these two parameters suggests that old-growth conditions are more pronounced farther from fishing lakes. This is likely because, historically, fishing was often a more important subsistence strategy for forest-dwelling Sami than reindeer herding (Norstedt, 2020; Norstedt & Östlund, 2016). Additionally, lake fish is a resource that tends to be less variable than reindeer grazing resources, meaning settlements primarily used for fishing were more frequently occupied and would probably cause more intense human impacts on forest structure, as well as more COs. Dead trees, often collected for firewood, could be gathered up to 300 m from regularly used settlements (Östlund et al., 2013). Therefore, it is understandable that volumes of CWD are generally lower near major fishing lakes.

The relationship between forest-structure variables and historical human impact is more complex and differs across sites. The same applies to the relationship between CO density and old-growth conditions.

Forest-Structure Variables and the Historical Impact of Humans

In the results of the PCA analysis, CWD volume is the forest-structure variable that contributes most to the first dimension, with smaller contributions from Scots pine age and basal area of dead standing wood. Since these are variables that are likely to reach high values under old-growth conditions, their co-variation is understandable.

Our study sites were clearly different from each other, especially in variables related to old-growth conditions like CWD volume and the age of Scots pine. This supports the findings of the “Tjieggelvas large” study, where total CWD volume, pine age, and the volume of standing dead trees were lower around the two abandoned settlements—specifically the hut by lake Plähkkájávrrre and the farmstead by lake Munjkájávrrre—compared to the surrounding areas. Each site has a unique history that has influenced its current forest ecosystem.

Ligas

The Ligas site has the most deviation in forest-structure variables from old-growth conditions. This is not surprising considering the historical evidence of a settlement established around 1913 and ongoing agriculture until the 1960s. The productive vegetation indicates that this was a good location for farming, which may also partly result from past land use where roaming cattle spread manure. Additionally, the Ligas site generally has a high volume of birch, with two-thirds of all plots showing a birch basal area of 2 m²/ha or more. Downy birch is a pioneer species that quickly establishes itself when other tree species are removed or the ground is disturbed (Lundmark, 1988, p. 133). It appears likely that birches thrive at Ligas due to former land use.

Plähkkájávrrre

The forest-structure variables at Plähkkájávrrre differ from old-growth conditions, but not as much as in Ligas. This matches historical evidence of multiple households living in the area during winter with their reindeer, whose firewood consumption led to low amounts of dead wood and many cut stumps. Temporary fishing would have similar effects, though on a smaller scale.

Hålgåsjávrrre

The Hålgåsjávrrre site significantly overlaps with Plähkkájávrrre and is characterized by forest structure variables that are not typical of old-growth conditions. However, besides evidence of fishing, historical sources provide little

information about this site. The small amounts of CWD and the relatively young age of pine might be related to the treatment of pine bark by heating in cooking pits (Rautio et al., 2013), which would require a lot of firewood. Also, the people staying at the site needed firewood for heating and cooking.

Rátkamjávrrátj

Unlike the first three sites, the forest at Rátkamjávrrátj appears to be genuinely old-growth, including some of the oldest Scots pines sampled during the survey—two of which are around 600 years old. These features suggest that the site was mainly used occasionally. The higher basal area of birches might suggest otherwise, but unlike in Ligas, we believe that birches do not thrive here due to human impact, but rather because of less competition from pine due to the higher elevation and harsher climate. The place name suggests that the site was suitable for the separation of reindeer herds, although it was not necessarily used every year.

Gállakvárre

The Gállakvárre site mostly overlaps with the Rátkamjávrrátj site and shows signs of having low human impact. Since Gállakvárre is mentioned as reindeer grazing land, probably used during winter, more human activity might be expected. However, it's likely that Sami families stayed below the mountain for protection from the wind and collected most of their firewood there.

Summary

In summary, our results from the five sites demonstrate that variations in forest-structure variables associated with old-growth conditions can largely be explained by land-use history. This is true even for sites where only small-scale, traditional land use is known.

