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Rocky pine forests in the High Coast Region in Sweden: structure, dynamics and history

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Abstract

Almost all forests in Sweden are managed and only a small fraction are considered natural. One exception is low productive forests where, due to their limited economical value, natural dynamics still dominate. One example is the Scots pine (*Pinus sylvestris* L.) forests occurring on rocky and nutrient-poor hilltops. Although these forests represent a regionally common forest type with a high degree of naturalness, their dynamics, structure and history are poorly known. We investigated the structure, human impact and fire history in eight rocky pine forests in the High Coast Area in eastern Sweden, initially identified as good representatives of this forest type. This was done by sampling and measuring tree sizes, -ages, fire-scarred trees, as well as dead wood volumes and quality along three transects at each site. The structure was diverse with a sparse layer of trees (basal area 9 m^2 and 640 trees larger than 10 cm ha^{-1}) in various sizes and ages; 13 trees ha^{-1} were more than 300 years old. Dead wood (DW), snags and logs in all stages of decay, was present and although the actual DW (pine) volume (4.4 m^3 ha^{-1}) and number of units (53 ha^{-1}) was low, the DW share of total wood volume was 18% on average. Dead wood can be present for several centuries after death; we found examples of both snags and logs that had been dead more than 300 years. Frequent fires have occurred, with an average cycle of 40 years between fires. Most fires occurred between 1500-1900 and many of them (13) during the 1600s. However, fires were probably small since most fire years were only represented at one site and often only in one or a few samples. The rocky pine forests in the High Coast Area are representative of undisturbed forests with low human impact, exhibiting old-growth characteristics and are valuable habitats for organisms connected to sun-exposed DW. Management of protected rocky pine forests may well include small-scale restoration fires and the limited DW volumes should be protected.

Keywords

boreal, coarse woody debris, dendrochronology, fire history, natural forest, pine heath forest, shingle field pine forest

Introduction

Human influence on boreal forests has varied considerably over time and has dramatically transformed forests in Fennoscandia during the last centuries (Östlund et al. 1997). The multi-aged, structurally diverse and old-growth forests that once dominated the Swedish forest landscape have today been replaced by young, even-sized and single-aged managed forests (Östlund et al. 1997; Axelsson and Östlund 2001). In forests with low levels of human impact, there are structures and processes, such as various kinds of disturbances, (e.g. wind, fire, insects and browsing) that create a structurally diverse and heterogeneous forest (Bradshaw et al. 2011; Brumelis et al. 2011). However, studies of natural forest structure and dynamics are hampered by the limited availability of unmanaged reference forests (Kuuluvainen et al. 2017).

In Sweden, nutrient poor forests with low productivity (< 1 m^3 ha^{-1} yr^{-1}) have been exempted from regular forestry by the Forest Act since the 1970s (Anonymous 2017). Approximately 4.6 M ha of forest land are left out from management because of low productivity (Fridman and Wulff 2018). Some of these forests occur on nutrient-poor, rocky areas on hilltops, where Scots pine (*Pinus sylvestris* L.) is the major tree species. Because of the nutrient-poor conditions, the distribution of trees is sparse and the forests are characterized by openness and sun-exposed conditions. There is no exact estimate on how much forest land consists of rocky pine forests; however, they constitute a significant share of the 14% of the Swedish forest land that is covered by unproductive forest (Forestry 2015).

Rocky pine forests can frequently be found in the High Coast Area in the eastern parts of Northern Sweden (Fig. 1). This area is characterized by a steep terrain and rugged topography and in combination with the highest isostatic up-lift in the world after the latest glaciation resulted in recognition as a World Heritage Area. The current land up-lift is 8 mm $year^{-1}$ and total recovery is almost 300 m in altitude (Berglund 2012). The area that formerly was below sea level has been exposed to wave action and coastal erosion and, in particular, convex land surfaces often consist of bare bedrock and very shallow soil.

The low productivity in rocky pine forests in the High Coast Area, together with their inaccessibility, partly explains why many of these forests have escaped extensive human use. These forests mostly have continuity in old-growth characteristics with diverse canopy structure, old trees and dead wood. Hence, these types of forests could function as small refuges for organisms dependent on old-growth conditions. For example, many threatened insects are dependent on dead wood (Stokland et al. 2012), including sun-exposed dead wood (Wikars 2015). An example is *Chalcophora mariana* L., a beetle dependent on sun-exposed dead wood, and currently found at only two sites in Sweden, of which the Skule National Park in the High Coast Area is one of them (Ehnström and Bader 2013).

To date, very few studies about the structure and history of nutrient-poor, rocky pine forests have been made. This is true not only for Northern Europe but also on a more general, global scale. Some studies have been made on rocky black pine (*Pinus nigra* Arn.) forests in Spain and even though these forests resemble Scots pine forests in northern rocky areas, they constitute a different forest type with a contrasting historical and landscape context (e.g. Fule et al. 2003; Rubiales et al. 2007; Hernandez et al. 2011; Camarero et al. 2013; Ehnström and Bader 2013).

Due to lack of knowledge of the special habitat that rocky, nutrient-poor pine forests constitute and the importance of baseline information on forests with low human impact, we have examined the structure, history of human use and fire history in rocky pine forests in the High Coast Region. We have used a combination of several methods; investigation of the current forest structure, the use of historical records and biological archives (dendrochronology), which allowed us to address the following questions: 1) What characterizes the forest structure and dynamic in rocky pine forests? 2) What is the fire history in the rocky pine forests? 3) To what extent has human use in the past influenced the rocky pine forests?

Methods

Study area

The study was conducted within a 15 × 75 km area (approximately at 62.5°–63.1°N, 17.9°–18.7°E, DD) in the High Coast Region situated in Västernorrland County located in the southern boreal zone of Sweden (Fig. 1). The High Coast Region on the east coast of Sweden along the Baltic Sea is characterized by a rugged and steep terrain. The area was covered with ice during the latest ice age and after the ice had melted the area was under sea level for millennia; only the highest hill tops > 285 m.a.s.l. could be seen as small islands (Lundkvist 1986). Most of the plots are situated on hilltops and the altitude ranges from approximately 50 to 230 m, i.e. below the highest coastline. Mean annual temperature in the region is around 3 ° C, mean annual precipitation is 800 mm, the length of the growing season (number of days with temperature > 5° C) is approximately 150 days. The average maximum snow depth is 70 cm and the snow covers the ground 150–175 days every year (SMHI 2016). Norway spruce (*Picea abies* (L.) Karst.) and Scots pine (*Pinus sylvestris*) are the two dominant tree species in the study area with Scots pine dominating on dry and nutrient poor sites. A general inventory of 26 sites with rocky pine forests was conducted in 2011 in the study area by the County Administration in Västernorrland with the aim to map core areas with high conservation values, e.g. presence of big and old trees, diverse forest structure and abundant dead wood (Salomonsson and Bader 2015). Eight of these 26 study sites with the highest ranking (high conservation values) were selected for this study.

Sampling for stand structure

In August 2014 we established three band transects at each site, resulting in total in 24 transects. We used band transects since they sample spatial heterogeneity better than circular plots. The studied forests are highly heterogeneous and exposed bedrock oc-

