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Historical legacy of the old-growth pine forest in Dividalen, northern Scandes

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The Dividalen (Sami: Dieváidvuovdi) valley in Troms county, North Norway, is well known for its old-growth pine forest, a biodiversity hotspot for dead wood-inhabiting fungi and lichens. The majority of the valley is protected within the Upper Dividalen Landscape Conservation Area and National Park. A general conception is that until the mid-nineteenth century when agriculture and forestry entered the valley, the landscape was entirely untouched by man and only used as a pathway for Sami and their reindeer herds on their annual migrations between Sweden and the Norwegian coast. Recent investigations on culturally modified trees and fossil pollen from mires have, however, revealed quite a different story. Sami reindeer pastoralism has affected the vegetation composition from the early seventeenth century to the nineteenth century, and traditional land use should be acknowledged as a long present factor in forming the landscape and cultural heritage. The climatic deterioration known as the Little Ice Age had a severe effect on the pine forest stand structure during the same centuries, forming the culmination of a period of climatic stress initiated already in the thirteenth century. Both long-term cultural and climatic factors are thus important to understand the vegetation dynamics and resulting biodiversity within the protected areas.

Keywords: culturally modified trees; human impact; landscape conservation; Little Ice Age; nature management; pollen analysis; Sami reindeer pastoralism; tree rings

1. Introduction

Even though the importance of historical legacy for the present landscape conditions has been widely recognized (e.g. Davies and Bunting 2010; Bryn and Hemsing 2012), there still exists a tendency of thinking that history ends today, or more precisely, with the establishment of a National Park (NP) or Landscape Conservation Area (LCA). This is even more evident if the area is considered pristine, since wilderness for all practical intent is commonly perceived as something static. The Dividalen old-growth pine forest is situated in the northernmost part of the Scandes Mountains and is considered to be one of the few remaining western European forests with no, or at the least, very late human impact. In this regard, the Dividalen old-growth pine forest more closely resembles the North American conifer forests than most European forests. Some of the forest protection began in 1971 as part of the Dividalen/Dieváidvuovdi NP, which was later expanded in 2006 with an LCA. The Dividalen/Dieváidvuovdi LCA was established in order to maintain habitat diversity, species richness, and cultural remains while allowing for the area to be used for reindeer herding and recreation. From a conservational point of view, it was the old-growth pine forest with its high biodiversity and high number of rare species that primarily required protection (Elvebakk 2005).

In the Dividalen/Dieváidvuovdi LCA (FOR 2006-12-01 nr 1316) regulations, it is stated that ‘The area is

protected against actions which can alter or affect the type and character of the landscape to a high degree.’ Thus, from a management’s point of view, a proper understanding of what the statement really denotes then becomes essential. Today, management is primarily based on the situation in which time the conservation area was established, which is more of an administrative date rather than of ecological or cultural significance.

The main purpose of this study is to evaluate the historical legacy of the old-growth pine forest and adjacent areas in Dividalen, northern Scandes. As such, the main focus is on stand structure dynamics and vegetation change through the analyses of both tree rings and pollen. The history of land use is assessed in order to understand human influences on the vegetation dynamics, and also to emphasize the fact that land-use history in itself is important for managers to reach a common ground of understanding with stakeholders. In short, the main objectives of this study are

- (1) to assess the long-term stand dynamics of this northern pine forest;
- (2) to determine the human impact and associated cultural values; and
- (3) to provide results assessable and useful for local management.

Despite the fact that our primary objective is to improve our understanding of local long-term stand dynamics,

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land-use history, and management decisions, many of the applied methods and results are most likely applicable to larger areas, in particular northern and/or remote mountain areas with a late agrarian settlement, such as northern Fennoscandia as well as the Rocky Mountains.

2. Material and methods

2.1. Study site

Dividalen is a north–south-oriented valley, with a continental (cold and dry) climate. Dividalen's mean temperature ranges from -9.4°C for the month of January up to $+12.8^{\circ}\text{C}$ for the month of July with an annual mean temperature of $+0.8^{\circ}\text{C}$. The average annual precipitation is reported to be only 282 mm (mean values for 1961–1990 for weather station 89950 'Dividalen,' long. $19^{\circ} 47' \text{ E}$, lat. $68^{\circ} 43' \text{ N}$, 228 m.a.s.l., Norwegian Meteorological Institute, met.no). The main study area is the old-growth pine forest and adjacent areas (Figure 1), with a valley bottom altitude of 200–400 m a.s.l. and most surrounding peak heights of 900–1300 m a.s.l. A few surrounding peaks, however, are known to reach as high as 1600–1700 m a.s.l. Considering biodiversity and uniqueness, the most valuable vegetation is the old-growth pine forest, rich in lichens (Holien 2005) and particularly rich in fungi living in dead wood (Kristiansen et al. 2005). There is also an interesting beetle fauna in the valley (Olberg 2005), particularly along the river bank. Along the river, one may also find traditional cultural landscape elements in the form of riverside hay meadows. In addition, along certain parts of the river there are silt flats with rich forests of alder (*Alnus incana*), willows (*Salix* sp.), and bird cherry (*Prunus padus*). Similar vegetation is also found across wet depressions along the valley side. Pine (*Pinus sylvestris*) thrives on dry ground alongside the valley bottom, while birch (*Betula pubescens*) dominates in intermediately moist areas as well as along the valley sides. The general vegetation and climatic history of the area through the Holocene is described by Jensen and Vorren (2008).

2.2. Pollen analysis of peat deposits

Two mires were used as archives for past environmental changes (Figure 1).

The Bjørkmomyra (BMM, 215 m a.s.l., $68^{\circ} 45'15'' \text{ N}/19^{\circ} 43'05'' \text{ E}$) mire is adjacent to an encroached riverside meadow. The mire is about 150 m north–south and 80 m east–west, and the core is extracted 30 m from the western edge. Most of the mire vegetation including the sampling point consists of sedges (Cyperaceae) and willow (*Salix*). On the eastern side, birch (*B. pubescens*) shrubs are commonly seen. The immediate surrounding vegetation consists of a pine forest alongside the eastern edge and birch–alder meadows to the west on riverside silt flat. The extracted 90 cm peat profile consisted of Cyperaceae peat, including less decomposed plant material within the upper 10 cm section of the peat. Thick roots at 25 cm depth, likely from present or past *Salix* shrubs, made extraction difficult.

