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Forest fire history in Tresdalen

Skogbrann-historikk i Tresdalen

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Forestry

Preface

This Master thesis ends my 5-year study of forestry at the *Norwegian university of Life Sciences* (NMBU), *Faculty of Environmental Sciences and Natural Resource Management* (MINA).

This thesis was chosen out of personal interest, and is mainly a study of forest fire history and to some extent forest ecology.

I would like to thank my supervisors at the *Norwegian Institute of Bioeconomy Research* (NIBIO), Ken Olaf Storaunet and Jørund Rolstad for lending me equipment and providing office space, and for reading my thesis and giving me valuable feedback and advice. In particular Ken Olaf Storaunet for guiding me through the world of dendrochronology, from the first sample collected to the last sample dated, and for giving me constructive feedback and advice throughout the whole process. I would also like to thank Mikael Ohlson for reading my thesis and giving me constructive feedback.

The thesis is part of the project CLIMFIRE - Impacts of climate change on fire regimes in Norway by *Norwegian Institute of Bioeconomy Research* (NIBIO).

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Abstract

Fire is one of the most important natural disturbance agents in the boreal forest. Therefore, knowledge about forest fires and its natural occurrences is important for understanding fires role in ecological processes, and subsequently how it may influence decisions regarding forest management.

I have studied the fire history in Tresdalen, located between Atna and Koppang, in Stor-Elvdal municipality, Hedmark county. The main objectives were: (1) to describe the historical fire regime of the Tresdalen area, and (2) to see to what extent human activity have affected the fire regime.

Stumps, trees and snags of fire scarred Scots pine (*Pinus sylvestris*) was searched for in five sampling areas of 15-20 ha, spaced out within a 40-50 km^2 landscape. Of 74 collected samples, 65 were successfully cross dated. Spanning 1043 (974-2016 AD) and revealing 170 fire scars. Altogether, the fire scars disclosed 38 different fire years.

There was no distinct change in fire regime over time before ca. 1750, even though people have been using the area for pastures and logging for centuries. The trend in fire intervals over time show a moderate decline. When performing a simple linear regression analysis on the data, it is near statistically significant. However, the sample size is smaller before 1550 compared to after 1550 and this may have affected the outcome. 91 of the fire scars were dated to season, the majority in middle to late season. There was no sudden change in fire frequency, as the fires are quite evenly distributed throughout the time-period. Apparently, there has been a natural fire regime in the area, as fire has occurred on a regular basis from the oldest fire documented in 1079.

There was a decline in forest fires after 1700, and only one fire was recorded after 1800. This is possibly due to a combination of legislation, increased timber values and active fire suppression.

Sammendrag

Brann er en av de viktigste storskala forstyrrelsesfaktorene i boreale skoger. Derfor er kunnskap om skogbrann og dens naturlige forekomst viktig for å forstå branners rolle i økologiske prosesser, og påfølgende hvordan det kan påvirke beslutninger knyttet til bærekraftig skogforvaltning.

Jeg har studert brann-historie i Tresdalen, som ligger mellom Atna og Koppang, i Stor-Elvdal kommune, i Hedmark fylke. Hovedmålene er: (1) å beskrive brann historikken i Tresdalen området, (2) å undersøke til hvilken grad brannregimet er påvirket av mennesker over tid.

Stubber og trær av furu (*Pinus sylvestris*) ble undersøkt for brannlyrer i fem forskjellige delområder på 15-20 hektar, innenfor et totalareal på 40-50 km^2. Av 74 prøver ble 65 av disse dendrokronologisk datert. En brannhistorie som strekker seg over 1043 år og 170 brannlyrer ble avdekket. Totalt ble det funnet 38 forskjellige brannår.

Det ble ikke funnet noe klar forandring i brannregime over tid frem til ca. 1750, selv om folk har brukt området til seterdrift og skogsdrift i århundrer. Trenden for tidsintervallene over tid viser en svak nedgang. Ved utføring av en enkel lineær regresjons-analyse ble resultatene nær signifikant. Imidlertid er utvalget mindre før 1550 sammenlignet med etter 1550, og dette kan ha påvirket utfallet. 91 av brannlyrene ble sesongdatert, med hoveddelen fra midten til sent i vekstsesongen. Brannene var forholdsvis jevnt fordelt gjennom tidsperioden, og det var ingen brå forandring i brannfrekvens. Dette kan tyde på at det har vært et naturlig brannregime i området, ettersom det har brent forholdsvis regelmessig fra den første brannen i 1079.