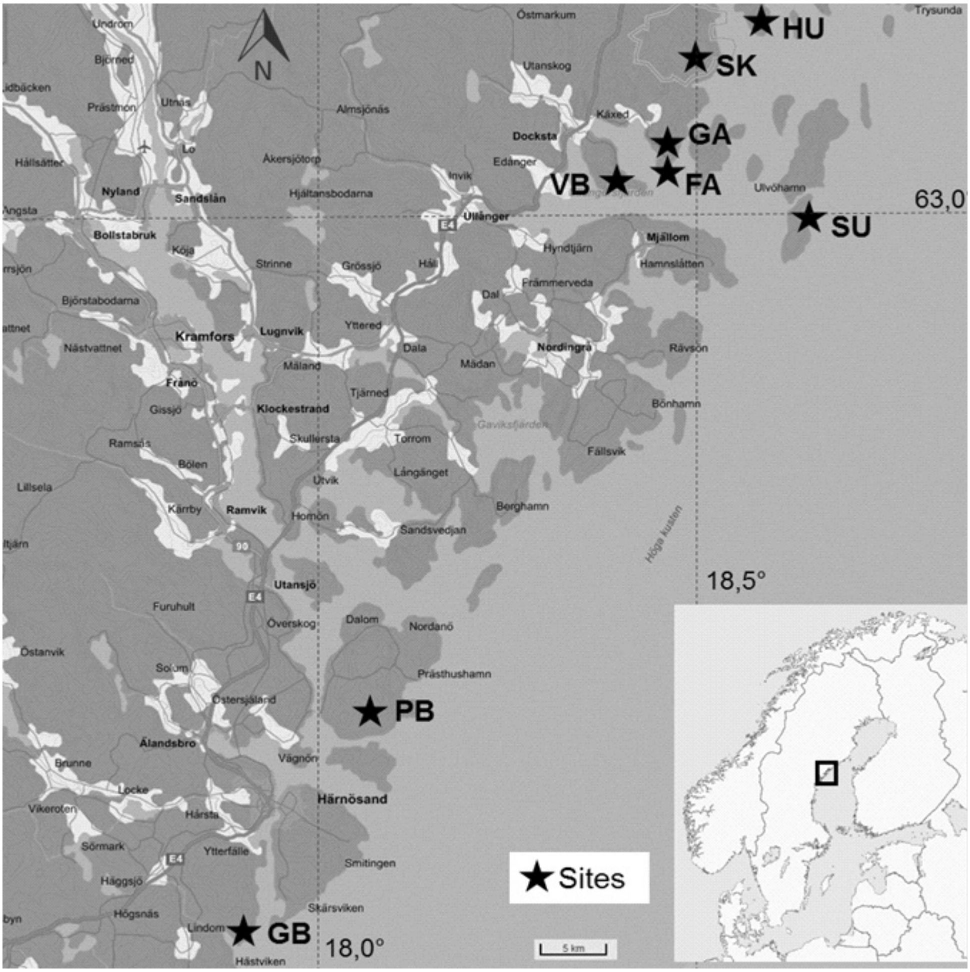

Figure 1. Study area. Location of the study area in the High Coast Area, Västernorrland County, in the southern boreal zone of central Sweden. Forest structure was investigated at eight sites with rocky pine forest (shown by stars, **GB** Gropberget, **PB** Porsmyrberget, **VB** Vårdkallberget, **FA** Fanön, **GA** Gårdberget, **SU** Southern Ulvön, **SK** Skuleskogen National Park, **HU** Hummelvik Nature Reserve)

curs mixed with parts of more closed forest. Transects were 10 × 100 m for living trees, but for dead wood sampling we expanded plots to 20 × 100 m to ensure a sufficient number of sampled dead wood units.

To avoid subjectivity in the placement of transects we randomized their placement by using a numbered grid that was placed over a map of the core area at each site and starting points as well as the direction (N, NE, E, SE, S, SW, W or NW) were randomly assigned, but with a minimum distance of 100 m. Within each transect, we recorded × and Y coordinates, species and diameter at breast height (DBH) for all living (stems ≥ 1.3 m high) trees. To describe the spatial distribution pattern, we calculated the distance from each tree to the nearest tree in the × direction and then computed the variance to mean ratio of these distance, i.e. a one-dimensional spatial analysis (Horne and Schneider 1995). We then used a χ^2-test to test whether the distribution of trees where random or significantly aggregated. We extracted two increment cores at 30 cm height from each living tree (DBH ≥ 10 cm) using a 6 mm increment borer (Haglöfs, Mora, Sweden). We measured the height of the tallest tree along the transect with a Laser Height Meter (Nikon Forestry 550) at 0 m, 50 m and 100 m.

All snags and logs with a maximum diameter of ≥ 10cm and with their base inside a transect were included. We recorded both base- and top diameters, DBH, length and decay class. We used a four class system for decaying wood: 1 Hard dead wood – The volume of the stem consisting of > 90% hard wood, hard surface, very little impact from wood-decaying organisms; 2 Partly decayed wood – 10–25% of the stems' volume consists of soft wood, a sheath knife goes through the surface but not through the whole sapwood; 3 Decayed wood – 26–75% of the stems volume consists of soft to very soft wood; 4 Substantially decayed wood – 75–100% of the stems volume consists of soft-very soft wood, a sheath knife can penetrate the whole stem, but a hard core can occur (Esseen et al. 2003). We collected samples for dead wood for dating with a chainsaw, taking only small samples (cookies) rather than whole cross-sections when possible. The dead wood samples were used for age determination and calculating time since death. Naturally created high stumps were recorded as snags. We used the conic-paraboloid formula (Fraver et al. 2007) to calculate the volume of dead wood, a formula that has a greater precision and lower bias than more commonly used formula. However, due to the shape of the trees with many branches and bent, crooked stems, the volume calculations are rough estimates rather than exact values. Cut stumps were not included in dead wood volume calculations but we noted diameter and species and took samples for dating to quantify past harvesting.

Sampling for fire history

In autumn (September-November) 2015 we carried out a comprehensive search of each site for fire scars in stumps, living and dead trees. Two persons visited each site one whole day, resulting in approximately 10 search hours at each site covering the core area and the adjacent forest. Every tree with a fire scar was mapped and samples were later collected with a chainsaw. We only took partial sections whenever possible to avoid unnecessary damage. A total of 52 fire-scarred wood samples were collected and dated from eight sites. An additional six samples from dead wood sampling in 2014 and 3 samples from Skuleskogen, sampled in 2010, also had fire scars and were included, resulting in a total of 61 dated samples. More than half of the samples (33) contained scars from repeated fires and the maximum number of fires in one sample was four.

Dendrochronology and cross-dating

We mounted cores from living trees and cross-sections from dead trees and sanded them with increasingly fine grain size until a fine polish was achieved (down to grain size 400 for all samples and to 600 for some samples) using standard methods (Speer 2010). Ring widths and number of rings (age) were measured using a scanner and the image analyzing software WINDENDRO (version 2014). We used Applequist (1958) pith locator in samples that had missing rings in the core. Age was determined by counting every year ring to the pith. A few samples had a rotten core and we then used the mean growth rate for each site and the DBH to estimate the age. As a measure of growth at each site, we used the average ring width from each tree and its variability for all trees at each site. Samples from living trees with high age and several samples from dead wood that were visually dated with high accuracy were selected to create a master chronology. We used the software program COFECHA (Holmes 1983; Grissino-Mayer 2001) to cross-date our samples and suggested years were always visually double-checked to make sure that distinct marker years (with typical late-wood features) were dated correctly. The program ARSTAN was then used to create a standardized master chronology and tree ring series with questionable dating were eliminated before standardization (Cook and Krusic 2005). The master chronology from living and some dead wood samples resulted in 130 samples covering 818 years (1197–2014) with a mean sensitivity of 0.30 and a relatively strong inter-correlation of 0.515. This master chronology was used to date samples from dead wood and as dead wood samples were dated, they were added to the master chronology. We were able to date 70% of all dead wood samples; 30% of the logs were too decomposed to allow sampling or difficult to date. The dated samples belonged to all decay classes but only a few samples in decay class four were possible to sample and date. The master chronology was also used to date fire scars and because the growth is related to precipitation during the main fire season in June, we noted the average ring width for all the fire years. The final chronology (see Appendix 1) with living as well as dead wood samples with and without fire scars resulted in 248 samples covering 819 years (1197–2015) with a mean sensitivity of 0.29 and an inter-correlation of 0.505 and with a minimum of ten samples, beginning with the year 1431. We also calculated time since death for the dead wood; however, we cannot rule out the possibility that we have overestimated this value as in some cases the outermost parts might have eroded. The computer program FHAES (Fire History Analysis and Exploration System, version 2.0) was used for structuring and analyzing fire data. FHAES was also used to produce fire history graphs.

Results

Site history

Very little written information is available that is relevant for the specific historical use of the rocky pine forests. The general history of the region is, however, relatively well documented (e.g. Lundkvist 1986; Baudou 1995) . Based on findings of old building structures in stone and grave cairns, it is clear that some places in the area have been populated by humans for at least 3,000 years (Baudou 1995). The few early settlers based their livelihood mostly on fishing and hunting (e.g. seal along the coastline) and fishing has been the main income in the region for a long time (Lundkvist 1986). The possibility for mining was explored during the 1700´s at several places along the High Coast Region, e.g. at southern Ulvön and Hemsön (sites SU and PB), and, although it never became an industrial use, the attempts might have impacted the nearby forests to some extent (Andersson 1975; Lindh 1991). When the first large-scale wave of industrial usage of the forests started during the 1800´s, it is unlikely that the nutrient-poor pine forests with rather small trees on the hill-tops along the High Coast also were exploited. In a map of Vårdkallberget from 1851 it is possible to read (in Swedish) that the area close to the hill-top where the rocky pine forests occur is named "Näs by skogsmark" and "Myre by skogsmark" (Renström and Hedström 1985). This means that this area was classified as a common forest resource, free to use for the village members, but to what extent it was actually used is not known. Close to one (VB) of the eight sites, remnants of two old tar pits have been found (Fig. 2). The pits are located just along the coastline and it is unclear whether the wood for the tar was collected nearby or from the pine forest in the hill-top (the hill-top is located approximately 500 m from the tar pit remnants). The area around VB was not populated before 1780 but nearby settlers used the area mainly for fishing even before the settlements (Renström and Hedström 1985; Lundkvist 1986) . We only found a few harvested stumps on our plots, at one plot at GA and in two neighboring plots at the SU site, indicating very limited forestry activities. We found nine stumps at GA and ten stumps at SU, most of them heavily eroded, and we were only able to date six stumps. The outermost year ring from the stumps at SU was dated to 1736, 1827 and 1886 and for GA 1752, 1813 and 1828, corresponding to 200 years since harvest on average.

Stand structure

Scots pine was the dominating tree species in rocky pine forests and stands were very scattered and open; they had very little mineral soil and the ground was interspersed with bare rock and with a vegetation dominated by lichens and dwarf shrubs (Fig. 3). A general pattern was that the forest became even less dense and increasingly rocky higher up on the mountain. Trees had different sizes and they grow upright but also strongly leaning, some even grow horizontally despite being healthy and alive.