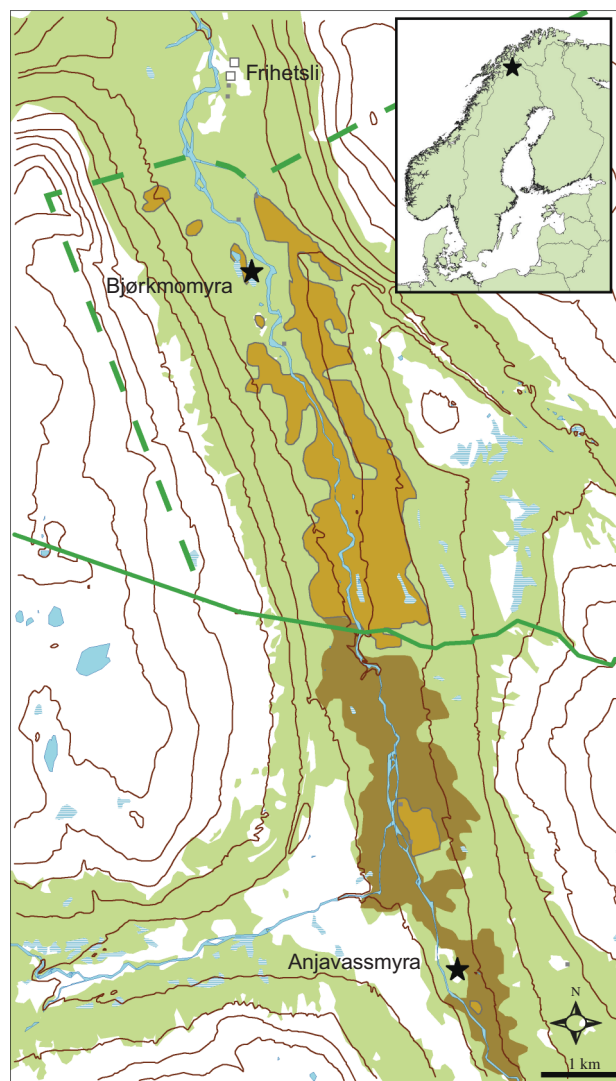


Figure 1. Forest map of Dividalen after Elvebakk et al. (2005). Brown indicates the old-growth pine forest unaffected by logging, yellow brown indicates the old-growth pine forest affected by selective logging, and green indicates other forests, primarily the mixed pine–birch and birch forests. The topography is indicated by 100 m contour lines (BMM and AVM are separated by the 300 m a.s.l. isoline). The border of the LCA and NP extension 2006 is marked with a slashed green line and the NP 1971 border with a green line. The pollen sampling sites are marked with stars and the uppermost farm, Frihetsli, is marked with squares.

Silt lenses in the peat between 10 and 80 cm in depth suggest repeated flooding of the nearby Divielva river.

Anjavassmyra (AVM, 370 m a.s.l., $68^{\circ} 40'30'' \text{ N}/19^{\circ} 47'15'' \text{ E}$) mire is positioned close to the uppermost limit of the old-growth pine forest, in an area with many culturally modified trees (CMTs). The mire is approximately 20 m in diameter, and the vegetation is dominated by crowberry (*Empetrum*) and peat moss (*Sphagnum*). The closest distance from the coring point to dry ground was 7 m. The immediate surrounding vegetation around the mire consists of scattered pine trees between bare rock outcrops. The extracted peat profile consisted of *Sphagnum* peat, which was rather undecomposed within the upper 33 cm and relatively loose within the upper 57 cm. The total peat

depth was 104 cm (99 cm core after compaction); however, ^{14}C dating and the correlation of pollen assemblages suggested a hiatus at about 60 cm, assigning the lower part of the peat deposit to the early Holocene.

The pollen samples were prepared using the acetolysis method (Berglund and Ralska-Jasiewiczowa 1986) and identification was aided by literature (Moore et al. 1991; van Geel et al. 2003; Beug 2004) and by a reference collection from the University of Tromsø. Black pieces fractured as glass $>10\ \mu\text{m}$ were identified as charcoal pieces. In BMM, where a high degree of black minerals made identification difficult, only large pieces $>40\ \mu\text{m}$ are presented in the main diagram. *Lycopodium* tablets were added to samples prior to chemical treatment to allow calculation of accumulation rates (Stockmarr 1971).

The depth–age relationships of the peat profiles are based on a total of four accelerator mass spectrometry (AMS) ^{14}C dates of moss stems calibrated with OXcal 3.10 (Oxford Radiocarbon Accelerator Unit, Oxford, UK; Bronk Ramsey 1995, 2001) using InCal04 (Reimer et al. 2004a). The results from the ^{14}C dates are presented in Table 1. The depth–age models for both BMM and AVM (Figure 2) are based on linear interpolation and extrapolation. The peat accumulation rate is commonly much higher in the upper undecomposed part of peat profiles (Sjögren et al. 2007), which makes direct interpolation between the upper ^{14}C date and the surface of the mire somewhat problematic. In BMM, an age of 30 years (AD 1980) has been assumed for the transition of rather undecomposed plant material to peat (10 cm). In AVM, such a clear transition from decomposed to undecomposed plant material is lacking. Peat accumulation in a *Sphagnum* patch (similar as the coring site) in the same mire has been determined to be $1.85\ \text{cm}\ \text{year}^{-1}$ for the top 13.5 cm. The measurement

is based on a ^{14}C sample at 13.5 cm depth (TRa 2164, ^{14}C activity $21.0 \pm 0.4\%$, post-bomb calibrated to AD 1984–1985 with CALIBomb using the Levin data set with 1 year smoothing (Levin and Kromer 2004; Reimer et al. 2004b)). Using linear extrapolation based on the two AVM ^{14}C dates and assuming a peat accumulation of $1.85\ \text{cm}\ \text{year}^{-1}$ in the upper top part, the assumed change in peat accumulation rate would be at 23 cm depth, with a corresponding date of AD 1970. Considering the lack in clear stratigraphic change in the uppermost part of the peat profile, this is probably the best possible approximation based on available ^{14}C dates.

2.3. Dendroecological studies of pine trees

The material for chronology building and climate reconstruction consisted of living and dead trees, as well as coarse woody debris, of Scots pine and was sampled approximately 7.5 km north of the LCA (Kirchhefer 2005). These trees grew on slopes facing south-to-west at or above the present pine forest line on mesic to dry substrates. For this study, a subset of one sample per tree with a maximum of 30 rings pith offset was selected. Low-frequency growth variability was extracted by means of the regional curve standardization (RCS; Briffa et al. 1992; for details, see the Supplementary Material).