Det var en nedgang i branner fra ca.1700 og det ble bare registrert én brann etter 1800, grunnen til dette kan være en kombinasjon av lovgivning, økte tømmerpriser og aktiv brann forebyggende arbeid.

Contents

1.0 Introduction

Forest fires are one of the most important large scale disturbances in forests (Ahlgren & Ahlgren 1960; Zackrisson 1977). Fires are important as they change forest structure, age class distribution, species composition and act as a factor in nutrition cycling (Esseen et al. 1997; Heinselman 1973; Zackrisson 1977). Fire also play an important role in forest regeneration, and is important for biodiversity as it leaves behind microhabitats and charred wood which is important for many different plant species and other organisms (Esseen et al. 1997). By studying historical forest fire regimes, we can better understand how to maintain sustainable forests and forest ecosystems (Swetnam et al. 1999).

The fire frequency, spatial pattern and characteristics of fires which is prevalent within an ecosystem over a longer period of time is commonly defined as a fire regime, and it describes the type of fire which usually occur (Neary et al. 2005). In boreal forests, fires usually occur with intervals at 50 – 200 years, although shorter and longer intervals have been recorded (Bonan & Shugart 1989).

The most dominant conifer tree species of the boreal forests of Fennoscandia are Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*). Pine usually grow in nutrient poor soils and dry hill tops, and spruce commonly is more dominant on wetter and more nutrient rich soils. Birch (*Betula pubescence*) is the most common deciduous tree species (Esseen et al. 1997; Niklasson & Granström 2000). The fire regime may determine many variables of a landscape, such as the species composition, the age distribution of trees and succession rate (Niklasson & Granström 2000).

Fire has been used extensively by people through history, both to acquire new land for settlements, but also to improve conditions for hunting, pasture or agricultural cultivation (Pyne 1998). In Fennoscandia, humans have influenced the fire regime significantly during the last centuries (Engelmark et al. 1994; Groven & Niklasson 2005; Lehtonen & Kolstrom 2000; Niklasson & Granström 2000; Rolstad et al. 2017; Storaunet et al. 2013), and the general pattern is that fires were fewer before settlements, increasing in the late half of the1500s and finally almost disappearing in the 1800s–1900s. This can indicate both that the fires in the early stages of settlement where man-made and that people were actively preventing the development of fires in the centuries following (Rolstad et al. 2017; Storaunet et al. 2013).

More effective fire suppression (Zackrisson 1977) and more careful use of fire as timber got increasingly more valuable (Wallenius et al. 2004), are some of the theories that are put forward to explain the lack of fires in recent time.

Pre-1600 fires were more affected by climatic conditions, more fires in dry-hot summers and fewer in moist-cold summers. Natural fires tend to start later in summer when the ground, and vegetation is dry, and fires in the early summer season could more likely be started by humans (Niklasson & Granström 2000; Rolstad et al. 2017; Storaunet et al. 2013).However, the number of forest fires in Fennoscandia have declined since the midst 1800s (Niklasson & Granström 2000),

The only natural source of ignition for forest fires in Norway is lightning, and the risk is highest during the summer months of June to August (Rokseth et al. 2001). The extent of a forest fire is a result of the size of the fire and the number of ignition points. It can either be the consequence of one large fire or many small ones, and to help estimate which fires has been the result of lighting-ignition, it is possible to compare numbers and size of fires in the past with lighting-ignition densities from present-day (Niklasson & Granström 2000).

Dendrochronology is the study of tree rings. Fire frequencies can be interpreted from analysis of tree rings and fire scars, and the information revealed from studying tree rings can give knowledge of fire year and season (Groven & Niklasson 2005; Niklasson & Granström 2000). Pine (*Pinus sylvestris*) is a species which is well suited for dendrochronological studies as it is adapted to survive a forest fire with thick bark and branches high up on the stem (Gill 1974). After a fire injury, the pine will generally have a fire scar in the wood, which in turn is possible to date. As the tree heals, new wood covers the scar, and this area of the tree will usually have thinner bark. In succeeding fires a scar will more often appear in the same area, and there can often be several fire scars successively in the same pine tree (Gill 1974).

1.1 Objectives

For this thesis, dendrochronological methods have been used to map out the pattern of forest fires as far back in time as possible. The specific goals have been: (1) to describe the historical fire regime of the Tresdalen area, and (2) to see to what extent human activity have affected the fire regime.

2.0 Study area: Tresdalen

The study was conducted in Tresdalen south-east of Atna in Stor-Elvdal municipality, Hedmark county: UTM33 6841772N 286959E (Fig 1). The area is one of six study sites in South-Eastern Norway for the project CLIMFIRE by NIBIO. This specific study site was chosen due to an abundance of fire scarred pine stumps. The property is owned by Mathiesen – Atna AS (http://mathiesen-atna.no/ 2017), and the study area represent 40-50 km^2.