The general stand structure at the eight sites was characterized by sparsely distributed trees with a mean basal area of approximately 9 m^2 ha^{-1} and a density of 640 trees ha^{-1} on average (Table 1). Variance to mean ratio showed that trees both had an aggregated and a random distribution pattern, depending on site (Table 1). The forests mainly consisted of Scots pine, which constituted approximately 90% of all the trees. The second most common tree species was Norway spruce, which constituted 7% on average. Deciduous trees were usually present but in very low density (Table 1). Less

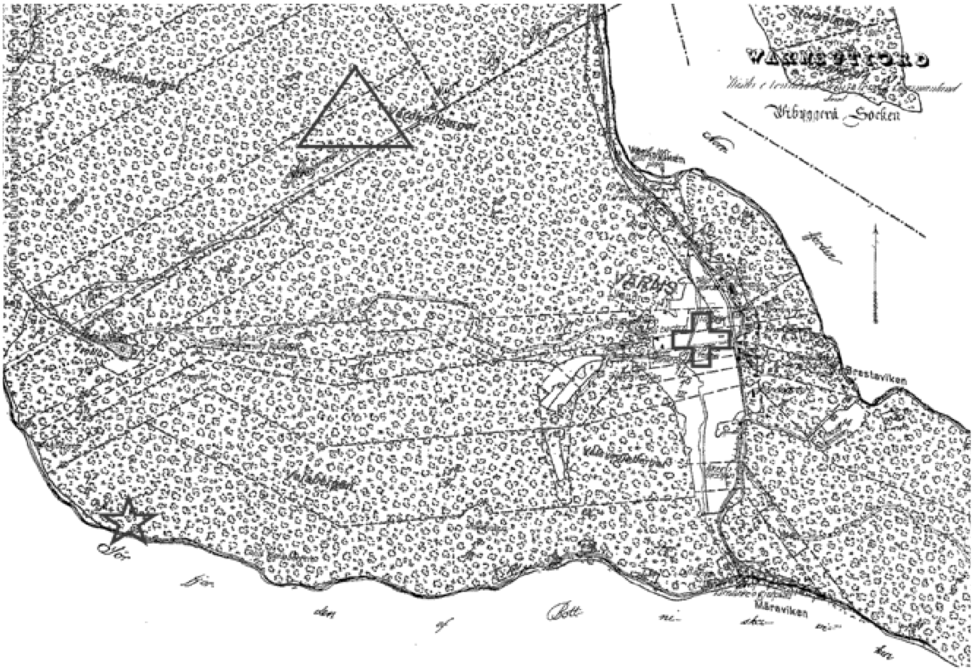

Figure 2. Old map from one rocky pine site. Map of Vårdkallberget (VB) from 1851, which shows the classification of the nutrient poor rocky pine forests around the hill-top (marked with a triangle) as “general forest land” and the nearby settlement (marked with a plus sign). Two remnants of tar pits are marked with a star. The widest distance from east to west is approximately 2 km.

than 4% of the trees were deciduous with birch (*Betula* spp.) as the most common species, while aspen (*Populus tremula* L.) and rowan (*Sorbus aucuparia* L.) occurred only sporadically. The average maximum tree height for pine was 7.5 m and varied between 5.5 and 10.1 m at the different sites (Table 1). The average age for living pines varied between 147 and 194 with a mean of 167.5 years and the maximum age was even more varied with the oldest living trees ranging from 276 to 418 years (Table 1) at the eight different sites. The average ring width of living pines varied from 0.52 to 0.68 mm yr^{-1} between sites ($\bar{x}$ = 0.55), indicating very low growth rate (Table 2). In addition, there was a considerable within-site variability in tree-ring width, indicating a large variation in growth at the stand level (Table 2).

The tree diameter distribution was positively skewed with small trees (DBH ≤ 10 cm), dominating and with decreasing frequency of trees with increasing size (Fig. 4a). However, even though the large trees were rare, they did exist and there were on average one pine ha^{-1} larger than 40 cm in DBH and 15 pines larger than 30 cm ha^{-1} in the studied forests. For trees larger than 10 cm in DBH, medium age classes (75–200 yr) were most common for both pine and spruce (Fig. 4b). Pines were on average 165 years (SD = 75, n = 624) and spruce 144 years (SD = 47, n = 52).

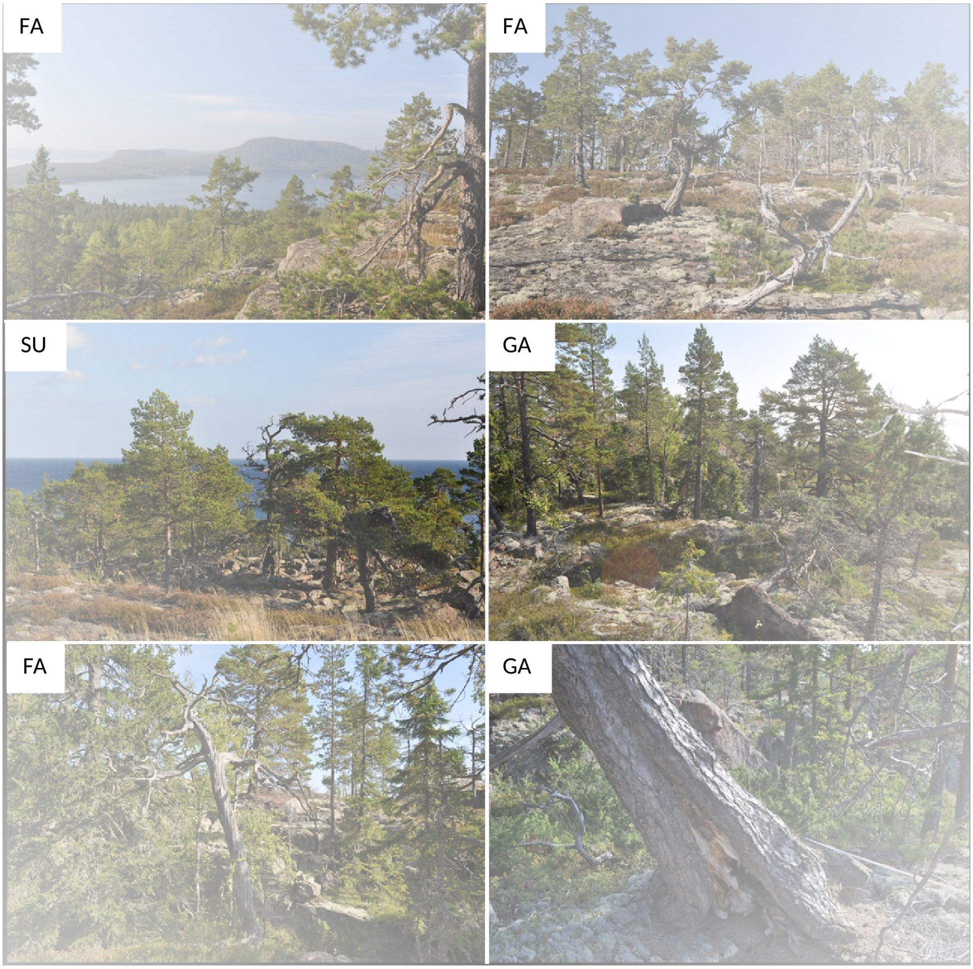

Figure 3. General description of rocky forests in the High Coast Area. Photos from Fanön (**FA**), Gårdberget (**GA**) and S. Ulvön (**SU**), which show the topography, typical characteristics in rocky pine forests with dispersed trees and dead wood in various sizes in rocky terrain, spruce interspersed at concave surfaces and a fire-scarred pine.

All ages are present for pine but really old spruces were lacking. The oldest spruces were a maximum of 275 years old whereas pines were older; approximately 1 tree ha^{-1} was above 400 years old and 13 trees ha^{-1} were more than 300 years old. The correlation between age and DBH was generally low ($R^2 = 0.31$ for pine and $R^2 = 0.11$ for spruce) but due to the large sample size significant for both tree species ($p < 0.001$ and $p < 0.05$ respectively; Fig 5). The oldest pine (418 years) was also the largest (48 cm DBH), while for spruce the oldest tree (259 years) was only 11 cm at breast height (Fig 5). The age span was wide across all diameter classes; for example, the age span of trees with a DBH of 10 cm varied from 28 to 282 years and from 57 to 216 years for pine and spruce, respectively.

Table 1. General stand structure. Stand structure data for eight rocky *Pinus sylvestris* dominated forests in the High Coast Region in Northern Sweden. Values are means with SE in parenthesis and based on three band transects per site. Site acronyms as in Figure 1.