Scars in CMTs were dated by means of dendrochronology (Swetnam 1984; BC Ministry of Small Business, Tourism and Culture 2001). Samples were extracted with increment corers preferably in the top of the scars (i.e. penetrating the dead wood tissue above the upper cutting mark, as well as from the lobe next to the scars, outside the original scar face). Cores above and next to the scar face show an abrupt growth decrease and release, respectively, due to bark removal. In addition, traumatic resin ducts and other indicators of disturbance may occur. Ring widths were measured to the nearest micrometer with a TA Tree Ring System (velmex.com) and TSAP-Win software (rinntech.de) and cross-dated against the Dividalen chronology (Kirchhefer 2005). Scars were assigned to five separate groups according to probable activity as follows: (a) large scars of approximately 75 cm in height witnessing bark peeling for food; (b) round scars of approximately 30 cm in diameter due to bark peeling for sinew storage; (c) deeply carved scars inflicted in autumn by bark/wood peeling (e.g. for the storage of food); (d) blazes by knife or axe marking for trails, borders, and so on; and (e) more or less healed scars of unidentified shape and origin.

3. Results

3.1. Pollen-induced vegetation change

The pollen data are expressed as percentages of the total amount of tree pollen with the exception of willow (*Salix*), as it grows locally on the BMM mire. Grasses, sedges, herbs, and dwarf shrubs are excluded from the pollen sum as many may occur on the mire surface, especially if grazed, and thus have an undue influence on the pollen

Table 1. ^{14}C age determinations.

Sample	Depth (cm)	Lab. nr.	Date (1σ)	Calibrated (2σ)
BMM-53	53–54	LuS 8840	$710 \pm 50\ \text{BP}$	$\text{AD}1305 \pm 90$
BMM-85	85–86	LuS 8841	$1295 \pm 50\ \text{BP}$	$\text{AD}760 \pm 110$
AVM 39	39–40	TRa 2157	$765 \pm 35\ \text{BP}$	$\text{AD}1250 \pm 40$
AVM-55	55–56	LuS 8838	$1475 \pm 50\ \text{BP}$	$\text{AD}550 \pm 110$

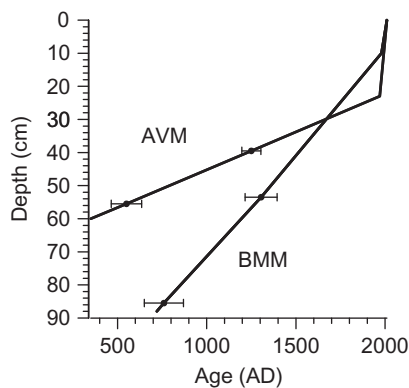


Figure 2. Depth–age relationship for BMM and AVM peat profiles. ^{14}C dates are shown with 2σ error bars.

Table 2. Date of zone borders for BMM and AVM individually and applied common date.

Pollen zones	Zone border		
	3/4	2/3	1/2
BMM	1970	1670	1240
AVM	1970	1660	1140
Dividalen	1950	1650	1200

spectra. Although some taxa from these groups safely can be considered to never been present on the mires, the influence on the pollen spectra would be so small that exclusion of these has no practical effect, while problematic decisions concerning potential habitats could be avoided by excluding all. The pollen accumulation rate (PAR, pollen grains deposited per square centimeter over a year) has been calculated for BMM but not for AVM, as high sample-to-sample variation presented potential problems with the peat homogeneity and/or accumulation rate. The assigned pollen zones were considered valid for both localities, and there has been no site-specific labeling. As there is a slight difference in age determination of the zone borders between BMM and AVM, common age intervals for the zones have been approximated (Table 2) and used throughout the text. The pollen data for selected taxa are depicted in Figures 3–5 and further described in Table 3. For more pollen types and pollen diagrams on depth scale, see the Supplementary Material.

3.2. Dendroclimate

Assuming that the observed trends in the RCS chronology are indeed steered by temperature, the following conclusions may be drawn (see Figure 6): during the first half of the twentieth century, Dividalen experienced the highest summer temperatures (mean July) of the past 500 years. In terms of floating 30-year averages, the first 30 years of the local instrumental record from 1921 to 1950 were the warmest (14.1°C), whereas the regional temperature composite indicates an earlier culmination between 1913 and 1942 (14.2°C, rescaled to Dividalen). Summers were cool during a prolonged period (1571–1825), with a mean of 12.2°C. The coldest 30-year period was from 1591 to 1620 (11.4°C). In terms of fixed decades, before 1890, the lowest temperatures were reconstructed for the 1600s (11.2°C), 1640s (11.5°C), 1720s (11.7°C), 1800s (11.7°C), and 1810s (11.9°C). Accordingly, the five warmest decades were the 1510s (13.3°C), 1530s (13.0°C), 1820s (13.1°C), 1850s (13.4°C), and 1860s (13.0°C). For comparison purposes, the mean temperatures of the coolest and warmest decades in the instrumental record were 11.6°C (1900s) and 15.1°C (1930s), respectively.

3.3. Culturally modified trees (CMTs)

A total of 26 human-inflicted scars (Figure 7; Elvebakk and Kirchhefer 2012) have been dated in 18 trees (Figure 8).

Of the 18 trees, four grew north of the protected areas near Sleppelva (two stumps and two living), seven in the LCA (four dead, one stump, and two living), and seven in the NP (one dead and six living). The scar dates ranged from 1619 to 1819. The data set implies an increase in the number of scars from 1619 to the 1760s, followed by another two scars in the 1810s. In sampling height, trees were 163 ± 42 years old when peeled for the first time (Figure 8) and were 23 ± 6.4 cm in diameter when scarred (maximum 37 cm). These statistics suffer from uncertainty concerning the age and diameter of some of the oldest trees due to heart rot. This data set includes six trees which were peeled in two different years, and one tree which was peeled at least 3 times. Revisiting intervals were 9, 10, 11, 13, 30, 44, 56, and 109 years, implying a regularity of bark harvesting or other utilization of the forest in about 11-year intervals. The six oldest scars were found in dead trees.

The scars as visible today are up to 110 cm high and up to 58 cm wide. During the course of the years, many scars are partly healed and five are already entirely closed; yet, the majority must be regarded as traces of Sami use of pine inner bark for food (18 scars, type (a)). There are two examples for the round scar type (b), which indicates the use of bark for wrapping reindeer sinews (1668 and 1819). The next youngest scar certainly witnesses the marking of a path or an area (27 cm × 7 cm, 1813, type (d)), but also in 1620 at the fringe of AVM, a tree was deeply blazed (≥ 15 rings deep, Figure 9). Also the big peeling of the ‘Lars Person pine’ (75 cm × 58 cm) is rather deep (23 rings), done with a traditional tool in autumn 1748. The latter implies that this piece of bark was collected for reasons other than food, possibly storage (type (d)) after crossing the Divielva river, and before heading toward the mountains on the way to the winter settlement in Sweden. In three cases, the original shape of the scars could not be identified as they were more or less overgrown. Concerning the timing of the peeling activity, six incidents of bark peeling with certainty could be dated to early summer due to the presence and/or characteristics of early wood cells defining the scar surface. The peeling of the ‘Lars Person pine’ in autumn is indicated by the presence of latewood as well as by an inscription on the scar surface. Another three scars are dated to the winter season (i.e. to the period of cambium dormancy), whereas the timing of the remaining peelings remains unclear. Both blaze-type scars occurred in early summer, whereas the seasonality of the round scars is unknown.