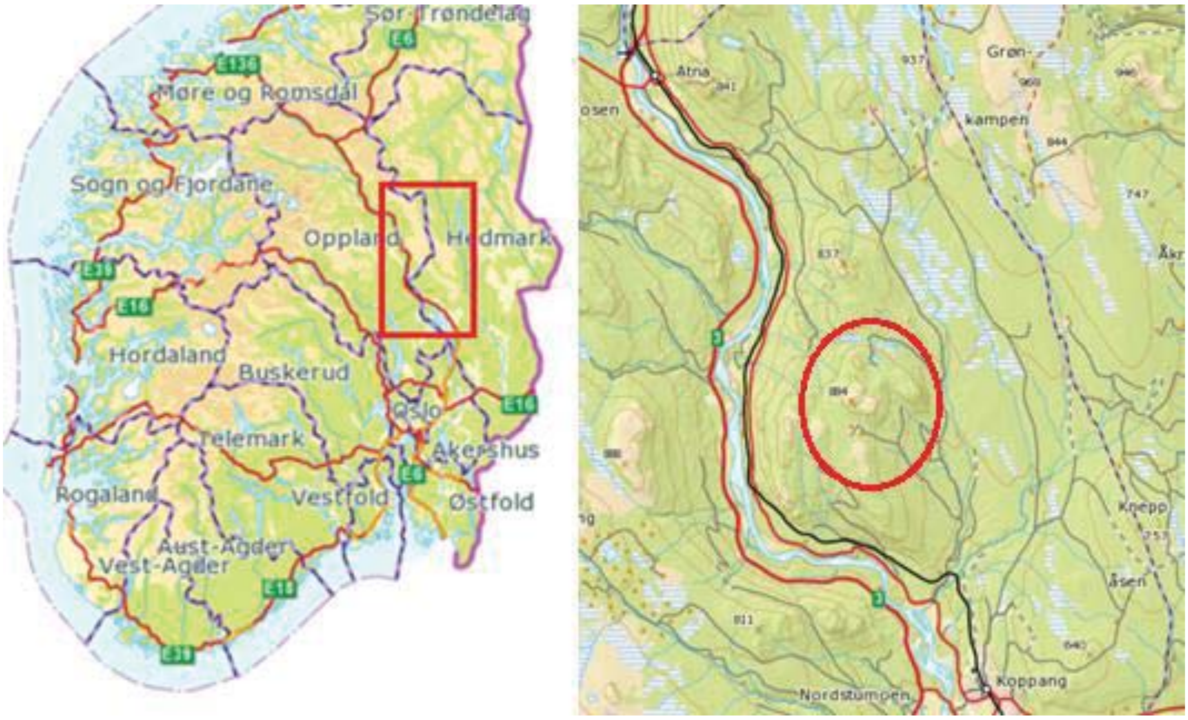

Figure 1: Location of study area (Norgeskart 2017)

The study area is situated in the middle-northern boreal zone, the mean annual precipitation is about 500-700 mm and the mean annual temperature is 2-4°C, with mean monthly temperatures varying from -10°C in January to 15°C in July (Moen et al. 1999). Altitudes range from about 400 to 900 m a.s.l. The terrain consists of soft ridges and mires. There were traces of cultivated mires in the area, in addition to cut stumps.

Figure 2: Partial view of the study area. Taken from Elgshøkletten (site C), direction approx. south-east. Photo: J. Rolstad

Figure 3: Morning mist cowering site E. Photo: B. Johansen

3.0 Historical background

For this thesis, I have studied historical sources from the rural area of Stor-Elvdal municipality to be able to interpret the connection between the frequency of forest fires and human activity.

3.1 Early History

Artifacts have been found dating back 4000 years, and people have been in the area since the Neolithic period. The oldest documents concerning the area was written in 1264, with mentioning of a farm Berg or Bergshaug from that era (Fosvold 1936). Preceding the Black Death (1350 AD) Stor-Elvdal was its own perish, with a priest, church and presbytery (Fosvold 1936).

Østerdalen was thriving in the 1200s – 1300s. Koppang was at that time a marketplace where people from the surrounding areas would come to exchange tools, furs, cloths, and food. Stor-Elvdal was a flourishing and fully developed rural community. From the middle of the 1300s there are no written records from the area, and it seems that the bubonic plague laid the area more or less deserted. The first document after the Black Death is a tax roll consisting of 11 taxpayers from 1528, which indicates that people were slowly resettling in the area. During the next centuries the area was repopulated and reaching approximately 500 inhabitants in 1665 (Fosvold 1936; Sæter, Ivar 1908).