Study site	GB	PB	VB	FA	GA	SU	SK	HU
Dbh (cm), Trees ≥ 1.3 m height	11.4 (0.6)	9.8 (1.2)	11.2 (0.8)	11.3 (2.8)	11.1 (1.0)	12.2 (0.7)	12.6 (0.3)	9.3 (0.6)
Basal area (m^2 ha^{-1}), Trees ≥ 1.3 m height	11.0 (1.9)	8.8 (0.9)	10.2 (1.1)	8.1 (2.4)	10.2 (1.9)	6.3 (0.8)	10.1 (2.1)	8.8 (0.9)
Maximum height, Pine (m), average	10.1 (0.67)	7.0 (0.27)	6.6 (0.23)	8.4 (0.42)	8.4 (0.45)	6.2 (0.05)	8.0 (0.67)	5.5 (0.25)
Age, Pine (yr), average ≥ 10 cm DBH	194 (16)	157 (10)	182 (10)	147 (4)	157 (15)	189 (21)	156 (30)	158 (24)
Age, Pine (yr), maximum	334	299	372	276	418	403	442	376
No. of living trees ha^{-1} ≥ 1.3 m height	647 (94)	713 (91)	636 (76)	563 (39)	753 (234)	363 (19)	593 (118)	783 (72)
No. of living trees ha^{-1} ≥ 10 cm DBH	280 (70)	300 (15)	297 (32)	300 (60)	323 (33)	220 (6)	303 (61)	363 (35)
Spatial distribution (variance to mean ratio, VMR)	1.9*	1.1	1.2	3.3*	1.2	1.7*	1.7*	1.0
Pine, share (%)	77 (15)	95 (3)	95 (1.4)	78 (6)	88 (11)	92.5 (4)	94 (1.3)	98 (2.3)
Spruce, share (%)	20 (13)	4 (2.2)	5 (1.4)	4 (0.2)	9 (7)	6 (4)	4 (0.8)	0 (0)
Deciduous, share (%)	3 (1.9)	1 (1.1)	0 (0)	18 (5.8)	3 (3.4)	1.5 (1.5)	2 (1.1)	2 (2.2)
Dead wood volume (m^3 ha^{-1})	4.8 (1.09)	1.0 (0.49)	1.7 (0.31)	1.9 (0.52)	2.6 (1.30)	1.9 (0.89)	1.5 (0.76)	0.6 (0.21)
Standing								
Downed	3.3 (1.56)	1.7 (0.29)	1.6 (0.30)	3.3 (1.14)	2.0 (0.15)	2.0 (0.99)	4.0 (1.44)	1.2 (0.52)
Proportion dead wood, basal area (%)	18.9 (1.91)	13.5 (1.69)	16.7 (2.88)	21.7 (5.64)	16.7 (2.64)	26.1 (6.00)	20.3 (8.47)	9.9 (2.61)

*Significantly aggregated

Table 2. Tree-ring width based growth. The growth of living Scots pines measured as average annual tree-ring width in eight rocky *Pinus sylvestris* dominated forests in the High Coast Region in Northern Sweden. Values are means and SD from all trees > 10 cm DBH at the sites. Site acronyms as in Figure 1.

Study site	GB	PB	VB	FA	GA	SU	SK	HU
Growth (mm yr-1)	0.53	0.53	0.58	0.68	0.56	0.48	0.55	0.52
SD	0.21	0.20	0.29	0.38	0.26	0.25	0.24	0.19
n	82	85	84	70	83	59	49	89

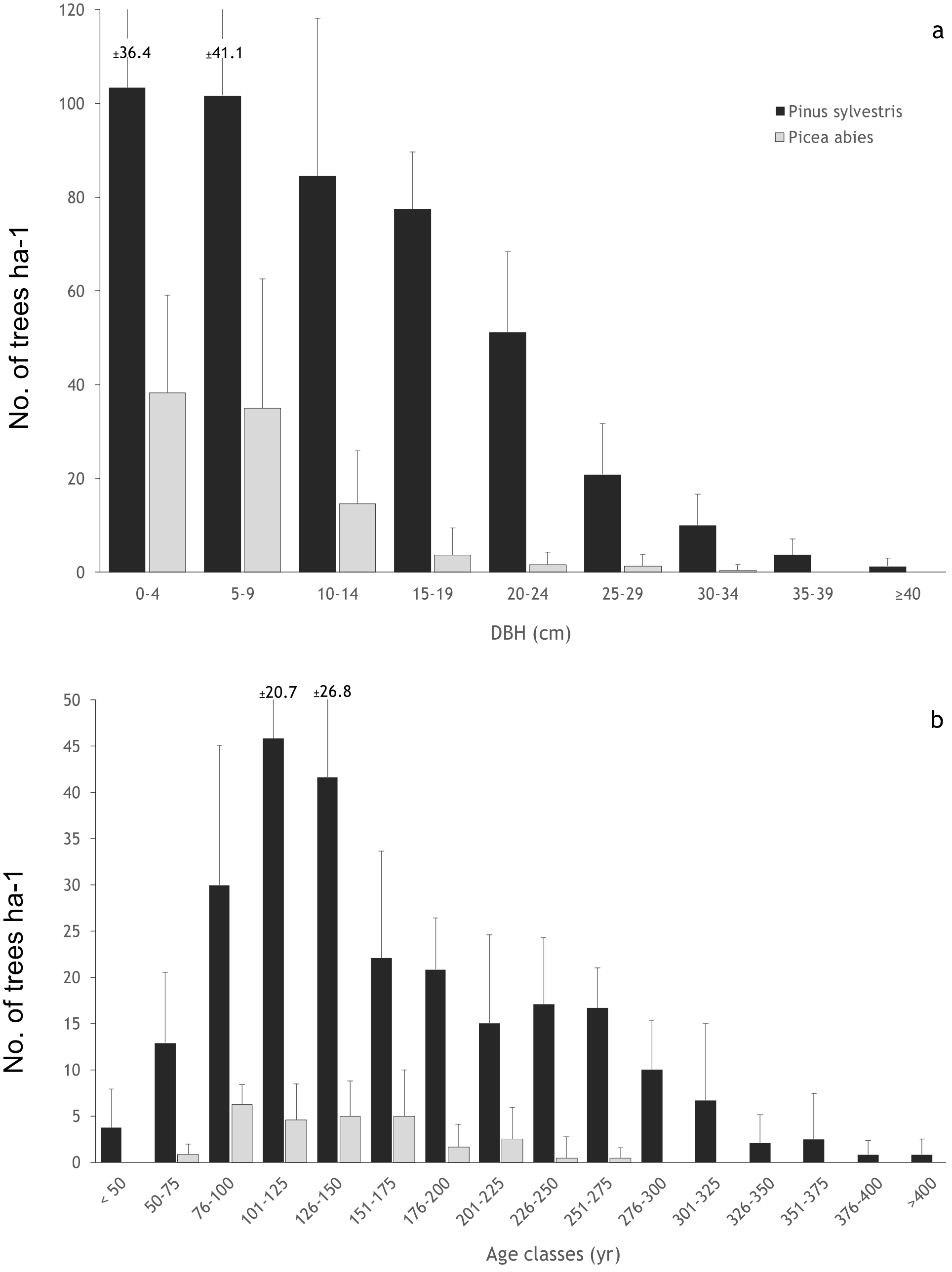

Figure 4. Categories of tree size and tree age. Summary of the distributions of diameter at breast height (DBH) (**a**) and age (**b**) (> 10 cm DBH) for living trees of pine and spruce at the eight sites combined (with mean and SD, n = 8).

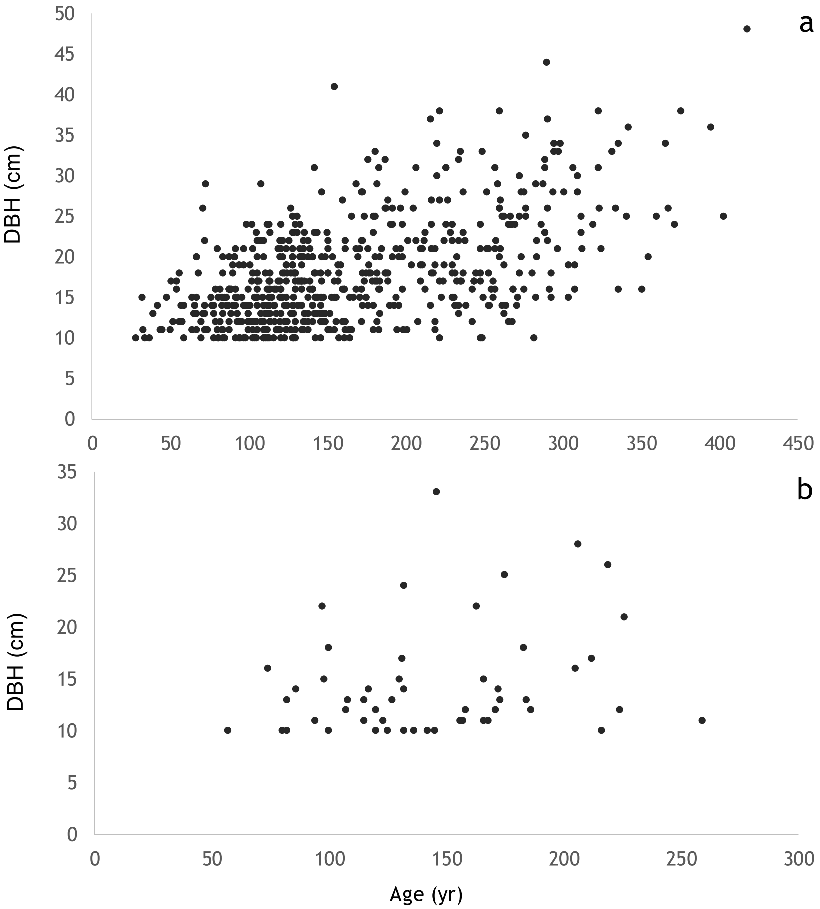

Figure 5. Relationship between size and diameter at breast height (DBH) for pine (**a**, n = 624) and spruce (**b**, n = 52). Only trees with a DBH larger than 10 cm are included.