For comparative purposes, selected proxies for vegetation change, land use, and climate change are graphically represented in Figure 9.

4. Discussion

4.1. The pine forest during the Little Ice Age

Around AD 1200, there was a decline in pine pollen percentages at both BMM and more profoundly at the higher situated mire, AVM. An increase in herb and grass pollen percentages was noted at BMM, and PAR data

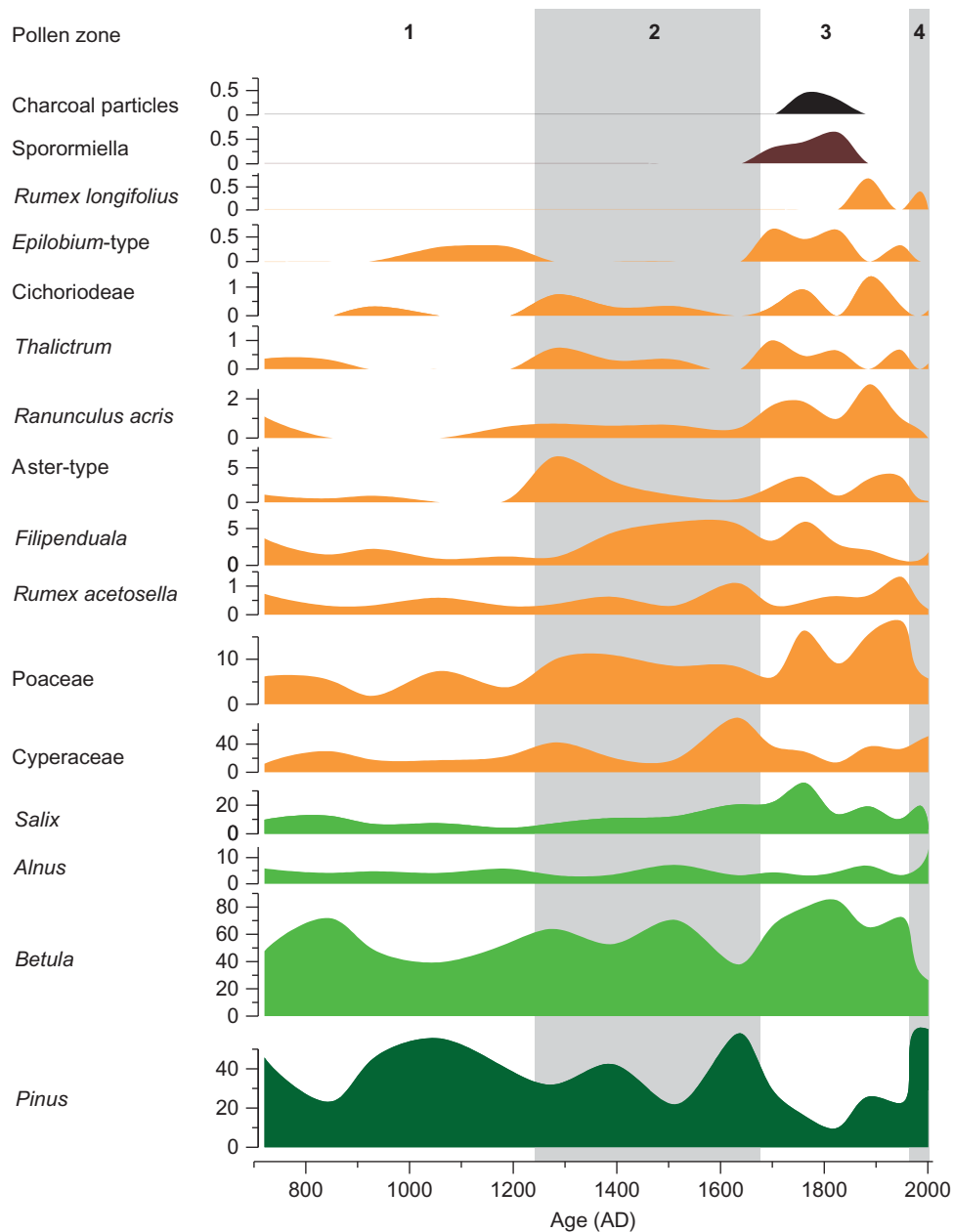


Figure 3. BMM – selected pollen percentage values. All percentages are calculated as the sum of tree pollen with the exception of *Salix* which is a common shrub on the mire (total percentage will thus exceed 100%). The graphs have been smoothed using a spline function. The charcoal curve is only based on large easily identifiable charcoal fragments as the high abundance of black minerogenic particles made identification difficult.

demonstrated that a strong decrease in pine pollen also occurred at about the same time. The changes in the pollen assemblages coincided with several indications of climate deterioration. Seppä and Birks (2002) placed the start of the Little Ice Age (LIA) in North Finland at approximately 1150. In addition, the Torneträsk tree-ring record depicted an abrupt climatic deterioration in the twelfth century, which further supports evidence of an early initiation of a LIA in the North Atlantic region (Grove 2001; Grudd 2008). Also at approximately 1250, coastal water temperatures (Hald et al. 2011) as well as northern Finnish summer air temperatures and pine tree densities were shown as declining (Helama et al. 2005, 2009).