Up to 1649 all land in Stor-Elvdal was property of the king or church, and the inhabitants of the area were the king's tenant farmers. Johan Gårdmann was the first private landowner, and in 1649 the right of ownership of several of the farms were passed on to him (Fosvold 1936). In 1662, Christen Jensen acquired the ownership of several other farms, including Bredshaug (Bergshaug) and Koppang. Farms and farmland was a means for speculation where the owners, magnates from the cities, would try to get as much resources as possible. Kristian the 5th act sets an end to this as taxes for taking out resources from farms where you did not have residence doubled. In the last part of the 1600s most of the farms where bought by the local farmers (Fosvold 1936).

3.2 Pasture

Summer pastures has been common in large parts of Europe, and is when the main farm sends its livestock and some workers up in the forests for better grazing opportunities during spring, summer, and autumn (Reinton 1955). Rokksætra and Månsætra were both part of Koppang farm, and they were probably established before the 1600s (Fosvold 1936). Both Rokksætra, Månsætra, southern- and northern-Koppangkjølen, are within the study area. They were used as spring, summer, and autumn pastures.

The forests around the pasture areas was important for the community, because of logging, materials for construction, pastures and for slash and burn cultivation to produce rye. This was a conflict of interest among the local farmers in the early 1700s. Logging was in some cases a collaboration as manpower was needed. Slash and burn cultivation however, was not, as slash and burn cultivation was done where ever the local farmers saw fit. The result was overcropping and exploitation, and because of the risk of forest fires, in 1719, the local farm owners came to an agreement about forest borders, and a set of rules concerning forestry and burn cultivation. Concerning fires, they agreed to act with caution and make sure fires were supervised, to ensure that the forest was not damaged. If a forest fire would occur, the responsible parties would have to pay a fine of 10 rdl. to the church and would be prosecuted by the law (Fosvold 1936 p.256-257).

3.3 Logging

Log driving in the rivers had its beginning in the 1600s when Christen Jensen was a large land owner in the easter part of the country. Christen Jensen owned 75 farms in Østerdalen and Solør. This including all the farms from the north end of Stor-Elvdal and down to Stai (Fosvold 1936; Sæter, I 1908). Much of the easily accessible forest had been cut and there was a need and a market for timber in more central areas. Christen Jensen saw the potential and started floating timber down the Atna river, down Glomma river and to lake Øyeren. Throughout the 1700s and 1800s logging was an important source of income, and large logging operations were performed, both legal and illegal (Brænd 2016).

The Norwegian timber industry was specialized to provide high-quality timber for the British marked in the 1700s. The Napoleon wars (1800-1815 AD) set an end to this, and due to changes in the political and economic relationships, the British marked got closed in 1807 (Hutchison 2015). The Norwegian timber industry adapted to this change, and consequently, prices fell as the market for timber disappeared (Hutchison 2015). Due to low timber prices, there was little logging in the Atna area until about the 1840-ies, when the timber prices increased. In the decade 1893-1902 there was an average of about 50 000 logs from the area around Atna, being driven down Glomma river (Brænd 2016; Sæter, I 1908).

4.0 Materials and method

4.1 Sampling.

During the early fall of 2016 five areas of approximately 15-20 ha, representing 40-50 km^2, was searched for fire scarred living trees, logs, stumps, and snags of Scots pine (Fig. 4). No fire-scarred living trees were found. Trees and stumps where examined, and if there were signs of fire-injuries such as scars, burned wood, or irregular wooden structure indicating a fire scar, a sample was collected.