Density of Cultural Objects and Old-Growth Conditions

In the PCA analysis, the density of COs in the study area was not strongly linked to old-growth variables. This was surprising, since a higher density of COs should indicate more human activity, which could harm old-growth features. At the same time, the same inconsistency was seen in the “Tjieggelvas large” study, where the density of culturally modified trees was highest at the Munjka settlement and lowest around the Plähkkájávrrre site.

Additionally, the PCA analysis indicated that CO densities mostly have a negative correlation with the basal area

of deciduous trees and a positive correlation with the basal area of coniferous trees in dimension 2. This can be attributed to the fact that most COs in this region are culturally modified coniferous trees, specifically pines.

Here we will discuss the results site by site for a better understanding of the relation between COs and former land use.

Ligas

The density of COs in Ligas was surprisingly low considering the presence of a year-round settlement from around 1913 to the 1960s. One reason for this could be that older COs, such as trees with bark-peeling scars, have disappeared because of cutting dead trees for firewood near the settlement. Additionally, lichen stumps were probably absent because reindeer herds were kept away from arable land.

Plähhkájávrrre

At Plähhkájávrrre too, the generally low CO levels did not well reflect human impact, as shown by historical sources. Since the site was characterized by extended winter dwellings of several households, we suggest that COs may have disappeared due to cutting firewood.

Hålgåsjávrrre

Here, the density of COs was higher than at any other site, mainly because of a concentration of Scots pines with bark-peeling scars. This aligns with the forest-structure variables that suggest a departure from old-growth conditions and also matches historical records indicating that the lake was valuable for fishing.

Rátkamjávrrtj

The density of COs on this site was relatively low. If the site was mainly used for herd separation without corrals, as the toponym suggests, this activity would leave few traces apart from a few hearths and some firewood stumps. The density of COs thus aligns well with what we know about the area's historical use and also matches the forest-structure variables.

Gállakvárre

On Gállakvárre, the density of COs is relatively high, surpassed only by the Hålgåsjávrrre site. The presence of lichen stumps aligns with the use of Gállakvárre as reindeer grazing land in winter, as suggested by a historical source. The

COs also indicate that activities such as bark peeling and trapping took place at the site. However, the forest still displays characteristics of old-growth, which we cannot explain with the available data.

Summary

In summary, the density of registered COs poorly reflects both how much the forest structure differs from old-growth conditions and how heavily the site was used historically. We suggest that this is mainly because of the nature of the COs. For example, marking a trapline with several stone piles and tree blazes does not necessarily cause any impact on the forest structure. On the other hand, a single hearth can be a remnant of a long stay with repeated cutting of firewood and construction timber, and if enough time has passed, stumps may have decomposed and no longer add to the CO density. However, there might still be a measurable impact on forest structure, given the longevity of Scots pine. Instead of counting COs and calculating their density, a qualitative analysis of the types of COs offers more insight into the forest impact.

Not only do different types of COs reveal various kinds of land use, but they also have different time depths. A bark-peeling in a living Scots pine causes the wood to be impregnated with substances that kill fungal spores and slow down decomposition. The scar can therefore remain visible for many centuries, even after the tree is dead and has fallen to the ground (Östlund et al., 2004). A lichen stump from a thin tree decomposes much faster because a dead tree cannot prevent spores from growing on the cut surface, which will also become wet and provide a favorable environment for rot. Therefore, the number of bark-peelings can accumulate and contribute to CO density more readily than lichen stumps. Stone remains, such as hearths, survive for an even longer time, but are much more difficult to find in forested terrains, especially in productive forests with lush ground vegetation.

A methodological outcome of our study is therefore that COs should be classified according to their expected impact and longevity to weigh their impact in the analysis.

Conclusion

Each site studied in Tjieggelvas Nature Reserve has unique features due to both natural qualities and historical land use. These sites, along with others in this large forest landscape, can be seen as cultural keystone sites (Cuerrier et al., 2015). They form a cultural landscape that has been slightly altered and “domesticated” by indigenous Sami over centuries and millennia (cf. Terrell et al., 2003). Just as in forest

landscapes where past human impact is more evident, an old-growth forest and its ecological processes can only be understood through a historical perspective of past land use (de Blois et al., 2002; Szabó, 2010).