A major question would therefore be how much of the observed reduction in pine pollen would be due to a result of lower pollen productivity, and how much of the reduction would be from a decreased abundance (cf. Mazier et al. 2012; van der Knaap et al. 2012)? A general increase in the altitudinal limit of pine since the early twentieth century (Kullman and Öberg 2009) is not enough to explain the extreme increase in pine pollen seen at both BMM and AVM in the past century. More likely, summer temperatures frequently dropped below the cut-off value for pollen production among pines (Hicks 2006) during the LIA. It therefore seems that the climatic variation of summer temperature in Dividalen is in a crucial range

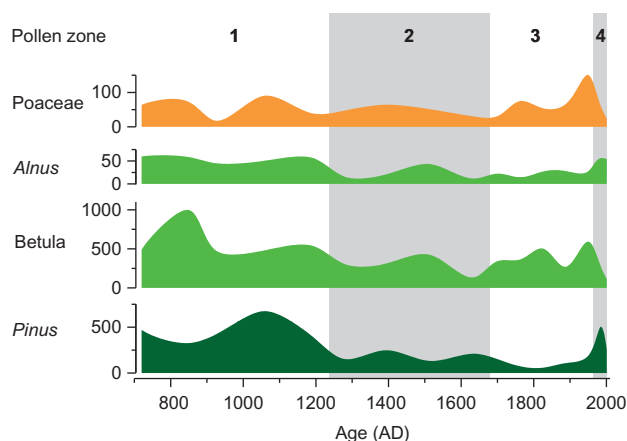


Figure 4. BMM – selected pollen accumulation values (deposited pollen grains $\text{cm}^{-2} \text{year}^{-1}$). The graphs have been smoothed using a spline function.

considering the pollen productivity by local pines, and during the course of many years, it is possible that no pollen production occurred at all. Although pine had stopped producing pollen, the trees would still grow in both height and width and still produce needles (Pensa et al. 2005; Salminen and Jalkanen 2005; Lindholm et al. 2011). Still, even if the trees did not die due to cold, there would be a reduced forest regeneration which over time would develop into a more open forest structure. Die backs due to cold events around 1130 and 1460, which triggered treeline depression of at least 50 m (Kirchhefer 2005), might initially have opened the forest structure, while a generally harsher climate prohibited or at least slowed down regeneration. In northern Finland, low deposition values of pine pollen were found in the period 1340–1630 and very low values within the period 1630–1810, roughly coinciding with the declines in Dividalen. The low deposition values have here been interpreted as regional declines in pine tree volume rather than in the pine pollen productivity (Mazier et al. 2012).

A temporary improvement of the climate occurred during the sixteenth century, probably between 1470 and 1570 (Grudd 2008; Helama et al. 2009; Figure 9), coinciding with a major recruitment phase of pine in Dividalen around 1500. A significant, stepwise deterioration of summer temperatures then started in 1571, with temperatures reaching a marked minimum in the years subsequent to 1601 (Grudd 2008; Helama et al. 2009; present investigation). According to the dendroclimatological results, a prolonged period of cool summers 1571–1825 then follows, with a mean July temperature in Dividalen of 12.2°C , a period roughly coinciding with the observed minimum in pine pollen percentage and PAR values. Whereas the youngest generation of mature pines in Dividalen germinated around 1800 (Elvebakk et al. 2005; Kirchhefer 2005; Figure 9), an increased germination of pine was again observed around 1930 (Helga Perander and A.J. Kirchhefer, unpublished results). Pulses of tree regeneration have also been observed in pine forests in northern

Sweden that co-occurred with periods of higher temperatures, e.g. 1770–1790, 1870–1890, and 1950–1980 (Zackrisson et al. 1995).

During the twentieth century, the amount of deposited pine pollen also increased dramatically, likely an effect of the establishment of new pine trees as well as higher pollen productivity due to warmer summers. As an illustration of the latter, the period 1591–1620 had a mean July temperature of 11.4°C compared to regional mean July temperatures of 14.1°C during 1921–1950, a difference of 2.7°C that may explain part of the observed increase in pine pollen deposition and germination rate during the twentieth century.

4.2. Human impact

In prehistoric times, the area was infrequently visited by hunters-gatherers (Blankholm 2008). The impact on the ecosystem at this time can be assumed negligible, with the exception of the large-scale pit-trap systems (Klaussen 2008), which may have affected the wild reindeer population temporarily. Remains of pit-houses, so-called stål-lotuffer, and associated pit-fall systems for large-scale hunting of wild reindeer have been found in the side valley, Devdsvuopmi, dated from the seventh to the tenth century AD (Sommerseth 2009, 2011). In AVM at this time, there is some charcoal dust, sorrels (*Rumex*) start to occur, grasses increase soon after, and occasional spores from dung fungi (*Sporormiella* spp.) appear. This may indicate a low level of human impact on the vegetation, although the impact values are so low that they cannot with any certainty be distinguished from the natural ‘background’ without further investigations. The increase in grass and herb pollen in the BMM mire around 1200 is probably caused by changes in the climate (see above). It should be noted, however, that an increase in grass and herb pollen in the thirteenth century in north-western Sweden has been associated with human activities and stål-lotuffer pit-house remains (Staland et al. 2011).

During the seventeenth century (according to written sources, Hansen 2007) or possibly as early as the fifteenth century (interpreted from archaeological remains, Sommerseth 2011), the practice of reindeer pastoralism became common among the Sami. It is known that Dividalen was used as a transit area between winter pastures in Sweden and summer pastures along the Norwegian coast, although the impact on vegetation has hitherto remained unknown. The first clear signs of human activity influencing the vegetation in Dividalen can be traced back to the seventeenth century and are evident in both BMM and AVM. At this time, grass pollen increases, herb pollen increases (especially in BMM), the number of charcoal particles increases, and dung fungi spores (*Sporormiella* spp.) start to occur. Pollen influx data from BMM demonstrate that these are real increases and not just a percentage effect of the climatically induced decrease in pine pollen. The increase in both grass and herbs together with dung fungi spores provides a clear indication of grazing in