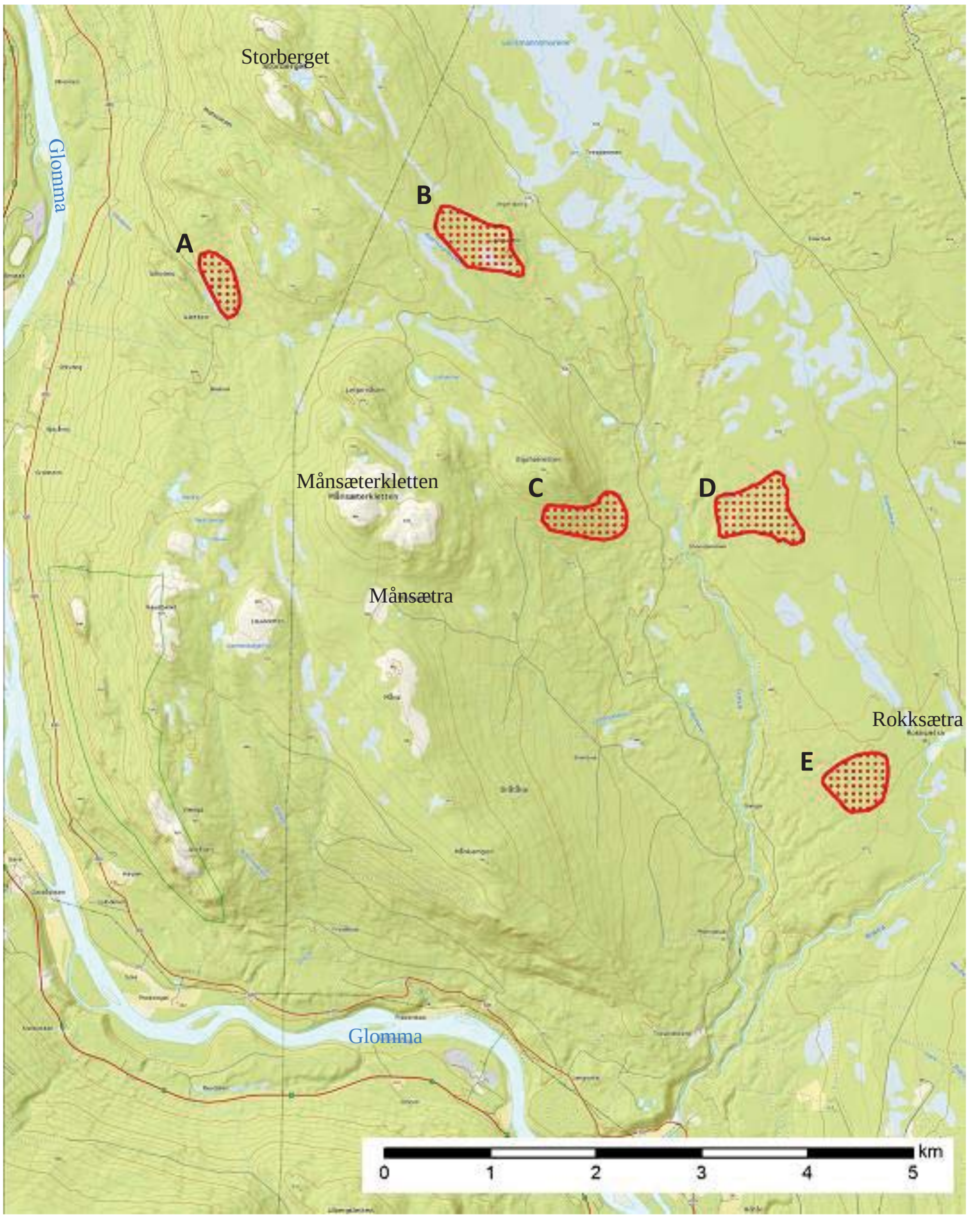

Figure 4: Study area and sampling sites.

Figure 5: T.L Example of typical fire scarred pine stump. T.R Crosscut section of sample collected in field, with three fire scars (1563,1661,1697). Photo: B. Johansen

A chainsaw was used to cut a cross section about 2-5 centimeters thick at a place where fire scars were most complete. Multiple cross sections were collected at different heights or angles. A typical cross section is illustrated in figure 5. The criteria for sample collection were that there had to be at least one fire scar, 50-100 tree rings and that the sample was in a good enough condition that further studies were possible. Increment core samples were collected from old, living trees to be used for making a chronology.

The method of separate subareas for collecting samples gives five different-, detailed, datasets. This enable evaluation of the difference between fire years in each subarea, to differentiate between smaller and larger fires and give an overall view of the study area. In addition, this method will reduce the fieldwork giving less ground to cover. The five sampling plots were chosen due to a relative high abundance of fire scarred stumps of Scots pine. From each plot about 15-20 stumps were chosen for sampling, providing a total of 74 samples (Fig. 6).