Dead wood

The amount of dead pine wood was low (average of 4.5 m^3 ha^{-1}, range: 2–8, SD = 2.0, n=8) and varied between sites, but both logs and snags were present at all sites (Table 1, Fig. 6a). On average, there were 53 pine DW units ha^{-1} (SD = 12.8, n=8). DW in all decay stages were present and with decay stage 2 as the most common. However, at three sites dead trees in decay stage 1 were more common (FA, GA, HU; Fig. 6b). The average decay class for all dead wood was 2.45 and for dated dead wood samples 1.92. The difference stems from lack of datable samples from dead wood in decay class four. The basal area of DW in relation to total basal area, including living trees, varied between 10–26% at the different sites with an average of 18%. Most dead wood had died fairly recently; almost half of the dated dead wood samples had died during the last 50 years (Fig. 7).

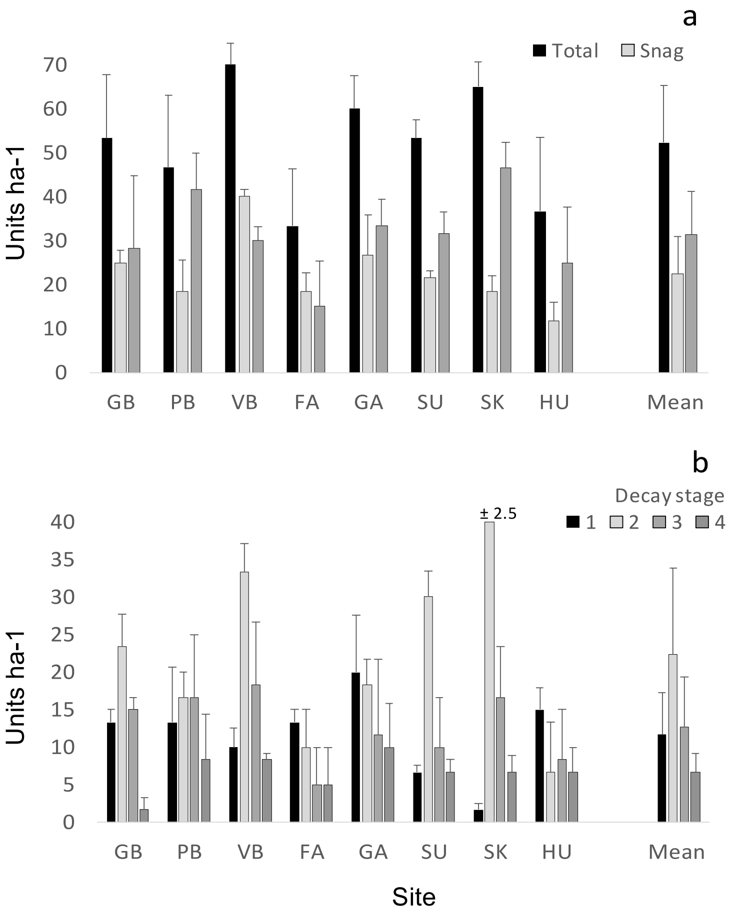

Figure 6. Number of logs and snags from pine in rocky pine forests at the eight different sites (SE, n = 3) as well as the total mean (SD, n = 8). The abundance of DW is classified as standing (Snag) or horizontal (Log) (**a**) and also classified in decay stages (**b**).

A majority of the DW, 88%, had died during the last 200 years, which corresponds to a DW addition of approximately 2 trees per ha^{-1} and decade since the beginning of the 1800s. However, there were clear signs that dead wood can remain for several hundred years. The DW did not totally decay even in cases when the logs had been dead more than 300 years and we even found DW that had been dead more than 500 years (Fig. 7). Snags constituted a higher proportion of newly dead wood whereas logs were the most common DW type for units older than 350 years, but important to note is that there were also really old snags present. For DW that had been dead between 100–300 years the two types are equally common (Fig. 7). The average time since death for all dated dead wood units was 106 years (SD = 129, n=220), for snags 92 years (SD = 151, n=109) and for logs 120 years (SD = 129, n=111). The average age for the dated DW was 192 (SD = 82, n=220).

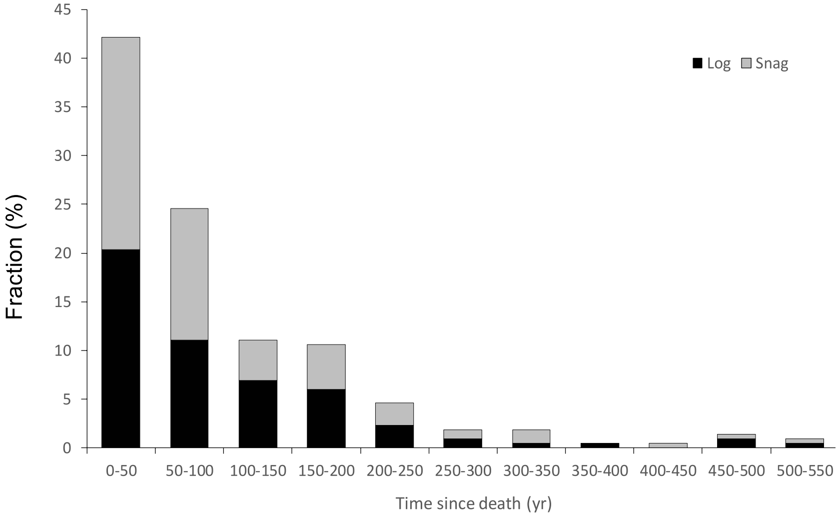

Figure 7. Time since death for dead wood for snags and logs.

Fire history

Most signs of fire were found in FA where 18 fire years were detected from 12 collected fire-scarred samples (Fig. 8a). FA was also the only site with individual trees that had experienced at least four fires. On average, 1.8 fires per sample from all sites was detected but on FA where most fires occurred, we detected 2.4 fires per sample. We did not find any fire-scarred trees at GB and only 3 fires could be detected at PB. On average, eight fire events per site were detected covering a time period from 1235 to 1923 but the number of detected fires varied between sites (Fig. 8a and Table 2). The period with most fires was during the 1600s and the 1800s when 13 fires occurred across all eight sites (Fig. 8b). We found signs of 47 fires between 1500 and 1900 and we detected very few fires earlier than 1500 and later than 1900. The earliest detected fire occurred in 1235 but as with most dated fires, this fire was only detected at one site (Fig. 8c). However, one of the fire years, 1693, was found at five sites. The fire in 1693 was found in PB, FA, SU, SK and HU but not in GA and VA which are located close to FA, SK and HU (Table 2). GA and FA are situated very close together but the only fire year that is common for the two sites is 1563. Approximately half of the fire-scarred trees (45%) had only one fire scar and trees with most scars (repeated fires) had four scars and was found at FA (see Appendix 2 for detailed information on samples with fire scars). In addition, most of the dated fire years was only detected in one sample (64%). The average fire interval varied between sites (shortest: FA 20.5 years and longest: VB: 65.5 years), but with an average fire interval of 42 years (excluding GB, where no signs of fire were detected) (Appendix 3). We also noted that many fire years had smaller year rings (indicating a dry fire season) than the average sizes in the master chronology. Twenty-eight fires had significantly smaller year rings than average, 25 had average size while only four had unusually large rings (Appendix 4).