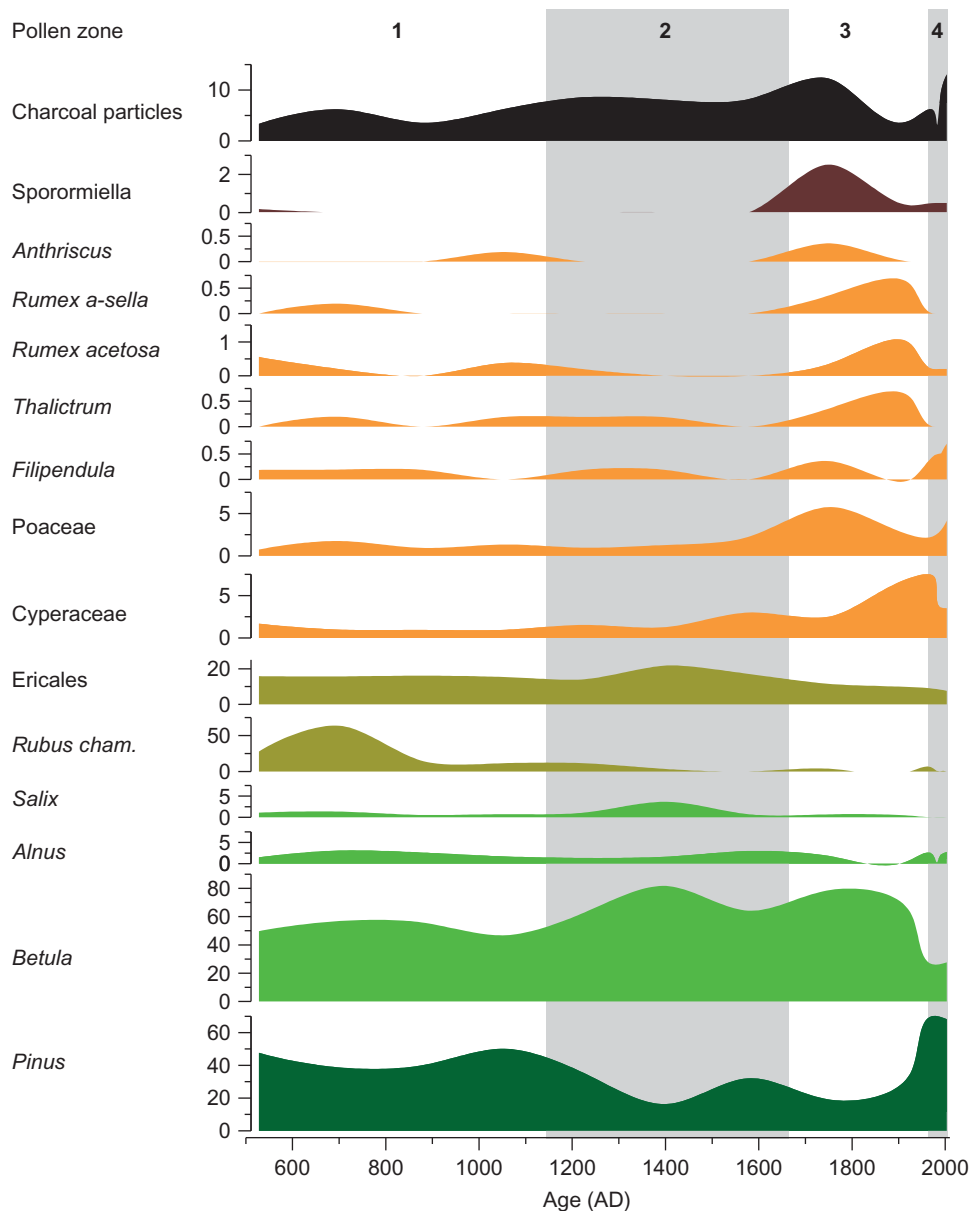


Figure 5. AVM – selected pollen percentage values. All percentages are calculated as the sum of tree pollen with the exception of *Salix* which is a common shrub on BMM (total percentage will thus exceed 100%). The graphs have been smoothed using a spline function.

the area. Considering the time in question (the seventeenth century), it is probably domestic reindeer that were present (although the type of animals cannot be determined based on pollen/spore data alone). An increase in charcoal dust and nutrient-demanding/ruderal herbs as fire weed (*Chamerion angustifolium*, *Epilobium*-type pollen), sorrels (*Rumex*), and goosefoot (*Chenopodium*) is also indicative of human settlement in the vicinity. From the fifteenth century, an increased Sami activity in the side valley, Devdsvuopmi, is registered in the archaeological archives, which seems to peak within the seventeenth and eighteenth centuries (Sommersteth 2009, 2011).

Generally, palynological, archaeological, and dendroecological evidence indicate high and diverse Sami activity in the area, particularly during the seventeenth and eighteenth centuries. At AVM, both reindeer grazing and

human presence seem to continue until today, although at a more moderate level. A large spring–summer–autumn Sami settlement from approximately 1900 during the extensive reindeer herding period was allocated within this area (Ruong 1937), which also suggests continued use at least up to the twentieth century.

Farmers colonized Dividalen in as late as 1850, and the uppermost farm, Frihetsli, was not permanently settled for any longer periods prior to the beginning of the twentieth century. The preservation of the old-growth pine forest may partially be explained by this late settlement of farmers in the valley, and also by the fact that many rapids in the river make log driving difficult, and in the uppermost parts, even impossible. It was primarily the availability of timber, agricultural land, hay meadows, and pasture land that drove the farmers this far inland. In forestry, logging was salient;

Table 3. The results from the pollen analysis.

Pollen zone	Time interval	Characteristics of the pollen assemblage		
		BMM		AVM
4	AD 1950 – 2010	Pine forest with birch: strong increase in pine at the expense of birch. Grass and many herbs decline. Alder increases in the topmost samples.		Pine–birch forest: strong increase in pine and spruce at the expense of birch. Grass, dung fungi, and charcoal present at lower levels than in the previous period.
3	AD 1650 – 1950	Birch forest with pine: the increase in herbs and grasses seen in the previous period becomes more accentuated and pine reaches very low values.		Birch forest with pine: the increase in grass and sorrels. Peak is observed in charcoal dust. Cow parsley and goosefoots are represented with a few pollen. The dung fungi <i>Sporormiella</i> spp. peaks and becomes more common from this time onward.
2	AD 1200 – 1650	Birch–pine forest: reduction in pine and increase in birch, temporary reversal toward the end of the period. An increase in the number of herbs is represented. Crowberry, willow, grass, and brackens also increase.		Birch forest with pine: major decline in pine and spruce, increase in birch and dwarf birch. Temporary reversal toward the end of the period.
1	AD 700 – 1200	Pine–birch forest: birch and pine dominate with about the same amount of pollen. Grass, willow, and several nutrient-demanding herbs are present.		Birch–pine forest: the tree pollen are dominated by birch and pine, with lower values of alder, spruce, and willow. Local vegetation is dominated by crowberry.

Note: The time intervals follow common dates of the zone borders, and dates based on the individual depth–age models might deviate (see Table 2).