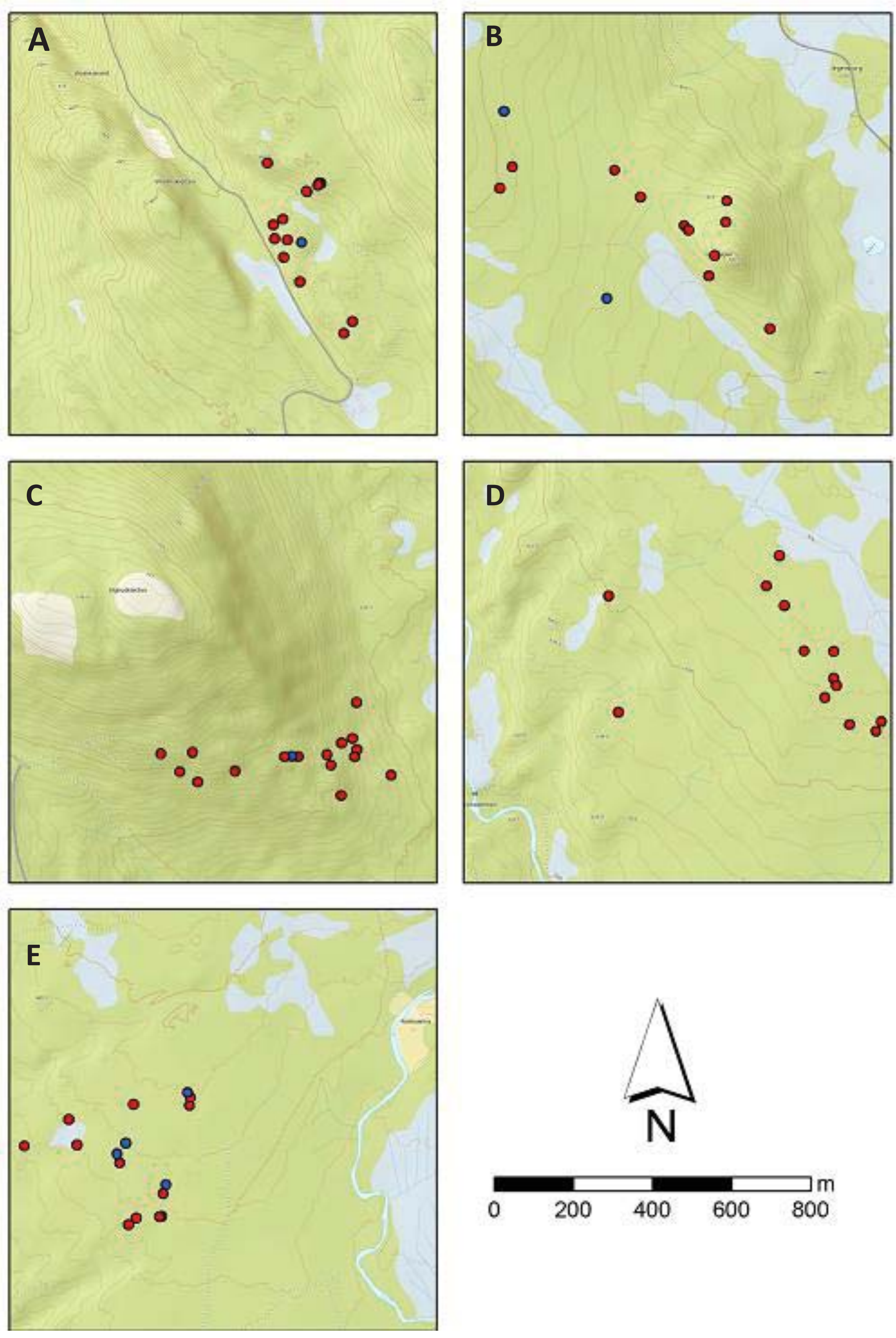

Figure 6: Collected fire scarred samples in sites A-E. Red dots represents samples dated, blue dots represent undated samples.

All samples were GPS coordinated during the fieldwork and information about the locality and fire scarred stumps were recorded in fieldnotes. Fire scars were marked with a marker in the field to make the identification work in the laboratory easier.

4.2 Lab work.

All cross-sections were dried for at least 4 weeks, and then sanded with an electrical belt sanding machine using increasingly finer sanding paper until the tree rings, scars and cell structure were visible. The tree rings were then measured with 1/100 mm accuracy (LinTab tree-ring measurement station) using a microscope (Leica MZ 125), the software Tsap-Win was used for registration of the measures. For some of the samples, a scalpel was used to cut layers of the wood, and sink-paste applied to enlighten the borders of the tree rings.

4.3 Dendrochronology and cross dating

The tree ring pattern is different year by year due to differences in growing conditions. In the north, temperature is the factor of most importance, and the tree grows narrow tree rings in cold summers and wider tree rings in hot summers, giving trees characteristic tree ring patterns. These patterns are during the course of many years never repeated exactly the same, so by comparing one tree sample of known age to another of unknown age, cross-dating is made possible (Stokes & Smiley 1968).