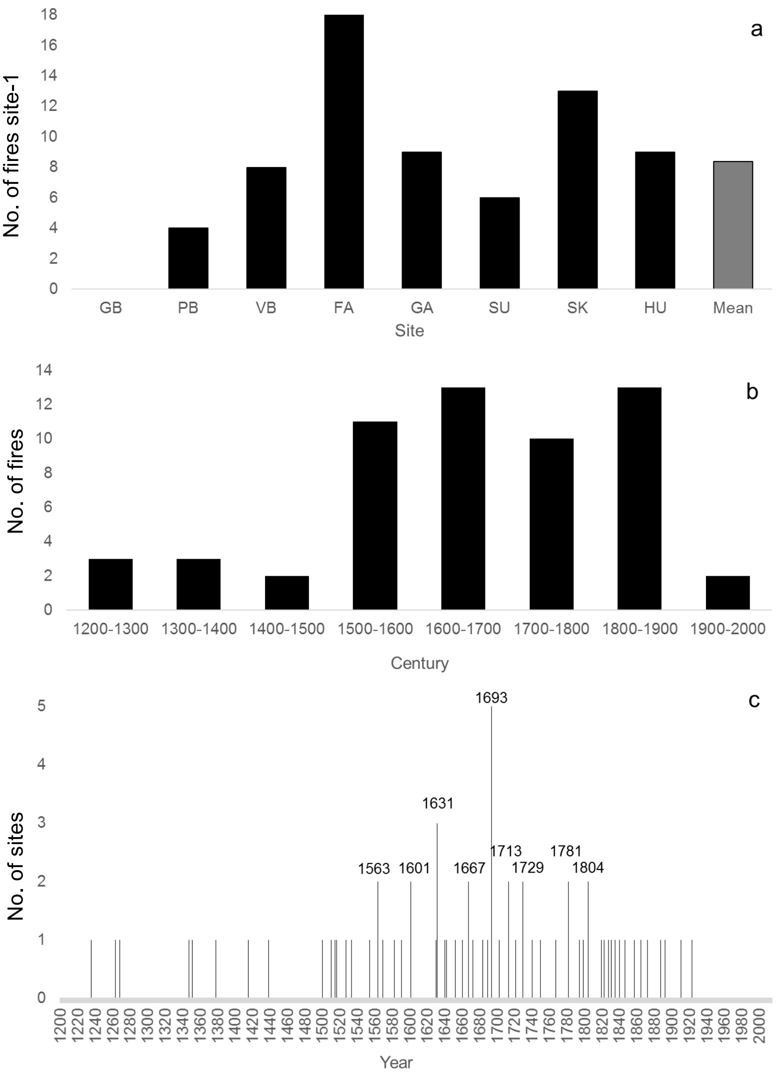

Figure 8. Fires in rocky pine forests. The total number of fires at the eight sites and the average from the sites (**a**). All detected fires are included, regardless of the number of samples the fire was detected in. Total number of fires are also separated into centuries (**b**) and individual fire years and their occurrence in the number of areas, with fire years occurring at more than one site highlighted (**c**).

Discussion

Forest structure

The studied rocky pine forests are characterized by a very open structure. The low density of trees can partly be explained by the scarcity of water and nutrients, as low productivity is generally connected with low basal area and openness (Liira et al. 2007). The rocky pine forests also have an uneven distribution of tree species, size and age. This creates a heterogenic and diverse environment and a wide age distribution typical for old pine forests (Kuuluvainen et al. 2002). Attributes that usually are associated with old-growth forests are present, such as several canopy layers, high variation in tree sizes and ages and high spatial heterogeneity of tree distribution (irregular distribution of gaps) (Bauhus et al. 2009).

Although the diameter distribution pattern in our study is descending with size, the pattern is not a typical reversed J-shaped curve, common in many undisturbed forest stands (e.g. Parker and Peet 1984; Linder et al. 1997; Kuuluvainen et al. 2002; Rouvinen and Kuuluvainen 2005). In a study by Lilja and Kuuluvainen (2005), three different semi-natural (old-growth) pine stands had all a descending pattern, one that showed a reversed J-shaped pattern and two stands that were more similar to our findings. Rouvinen and Kuuluvainen (2005) found a bimodal pattern in a managed pine stand but a descending pattern, but no sharp reversed J-curve, in a natural pine stand. In a sub-xeric old-growth stand, dominated by pine, Uotila et al. (2001) found a pattern with most trees in intermediate diameter classes and not a clear descending pattern. Since we have no data on regeneration (trees < 1.3 m), we have no clear explanation to why we did not find a clear reversed J-shape on the diameter distribution in our study. It could be that the small trees are less frequent because there are only a few places/spots where trees can establish or it could be influenced by moose (*Alces alces*), which browses on small trees in winter. Neither did we find a bimodal diameter distribution pattern, often seen in forests with repeated disturbances, such as fires (e.g. Zenner 2005). This could indicate that the fires in this type of forests have been low-intensity fires of small sizes, as discussed below. In addition, the lack of bimodal diameter distribution pattern also could be an effect of lack of fires during the last 150 years.

As well as being a sign of naturalness, the heterogeneity and patchiness of tree distribution may also be influenced by an uneven water and nutrient availability for the trees. A tree that grows where the ground consists of bare rock has a very different potential for growth than trees in a concave patch covered with mineral soil, which probably can explain why the trees grew spatially irregularly at four of the sites. The trees generally have a low growth and high variability between trees at all of the sites, indicating also heterogeneity in growth. The high variability in growth between trees clearly contributes to the limited correlation between age and DBH. Kuuluvainen et al. (2002) found a stronger correlation between age and size; their R^2 was 0.58 for pine. However, they had a wider range of stand types included in their study and not only nutrient poor pine forest, which could explain the higher predictability. Nevertheless, they also found a lower correlation for spruce (R^2=0.36) than for pine, similar to our findings.

The average maximum tree height is generally low in rocky pine forests. The maximum tree height is related to height growth when the tree is young (Ryan and Yoder 1997), which in turn is influenced by genetic and environmental factors (Junttila 1986; Kaya et al. 1999; Pensa et al. 2005). Tree height seems to depend on a combination of temperature, precipitation and nutrient availability (Jansons et al. 2015) and the environment in the rocky pine forests is characterized by low water and nutrient availability and can probably partly explain the low mean maximum tree height. Other factors that might influence tree height in the rocky pine forests are wind-exposure and openness (Tomczak et al. 2014).

The presence of old trees is one of the key features of natural forests (Östlund et al. 1997; Andersson and Östlund 2004). Old trees are relatively common in the studied rocky pine forests and we found approximately 13 pine trees ha^{-1} older than 300 years and as many as 70 pines ha^{-1} older than 200 years. As a comparison, Edwards and Mason (2006) found approximately 20 and 60 trees ha^{-1} older than 200 years in two different old-growth pine stands in Scotland. In another Scottish old (and open) forest, only about 6 trees ha^{-1} older than 250 years were found (Summers et al. 2008). This is in line with the findings of Kuuluvainen et al. (2002); they found approximately 5–10 trees ha^{-1} older than 250 years in an old-growth pine forest. The oldest living pines in our plots were 418 years but we know that living trees older than 600 years (data not shown) existed in the studied area. In line with our findings, in old-growth forests in Finland, ages of more than 500 years for pine and almost 300 years for spruce were found (Kuuluvainen et al. 2002). In a study from a similar area, Hornslandet, approximately 200 km south from our study area, the authors actively searched for very old pine trees and found the oldest recorded pine in Sweden with an age of more than 750 years (Andersson and Niklasson 2004).

There are not many deciduous trees in the rocky pine forests and although birches (the most common deciduous species in the area) can tolerate rather dry conditions (Sutinen et al. 2002), regular drought may well limit the abundance of deciduous trees. In addition, it is likely that the density of deciduous trees is limited by the presence of moose (*Alces alces* L.), which can reduce the abundance of several deciduous species (e.g. rowan and aspen) when present (Edenius et al. 2002). The abundance of moose has since the 1970s massively increased in northern Sweden (Cederlund and Bergström 1996) and moose is today abundant throughout the whole of Sweden with the highest densities in the world (Skogforsk 2016). Moose is highly abundant also in the rocky pine forests in the High Coast Region and likely have a negative impact on the abundance of deciduous trees.

Dead wood and human impact

The CWD volume is very low and corresponding to levels in managed forest (Jonsson et al. 2016; Ylisirniö et al. 2012) and at a much lower level than what usually is common in natural forests with no or little human impact (e.g. Rouvinen and Kuuluvainen 2001; Karjalainen and Kuuluvainen 2002; Koster et al. 2005; Shorohova and Kapitsa 2015). Given the low tree density it is, however, more relevant to compare the proportion of dead trees to living trees. In the rocky pine forest the CWD share of the total basal area (living and all dead wood combined) is 18% on average, which is in line with several other pine-dominated forests with old-growth characteristics (e.g. Sippola et al. 1998; Siitonen et al. 2000; Rouvinen and Kuuluvainen 2001). By contrast, Karjalainen and Kuuluvainen (2002) found a higher proportion (32%) of the volume of

CWD in forest stands on dry soils. The variation in CWD:live wood volumes is greater in pine dominated forests than in spruce forests (Shorohova and Kapitsa 2015). We found a slightly lower proportion of dead wood in this study, but it should be noted that the ratio between dead and living trees is driven primarily by tree life span (mortality rate) and decay rates. Even though decay rates are slow in the studied rocky pine forests, it is to be noted that tree life span is likewise very long.

Charcoal and tar production has been common in the area a long time and the CWD quality in rocky pine forests is particularly suitable for tar production. Situated < 1 km from our sampling sites, two old remnants of tar pits have been found at one site, but there were no reported signs of old tar pits at the other seven sites. Hence, we cannot totally rule out the possibility that some CWD has been used for char and/or tar production in the studied area because these activities tend not to leave any visible traces behind.

The most common decay stage in this study is stage 2, which is in line with other pine forests with a high degree of naturalness (Karjalainen and Kuuluvainen 2002). The late decay stages were not as common in the study area as the most decayed wood (decay stage 4) constituted approximately only 12% of the total amount of CWD. In other studies of pine forests with high degree of naturalness the distribution of CWD in decay classes was more even (Rouvinen and Kuuluvainen 2001) or later decay classes were also more common (Sippola et al. 1998). One explanation for the relatively low presence of CWD in late decay stage found in this study could be reoccurring small fires because fire consumes logs in later decay stages to a higher extent than logs in earlier stages (Eriksson et al. 2013). It seems that CWD is accumulating slowly and can remain for very long periods in dry conditions. This makes every CWD unit very valuable and even a small outtake can have a large impact on the CWD-depending organisms. The slow decay rate also explains why there is really old CWD; some has been dead for 300–500 years, in the rocky pine forest. In addition, we were not able to sample and date the most decayed dead wood, so the result is probably an underestimation of the amount of very old CWD.