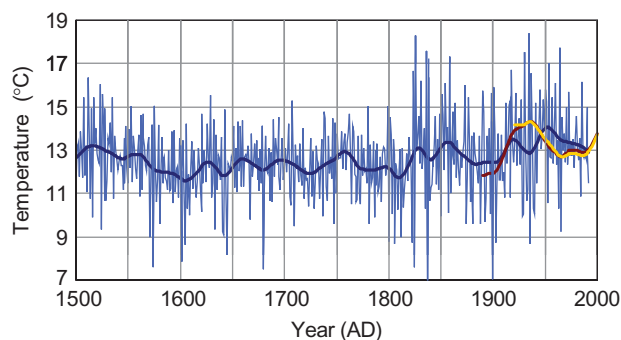


Figure 6. July temperatures for Dividalen 1500–1992 as estimated from the RCS pine chronology and scaled to the observed temperatures at Frihetsli 1921–1992. Bold lines show the multi-decadal variability (32-year spline) for the reconstructed (blue) and observed temperatures (local, gold; regional, red).

however, tar production was also common in the period 1914–1958 (Stenvold 2004). Many of the silt flats along the river were used as semi-natural hay meadows during the late nineteenth and early twentieth centuries. At BMM, some small palynologically, but potentially historically important, changes occurred around 1850. Charcoal particles and dung fungi spores decrease or disappear, grass values (PAR) increase, and northern dock (*Rumex longifolius*, *Rumex obtusifolius* type of pollen) starts to appear for the first time. At this time, the use of the silt flat adjacent to BMM most likely changed from Sami reindeer pasture and settlement to a farmers’ hay meadow. This new situation possibly prevailed for approximately 100 years before a rapid encroachment started around 1950.

4.3. Culturally modified trees

The earliest scar in a CMT dates back to 1619. The harvest of pine bark as a source for food was a seasonal activity, preferably done while the sap was rising within the stem. The appearance of scars may therefore mark the very first appearance of reindeer pastoralism in Dividalen or simply the year when Sami began to stay for sufficiently long periods of time in spring to early summer, allowing them to gather pine bark.

In northern Sweden, the use of pine bark has a longer known tradition, with finds dating back to AD 1450 and 2805 ± 60 BP (Zackrisson et al. 2000; Östlund et al. 2004). However, few CMTs were found from the period prior to 1650, and considering the limited number of dated CMTs in Dividalen, older scars may just have been overlooked. The absence of scars from earlier times may also be related to pine forest dynamics. High mortality rates of pine in the twelfth century and the 1460s (Kirchhefer 2005) probably had a strong impact on the pine abundance and subsequent age structure. It is possible that the pine forest was still recovering from these declines around 1600 and that the forest mainly consisted of young trees, which germinated following the 1460s. Hence, first in 1620, these pines would have reached a diameter preferred for bark peeling, which on average was 21.3 ± 6.6 cm at first peeling, but



Figure 7. Scars in culturally modified pines. Left: round type (AD 1669, height ca. 30 cm), middle: long bark peeling for food (AD 1619, height 110 cm), and right: scar showing several deep blazes (AD 1620, height ca. 90 cm). Photographs by A.J. Kirchhefer.

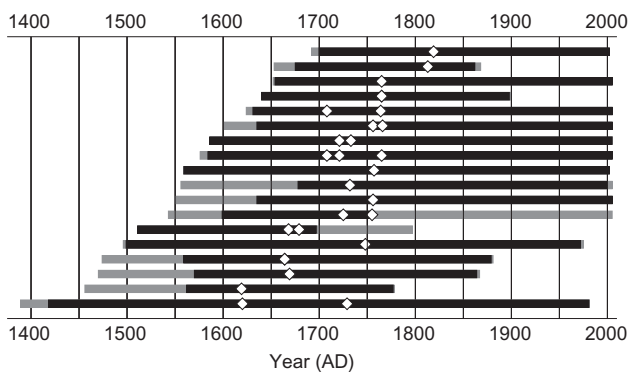


Figure 8. Culturally modified trees: ages and scar dates. Black: tree rings documented on samples and grey: estimated rings missing to pith and death year.

only 14.0 and 12.1 cm for the first two trees peeled in 1619 and 1620, respectively. Although there was a cohort of young trees surviving the event in the 1460s, rather few mature pines did survive (Kirchhefer 2005). Neither of the two trees studied in the NP and of sufficient age showed any sign of bark peeling or blazing prior to 1620 (Elvebakk et al. 2005; Elvebakk and Kirchhefer 2012).

The maximum frequency of scars occurred in the 1750s and 1760s immediately after the establishment of the border between the kingdoms of Sweden (including Finland) and Norway–Denmark in 1751. The border tractate included specific regulations for the Sami reindeer herders (Lappekodisillen of 1751), who traditionally traveled between winter pastures in Sweden and summer pastures in Norway. The nearly complete lack of scars after 1766 can be explained by several factors. Some crises seem to have occurred in the reindeer pastoralism around 1760, with a population decline in the Jukkasjävri parish from approximately 1300 Sami nomads in the 1750s to approximately 800 in the 1760s (Ruong 1937). It may have been that the route through Dividalen was abandoned at this time and never fully resumed due to changing economical and

political conditions. From the 1790s onward, an increased number of settlements by farmers had a large impact on the migration routes and pasture lands available for the Sami pastoralists. The habit of scarring trees probably ended around the time of the last dated CMT in 1819. However, one has to consider the effect of forestry which came into the valley in the first half of the nineteenth century: pines with deep scars and associated lobes were not of interest as timber; therefore, the pines were left untouched or cut above the scar (see Figure 7, left). Young, shallow scars probably did not reduce the value of the timber in the same manner, and such trees, at least outside the NP, might have been removed from the natural archive of CMTs.

Due to the small number of trees and scars dated so far, it is not possible to draw any firm conclusions concerning the natural forest dynamics, the density of CMTs, and the amount of bark taken. However, the CMTs provide a first dating framework for Sami activity within the forest.

4.4. Summary and management implications

The present results support the notion that the northern boreal pine forest regenerates in a highly episodic pattern primarily controlled by the climate (cf. Zackrisson et al. 1995). In addition to phases of regeneration (here c. 1500, 1800, and 1930 onward), there seems to be phases of actual die backs (here c. 1130 and 1460) triggered by extreme climatic cold events. Based on pollen deposition data, the pine forest of Dividalen has been under climatic stress from approximately 1200 to 1950, interrupted with regeneration phases during warmer periods. It is unclear if a similar wave-like regeneration pattern had occurred prior to 1200, and it is possible that it may be restricted to the LIA (for the present altitude). One of the hypothesized processes behind this wave-like pattern seems to be that a cooler climate severely hampers the pollen productivity of pine and, presumably, seed production. In addition, there is likely a