A chronology is made from combining several ring series from trees which has been growing in similar climatic conditions (Stokes & Smiley 1968), and to date samples of unknown origin, the tree ring series are compared to a master chronology.

Using the COFFECA software, the tree-ring series were cross dated against three tree-ring chronologies from other areas, one that was made from several measures from sample A-13, and one local chronology constructed from increment cores of the living trees and a selection of the fire scarred samples. The software works by comparing undated tree-ring series against a master chronology. Each series is filtered to remove low-frequency variance in the form of difference in growth area, soils, or competition from other trees, so that the growth pattern better reflects climatic conditions. The individual tree-ring series are divided into segments, and all segments are then correlated against all possible positions in the master chronology. The program produces a list of suggestions with the highest correlation to where the segments might fit in the master chronology (Holmes 1983; Holmes 1994).

Five different pine chronologies were used, Varaldskogen (located 180 km SE of the study area) made from 15 trees with ≥3 tree-ring series dating back to 1511, the chronology was constructed during the master thesis «Fire history at Varaldskogen» (Bråthen 2016). Rollag (200 km SW), constructed from 45 trees with ≥3 tree-ring series dating back to 1248, Sigdal (200 km SW), constructed from 117 trees with ≥3 tree-ring series dating back to 1223, both Rollag and Sigdal were made during the study by Rolstad et al. (2017). A-13 (present study) dating from 1042-1762, and Atna (present study) made from 20 trees with ≥3 series dating back to 1099.

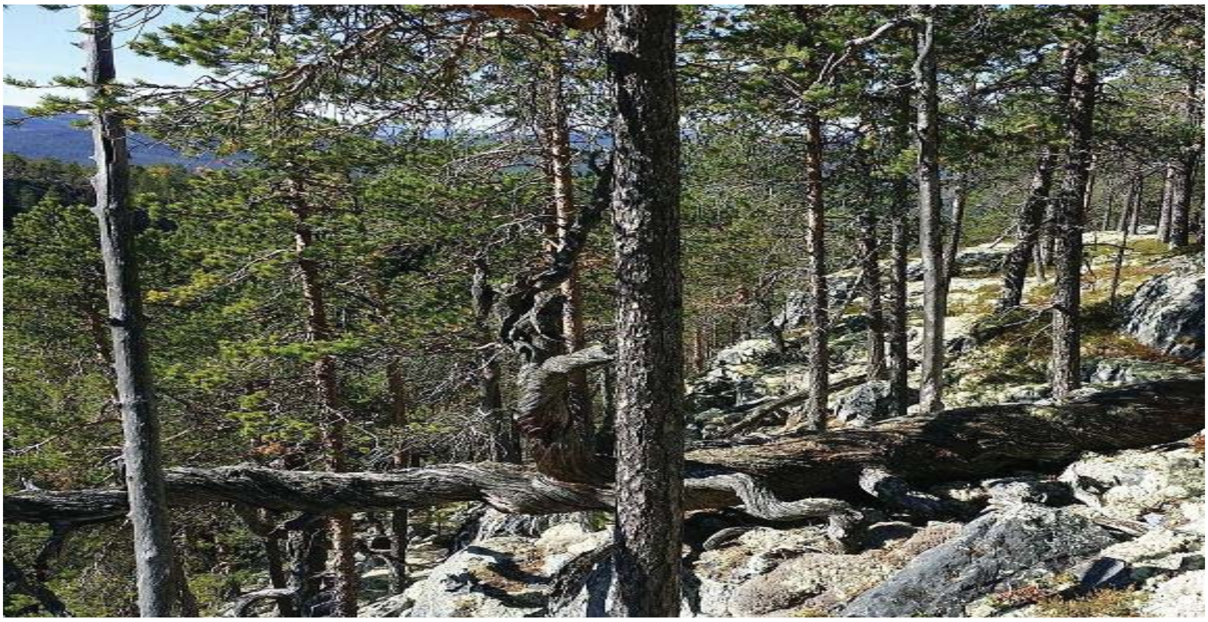

Figure 7: Sample A-13, laying in its original state and position.

Figure 8: Sample A-13, with fire scars and remains of charcoal. Photo: J. Rolstad

Some of the samples had low correlation with the master chronologies, and had to be measured several times before the tree-ring series were successfully dated. This is because of occurrences of missing or false rings, or that the tree-ring pattern is slightly different along another radius of the stem. A missing ring is caused when the tree is under stress, and the ring is only partially formed or missing completely (Novak et al. 2016; Stokes & Smiley 1968). A false ring is when a dark-colored area resembling an annual ring appears and is mistaken for a tree-ring (Stokes & Smiley 1968). In most cases after a closer examination of the sample, the missing or false ring was located and the ring series were dated successfully.