Only two of the sites had signs of past cutting. A low frequency of manmade stumps indicates a high degree of naturalness (Uotila et al. 2001; Rouvinen et al. 2005). The outermost year rings on the six dated stumps varied between 1736 and 1886. This suggests that harvesting took place a very long time ago, although not necessarily giving the exact year of harvest since all stumps lacked bark and some erosion of the outer parts cannot be excluded. Consequently, the years should be regarded as the earliest possible cutting year but the actual cutting could have happened later. Nevertheless, there is evidence that the limited cuttings that did occur happened during the 1800s, or even earlier, and with no recent harvesting during the last 100 years. It is unlikely that rocky pine forests were targeted by industrial forestry since trees with large diameter are rare and the accessibility is very low. However, it is possible that settlers used the pine forests at small-scale for certain construction details, e.g. window frames, for which dense high quality wood was preferred. Such limited harvest/extraction is unlikely to leave any long-lasting visible traces.

Fire history

Surprisingly, many fires were detected in the rocky pine forests. There is not much fuel on the ground in the studied rocky pine forests, bare rock is common and trees are scattered. On the other hand, the ground surface easily becomes very dry and vegetated areas are mainly composed of reindeer lichens and dry mosses, which together with scattered dwarf shrubs potentially could carry a ground fire during dry years. Not many fires were detected before 1500. This could partly be a sampling artefact due to the limited number of fire scarred old trees and snags, but different climate and lower human population size cannot be ruled out as explanations for lower fire frequency in the beginning of our time series. Many fires happened during the 1600s, a pattern also observed by others (Zackrisson 1977; Niklasson and Granström 2000; Wallenius et al. 2004). The year 1693 stands out as a major fire year; a fire year that has also been documented by others (Drobyshev et al. 2014).

There was a population increase after the Black Death plague during the 1600s and several "slash and burn" immigrants from Finland also settled down in northern Sweden during this period, which can be an explanation for more frequent fires. However, most of the ”slash and burn” farmers did not settle down along the coast area where fishing was the main livelihood but rather in the inland areas where the land was more suitable for the ”slash and burn" cultivation technique (Lundkvist 1971). One fire happened in 1721 in Hummelvik nature reserve, a year when Russians made raids where they burned hundreds of farms along the coastline in the studied area (Lundkvist 1971; Lindh 1991). A village just outside Hummelvik nature reserve is mentioned as being burned (Lundkvist 1971), which could potentially explain the fire 1721 since the year ring has an average size. Unusually small year rings have been shown to be closely related to low precipitation in June in the Rocky pine forests in the High Coast Region and fire years are influenced by summer temperature and precipitation to a large extent in the northern region (Drobyshev et al. 2012; Drobyshev et al. 2014).

Most fire years were detected only in a few samples, which indicates that the fires in this area and forest type might have been small in size, but not necessarily rare events. A plausible explanation is that there are plenty of small-scale dispersal barriers for fires in this heterogenic landscape. Both bare rock and wet hollows often occur. Moist depressions, swamps and *Picea abies* patches often do not burn even when nearby dry patches do (Wallenius et al. 2004). The mean fire interval varied between 20.5 and 65.5 years at the different sites (except of one site with no fires found at all). These intervals included fire years that only were detected in one sample, and hence do not necessarily indicate that the whole forest area (site) burned. It is more likely that the fires were small in this heterogenic environment which creates a small-scale spatial variation influencing fire frequency and size (Wallenius et al. 2004). Many trees also survived the fires and many age classes were present. Taken together, this suggests that the fires were not stand-replacing, had low intensity but happened on a regular basis.

Conclusions

The rocky pine forests in the High Coast Region show a high degree of naturalness and possess many old-growth characteristics, e.g. presence of old trees, diverse structure and although the volume of dead wood is low, it constitutes approximately 18% of the total basal area. The dead wood is diverse with a variety of both snag and log sizes and can be present for a long time due to the slow decay rate. The diverse presence of dead wood, e.g. all decay stages represented, indicates that there is a constant supply of dead wood and that these types of forests have natural features. The high degree of naturalness is also supported by the lack of signs of human use; only a few man-made stumps have been found. All sites but one have clear signs of fires and it seems that the fires have happened quite frequently, but have been small in size. It is likely that these type of forests host a specific biota, evolved and adapted to the specific conditions that rocky pine forests constitute.

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Appendix 1

Master chronology, marker years and ring widths

Abbreviations: ++ much bigger than normal; + bigger than normal; - Smaller than normal; -- much smaller than normal. All other years with ring widths are of average size. Bold years means that they are valuable marker years (unusually thin latewood = TH, unusually thick and dark latewood = DL, unusually thick latewood = B).

Year	Ring width	Year	Ring width	Year	Ring width	Year	Ring width	Year	Ring width
1204	+	*1329*	+	1464	-	1647	+	1874	--
1207	-	*1331*	+	1466	--	1648	+	1878	+
1209	-	*1332*	+	1468	+	1656	+	**1881**	**--**
1210	--	*1333*	-	1473	--	1659	--	1886	+
1212	+	*1335*	+	1476	+	1665	+	1888	--
1213	--	*1339*	-	1484	++	1666	-	**1890**	**++**
1214	+	*1347*	-	1490	-	1667	-	1891	-
1216	+	*1348*	-	1491	+	1673	+	1896	+
1218	-	*1351*	-	1494	-	1686	+	**1901**	**B**
1219	-	*1353*	+	1498	+	1687	+	**1902**	**--**
1223	+	*1357*	+	1503	-	1693	--	1907	+
1228	+	*1358*	+	1505	+	1696	-	1911	-
1229	++	*1362*	-	1506	-	1698	-	**1913**	**+ B**
1230	+	*1363*	-	1508	-	1713	-	1917	-
1233	--	*1364*	+	1509	--	1723	+	1918	-
1234	--	*1366*	--	1511	-	1726	-	1922	+
1235	-	*1368*	+	1512	+	1736	-	1923	+
1239	-	*1370*	-	1513	+	1742	-	1924	++
1243	+	*1372*	+	1514	-	1747	-	1925	+
1244	++	*1373*	+	1525	++	1749	-	1928	+
1247	+	*1376*	++	1528	+	1752	+	**1929**	**+ DL**
1252	++	*1381*	+	1531	-	1771	-	1933	--
1256	--	*1382*	++	1533	-	1776	+	1934	-
1259	-	*1384*	-	1535	+	1777	++	1936	--
1261	+	*1385*	-	1538	--	1778	+	**1939**	**B**
1262	+	*1386*	-	1541	+	1781	-	1940	--
1263	-	*1388*	--	1543	-	1786	-	1943	-
1265	--	*1389*	-	1547	+	1792	+	1945	+
1267	++	*1391*	-	1550	--	1793	+	1946	+

Year	Ring width	Year	Ring width	Year	Ring width	Year	Ring width	Year	Ring width
1268	+	*1394*	+	1551	+	**1794**	**B**	1947	+
1269	-	*1396*	++	1554	--	**1795**	**--**	1953	+
1274	--	*1398*	-	1561	++	1805	++	1954	+
1275	--	*1401*	+	1562	+	1806	+	1955	-
1278	++	*1403*	+	1568	--	1810	-	**1957**	**++ DL**
1279	+	*1404*	++	1572	--	**1816**	**-**	**1959**	**--**
1283	--	*1406*	++	1578	+	**1821**	**B**	**1960**	**--**
1285	++	*1411*	--	1583	+	1822	-	**1961**	**-**
1287	-	*1418*	--	1585	+	1827	+	**1962**	**+**
1291	-	*1420*	--	1588	--	1828	+	1969	--
1293	-	*1422*	-	1590	--	1831	-	1972	+
1296	+	*1423*	+	1594	+	**1832**	**--**	1974	+
1297	-	*1425*	+	1601	--	**1835**	**-**	**1976**	**-- TH**
1298	+	*1426*	+	1603	-	1840	+	1984	+
1299	-	*1427*	+	1606	-	1844	+	1987	+
1302	--	*1428*	+	1611	+	1847	--	1991	+
1303	+	*1430*	-	1615	-	1850	+	1992	--
1304	--	1432	--	1623	+	1851	+	1997	--
1305	+	1434	+	1625	+	1853	--	2000	+
1307	+	1442	-	1626	+	**1859**	**TH**	2002	-
1309	+	1446	--	1628	+	**1860**	**B**	2004	+
1312	--	1451	+	1630	-	**1861**	**--**	**2008**	**--**
1319	+	1454	+	1631	--	1862	-	2009	--
1321	+	1455	-	1633	-	1866	+	**2011**	**+ B**
1324	-	1459	-	1638	+	1868	+	2012	+
1325	--	1462	+	1642	-	1869	+	2014	+
10 or more samples from 1431									
								Total no. of samples	248
								Age span	1197–2015
								Total no. of years	819
								Total no of rings	56329
								Mean age	227
								Sensitivity	0.29
								Series intercorrelation	0.505