Nevertheless, interdisciplinary approaches face challenges. Even when combining results from various fields within the humanities, such as history, archaeology, and anthropology, conflicts often occur due to differences in methodologies, epistemologies, and theoretical concepts (Strong, 2017). When data gathered using methods from the natural sciences are also included, these challenges become even greater. Integrating data from different sources requires a thorough understanding of the possibilities and limitations of both the data and methods. In this study, we have become very aware of the challenges associated with such an approach. However, we firmly believe that progress in this field depends on recognizing the complexity of indigenous low-intensity historic land use in forested ecosystems, rather than avoiding it. New pathways must be explored, and steps toward a holistic understanding of history and ecology in forest ecosystems are needed (Hauenschild et al., 2023).

Sweden has an abundance of documents created by bailiffs and courts from the mid-sixteenth century onward, probably more than most countries with indigenous populations. For instance, the historical sources cited in a report on indigenous land use in the Albury area in New South Wales, Australia, are no older than the 1830s and mainly consist of local newspaper articles (Spennemann, 2015). Similarly, a book on the history of the Lakota in the USA and Canada cites no official sources from before 1800 (Andersson & Posthumus, 2022). However, easy access to official primary sources does not guarantee meaningful incorporation of historical data, since the facts and events captured in documents are not unbiased samples of reality, and the documents preserved for posterity in archives result from selective procedures (Strong, 2017). Additionally, earlier judicial and administrative sources were rarely created by indigenous land users, so misconceptions and biases are likely.

In some cases, sources kept by indigenous people can counteract the biases inherent in official documents. For example, in the work on the Lakota mentioned earlier, a valuable primary source is the “winter counts,” which are pictographs created throughout the eighteenth and nineteenth centuries to record significant events (Andersson & Posthumus, 2022, p. xiv). In a northern Swedish context, the traditional songs or *joiks* of the Sami can provide valuable insights into the relationship between individuals and their land use (Stoor, 2007). Additionally, dedicated Sami have interviewed elders and collected field data on cultural remains for their families and communities, creating

invaluable documentation (cf. Ljungdahl, 2017; Niia & Norstedt, 2023).

In areas where cultural legacies in forests have been largely destroyed by activities such as forestry, mining, and wind turbines, nature reserves provide valuable sites for research using new interdisciplinary methods. In Sweden, forest reserves are increasingly valued by Sami reindeer herders who struggle to find lichen grazing resources and shelter for their herds in landscapes dominated by forest plantations. This raises the question of incorporating indigenous traditional knowledge into the future adaptive management of areas initially protected for biodiversity (Berkes et al., 2000; Fa et al., 2020). Although this is rarely practiced currently, we believe it would be respectful of the traditional land rights of indigenous peoples and could also help protect valuable forest ecosystems more effectively (cf. Fa et al., 2020).

We conclude that the designation and management of forest reserves should incorporate cultural history and cultural values to a greater extent than has been done so far. The cultural heritage enhances the overall value of a protected area, connecting the present to the past and recognizing the history of indigenous peoples.

Author Contributions Lars Östlund started the study, took part in all the fieldwork, wrote the first draft with Marlène Baudet and Torbjörn Josefsson, and finished the manuscript with Gudrun Norstedt.

Gudrun Norstedt also supplied historical data and incorporated the historical perspective into the analysis.

Magdalena Fassl performed the PCA analysis and contributed to writing the final manuscript.

Marlène Baudet participated in the fieldwork, conducted the initial PCA analysis, and helped write the first draft of the manuscript.

Petter Sjaggo took part in the fieldwork and provided detailed information about traditional Sami land use and history in the forest reserve.

Torbjörn Josefsson assisted with the PCA analysis and initial data interpretation.

All authors have reviewed and approved the final manuscript.

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Data Availability The data sets, PCA analysis, and transcripts or images of the historical records are available from the corresponding author upon reasonable request.

Declarations

Competing interests The authors declare no competing interests.

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