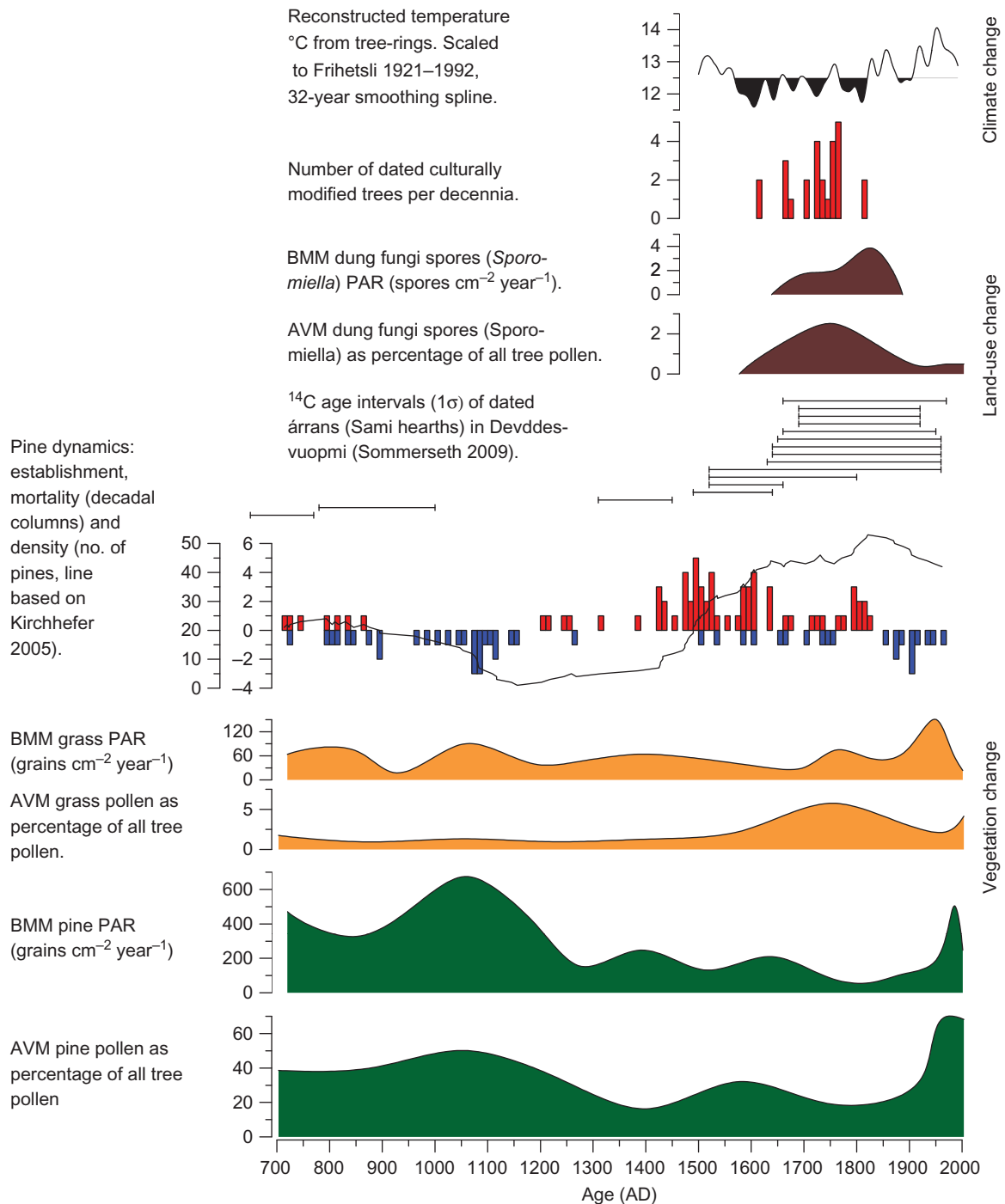


Figure 9. Summary diagram of selected vegetation, climate, and land-use proxies from the Dividalen area. Devddevuopmi is situated in a side valley c. 10 km north–north-east of the main investigation area.

climate effect on seedling recruitment, either direct or indirect by altering the forest floor vegetation (Zackrisson et al. 1995).

The volume of dead wood would thus vary through time, and dead wood-inhabiting fungi, which constitute most of the biodiversity in the area, may be more resilient to variations in dead wood density for survival than previously thought. On the other hand, periods of high dead wood density may be important for dispersal, occurring only once every few 100 years. The modern stand structure of the pine forest of Dividalen shows a clear legacy of

the past climatic change, and the present situation should be considered as a product of several regeneration phases. At present, the pine forest seems to be in the middle of such a regeneration phase.

The birch tree line in the upper part of the valley has not responded to the recent warming, probably due to browsing by domestic reindeers (Aune et al. 2011). This may lead to a historically unique situation with an expanding pine forest while the birch tree line remains stationary. Higher temperatures may, on the contrary, make the birch more exposed to disease and insects, which combined with

hampered recruitment due to high densities of domestic reindeer could even lower the birch tree line (cf. van Bogaert et al. 2011). The total mountain birch forest habitat may thus decline, although this hypothetical development is sensitive to future changes in climate and grazing pressure.

Sami pastoralists have utilized and affected the landscape since the seventeenth century. The tradition of bark peeling practically ended after the mid-eighteenth century, and during the nineteenth century, the lower part of the valley was abandoned as a major living and transit area by the Sami, possibly as a result of conflicting interests with farmers. CMTs created by the Sami tradition of bark peeling are common in most areas containing old pine trees. These are dated back to between 1619 and 1819, with a peak occurrence during the 1750s and 1760s. As the CMTs are older than 100 years and are linked to the Sami culture, they automatically become protected by law under the Cultural Heritage Act.

From the mid-nineteenth century, farmers started utilizing semi-natural riverside meadows for winter fodder and logging commenced in the pine forest. Today, former meadows and pastures are becoming increasingly encroached. Even minor forest logging as carried out a century ago in parts of Dividalen LCA has been shown to have continuing effects on forest stand structure, dead wood dynamics, and the wood-inhabiting fungal community, in particular on the abundance of red-listed species (Josefsson et al. 2010b). In addition, a low-impact human presence on the extensive Sami land use may lead to a decrease in pine density and volume of dead wood if preserved over time (Josefsson et al. 2010a). No part of the investigation areas can therefore be considered truly pristine, and the use of the pine forest as a potentially pristine ecological reference should not be done uncritically. Protection should therefore not only focus on preserving 'naturalness,' but rather on structurally important elements for maintaining a high biodiversity such as old pine trees and large trunks of dead wood, particularly standing dead trees, which are of high value. In addition, traditional land use should be acknowledged as an important factor in forming the landscape within the investigation area, and there should be more focus on protecting the cultural heritage, especially the CMTs.

Thus, the main vegetation development in Dividalen in the past millennia is similar to that of north-west Swedish pine forests with a clear decline in pine pollen as well as indications of a low intensity human impact beginning in the seventeenth century (cf. Josefsson et al. 2009). It is highly likely that large parts of the northern boreal pine forests in Fennoscandia may have undergone a similar development and that parallels may well be found in other northern boreal pine forests.

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