Appendix 2

Dated samples with fire scars and fire years

Site and Sample ID	Correlation with master	Pith year	Outermost ring year	Age	Year of fire1	Year of fire2	Year of fire3	Year of fire4	Sample type	Scar direction
Gropberget										
No fire scars detected										
Porsmyrberget										
BrandPO8	0,206	1467	1783	316	1702				Dead	
BrandPO12	0,248	1500	1990	490	1660	1693	1804			
BrandPO14	0,614	1773	2015	242	1804				Living	
Vårdkallberget										
VA1d20	0,275	1230	1505	275	1268	1347			Dead	
VA1d29	0,338	1671	1846	175	1740					
BrandVA1	0,454	1783	2013	230	1804				Living	E
BrandVA3	0,562	1580	1838	126	1835				Dead	N
BrandVA4	0,468	1661	2015	354	1804 or 1805				Living	SE
BrandVA5	0,56	1561	1854	293	1601	1631	1729		Dead	W
BrandVA7	0,606	1604	1896	292	1601				Stump	W
BrandVA10	0,323	1574	1819	269	1631					
BrandVA12	0,273	1731	2015	284	1749	1923			Living	E
Fanön										
BrandFA1	0,333	1518	2015	497	1781				Living	S
BrandFA4	0,342	1494	1647	153	1533				Stump	
BrandFA5	0,163	1526	1990	463	1582	1640	1713	1822	Dead	
BrandFA6	0,58	1712	2015	303	1822				Living	E
BrandFA7	0,338	1435	1863	428	1527	1563	1693	1819	Dead	E
BrandFA8B	0,492	1518	2004	486	1693	1798	1846	1910	Dead	N
BrandFA11	0,587	1484	1912	428	1590	1693	1827 (1828)		Dead	S, N
BrandFA12	0,57	1702	2015	313	1693	1857			Living	Fire 1 SE, Fire 2 N
BrandFA16	0,585	1599	1855	256	1689	1781	1822		Dead	
BrandFA19	0,296	1407	1546	136	1500				Dead	SW
BrandFA20	0,382	1640	1972	332	1640	1693	1781	1846	Dead	S
BrandFA22	0,343	1642	1837	195	1693	1781			Living	S
Gårdberget										
Gamlingen	0,397	1419	2014	595	1563	1601	1631	1713	Living	
GA1dStump1A	0,596	1409	1736	327	1438	1601			Dead	

Site and Sample ID	Correlation with master	Pith year	Outermost ring year	Age	Year of fire1	Year of fire2	Year of fire3	Year of fire4	Sample type	Scar direction
GA1dStump1B	0,663	1465	1713	248	1601	1713				
BrandGA4	0,456	1698	2013	315	1713	1826–1827			Living	NW
BrandGA6	0,585	1436	2000	564	1516	1830			Living	Fire 1 NW, Fire2 SW
BrandGA10	0,306	1587	1905	318	1667	1830			Living	NW
BrandGAlst14	0,146	1773	1996	223	1830				Dead	SE
BrandGAX1	0,391	1338	1517	179	1378				Dead	
BrandGAX2	0,53	1582	1715	133	1667				Stump	N
BrandGAX3	0,3	1447	1723	276	1516	1601 or 1602	1667		Dead	W
S. Ulvön										
BrandULV1	0,3	1683	1868	185	1729	1864			Living	E
BrandULV2	0,237	1745	2015	270	1767				Living	E
BrandULV3	0,484	1760	1959	199	1767				Dead	S
BrandULV4	0,28	1641	1991	350	1693				Living	E
BrandULV5	0,37	1725	2015	290	1767				Living	NE
BrandULV6	0,543	1735	1817	82	1794				Living	W
BrandULV7	0,561	1749	1925	176	1892				Stump	S
BrandULV8	0,423	1587	2015	428	1794				Living	E
Skule										
BrandSKU2	0,305	1428	2004	576	1781-1782	1840			Living	W + E
BrandSKU6	0,196	1662	2014	352	1693	1840			Living	W
BrandSKU9	0,396	1657	2015	358	1840				Living	NE
BrandSKUX1	0,225	1565	1826	261	1631				Dead	
BrandSKUX2	0,212	1295	1626	331	1351	1415	1510		Dead	W
BrandSKUStump	0,476	1796	161		1652	1693 or 1694			Stump	
BrandSKUStump8	0,451	1559	1853	294	1554	1631	1672		Stump	W
T4.126	0,617	1598	1808	210	1642				Dead	
T5.95	0,338	1203	1546	343	1235	1263	1351	1415	Dead	
T6.05	0,484	1421	1753	332	1510	1631			Dead	
Hummelvik										
HU1d02A	0,408	1864	2006	142	1872				Dead	
BrandHU5	0,365	1546	1983	437	1568 or **1569**	1668 or 1678	1887		Dead	SE
BrandHU8	0,451	1411	1759	348	1458	1514	1569	1693	Dead	E
BrandHU9	0,201	1648	1918	270	1683	1872			Dead	E
BrandHUlst13	0,31	1617	1937	320	1721				Dead	NW
BrandHUStump1	0,472	1446	1725	279	1514	1568 (+- 1 yr)	1630		Stump	
BrandHUStump2	0,503	1469	1578	109	1514	1630			Stump	

Appendix 3

Fire years and interval

Fire years. The individual fire years at the different sites and the number of samples where fires were detected and the average fire interval at each site (calculated as: number of fires/(last fire year minus first fire year)). GB = Gropberget, PB = Porsmyrberget, VB = Vårdkallberget, FA = Fanön, GA = Gårdberget, SU = Southern Ulvön, SK = Skuleskogen National Park, HU = Hummelvik Nature Reserve. Gropberget (GR) did not have any signs of fire.

GB	**PB**		**VB**		**FA**		**GA**		**SU**		**SK**		**HU**	
No signs of fires	**Fire year**	**n**	**Fire year**	**n**	**Fire year**	**n**	**Fire year**	**n**	**Fire year**	**n**	**Fire year**	**n**	**Fire year**	**n**
	1660 ±2 yr	1	1268	1	1500	1	1378 ±2 yr	1	1693	1	1235	1	1514	3
	1693	1	1347	1	1527	1	1438	1	1729	1	1263	1	1569	3
	1702	1	1601	2	1533	1	1516	2	1767	3	1351	2	1630	2
	1804	2	1631	2	1563	1	1563	1	1794	2	1415	2	1668	1
			1729	1	1582	1	1601	4	1864	1	1510	2	1683	1
			1740	1	1590	1	1631	1	1892	1	1554	1	1693	1
			1749	1	1640	2	1667	3			1631	3	1721	1
			1804	3	1689	1	1713	4			1642	1	1872	2
			1835	1	1693	6	1830	4			1652	1	1887	1
			1923	1	1713	1					1672	1		
					1781	4					1693	1		
					1798	1					1781	1		
					1819	1					1840	3		
					1822	3								
					1827	1								
					1846	2								
					1857	**1**								
Average fire interval (yr)	**36**		**65.5**		**20.5**		**50**		**33**		**46.5**		**41.5**	

Appendix 4

Fire years and ring widths

Abbreviations: ++, much bigger than normal; +, bigger than normal; aver, average size; -, smaller than normal; --, much smaller than normal. GB = Gropberget, PB = Porsmyrberget, VB = Vårdkallberget, FA = Fanön, GA = Gårdberget, SU = Southern Ulvön, SK = Skuleskogen National Park, HU = Hummelvik Nature Reserve.

Fire years	**Site (and number of samples)**	**Ring width in master**
1235	SK (1)	-
1263	SK (1)	-
1268	VB (1)	+
1347	VB (1)	-
1351	SK (1+1)	-
1378+- 2 yr	GA (1)	aver
1415	SK (2)	aver
1438	GA (1)	-
1500	FA (1)	aver
1510	SK (2)	-

Fire years	Site (and number of samples)	Ring width in master
1514	HU (3)	-
1516	GA (2)	aver
1527	FA (1)	aver
1533	FA (1)	-
1554	SK (1)	--
1563	FA (1), GA (1)	aver
1569	HU (3)	aver
1582	FA (1)	aver
1590	FA (1)	--
1601	VB (2), GA (4)	--
1630	HU (2)	-
1631	VB (2), GA (1), SK (3)	--
1640	FA (2)	-
1642	SK (1)	-
1652	SK (1)	-
1660 ± 2 yr	PB (1)	aver (1659 --)
1667	GA (3)	-
1668/1669	HU (1)	aver
1672	SK (1)	aver
1683	HU (1)	aver
1689	FA (1)	aver
1693	FA (6), SU (1), SK (2), HU (1), PB (1)	--
1702	PB (1)	aver
1713	GA (4), (FA (1)	-
1721	HU (1)	aver
1729	VB (1), SU (1)	-
1740	VB (1)	-
1749	VB (1)	-
1767	SU (3)	aver
1781	FA (4), SK (1)	-
1794	SU (2)	aver
1798	FA (1)	-
1804	VB (3), PB (2)	aver
1819	FA (1)	aver
1822	FA (3)	-
1827/1828	FA (1)	+
1830	GA (4)	-
1835	VB (1)	-
1840	SK (3)	+
1846	FA (2)	aver
1857	FA (1)	aver
1864	SU (1)	aver
1872	HU (2)	aver
1887	HU (1)	aver
1892	SU (1)	aver
1910	FA (1)	aver
1923	VB (1)	+