For some samples that had low correlation in COFECHA but with two or more fire scars, the number of rings between the scars was counted, and if there was a match with other samples from the same area in the years between a fire, the difference in time was searched for in the COFECHA output.

Samples with poor correlation and uncertain dates were discarded and labeled as undated.

When a fire kills part of the cambium layer, a fire scar is formed. As the tree starts to heal new wood will grow over the damaged part (Gill 1974). The fire year was determined by studying the fire scar under magnification (LEICA MZ 125), after the sample had been successfully cross-dated. In some cases the season of the fire event can then be estimated by studying where in the actual tree-ring the damage occurred (Baisan & Swetnam 1990). Five categories were used to represent the season date: dormant (D), early earlywood (EE), middle earlywood (ME), late earlywood (LE), and latewood (LW). By averaging the individual dated scars a fire season index was calculated, between 1 (dormant) and 5 (latewood). Unknown (U) was used for fire scars where it was not possible to determine season.

There are several reasons why a fire event is not necessarily located in the wood, there are various factors that can cause this. The fire may have had a low intensity not damaging the cambia at all (Piha et al. 2013), the injury may have burned away in a later fire, or it may have disappeared due to decay. However other signs of the fire event can appear. Applying morphological studies of the wood, indicators of fire can be resin ducts or growth depression in the following tree-rings (Brown & Swetnam 1994). In the current study, such signs were applied only in cases where other nearby samples had unambiguous fire scars in the same year.

5.0 Results

Samples of 74 individual logs, snags, and stumps were collected, and 65 of these were successfully dated (Tab. 1). There was a total of 38 different fire years, and 170 fire-scars were dated. The oldest fire was from 1079 and the most recent from 1839. The dated time span was from 974 to 2016, which gives a total length of 1043 years. Pith was present in 28 of the 65 samples, including the oldest sample (Fig 6). The time-frame for each individual sample does not necessarily represent the total life span of the trees, because in many of the samples several inner and outer rings were missing due to decay. In this thesis, it was not attempted to estimate the germination year of the samples, or to estimate the exact year of death. Sample A-13, cut from a fallen tree, had oldest ring in 1042 and youngest ring in 1762 giving a time span of 721 years, with 7 dated fire scars (Fig. 7, Fig. 8). The exact year of germination and death was not dated due to decomposition.

Tabell 1: Number of collected and successfully cross-dated samples, fire-years and fire-scars in the different sites.

	Site A Vibekk-skaret	Site B Jegersborg	Site C Elghud-kletten	Site D Stein-dammen	Site E Rokksætra	Total
Number of samples collected	15	13	17	13	16	74
Number of samples dated	14	11	16	13	11	65
Period dated	974 - 2016	1313-1777	1098-2016	1262-2016	1375-1815	974 - 2016
Number of fire-years	14	8	9	13	9	38
Number of dated fire-scars	41	19	45	35	30	170

Site A covers the longest time-period from 974 to present, with a total of 1043 years. The oldest fire is recorded in 1079 and the youngest in 1839 (Fig. 6). The fire years are quite evenly distributed over the time period with approximately 1 to 2 fires every hundred years, with a small peak of three fires in the 1500s, and a slow decrease in fires from the 1700s. This site has the highest number of fires recorded.

Site B has its first fire in the 1300s and after that it burns once about every hundred years, with a peak of five fires from approximately 1650 to 1750 (Fig. 6). The data covers the period 1313 to 1777 giving a time span of 465 years with 8 different fire years.

Site C covers a time span from 1098 to present (Fig. 6). The first fire was from 1137, and there are one to two fires every hundred years. The distribution of fires is uneven, with a gap where no fires were recorded between 1350 and 1550. Then the fire frequency evens out with one to two fires every hundred years. The most recent fire was recorded in 1741.

The oldest sample from site D was from 1262, while the first fire recorded is in 1446, 182 years later. There are 13 fires from about 1450 to the late 1700s and no fires were identified after 1794. The total time period dated is from 1262 to present.

Site E is the site with the shortest dated time period, from 1375 to 1815 giving it a total of 441 years. It burns once or twice every hundred years until the late1600s.

Most samples collected were from the 1500s to about 1700 (Fig. 6, Fig. 7). All the sites had samples dating from before the 1400s, the majority coming from site A. Only a few of the samples were from before 1100, and only one fire was recorded in that time period, found in three different samples from site A.

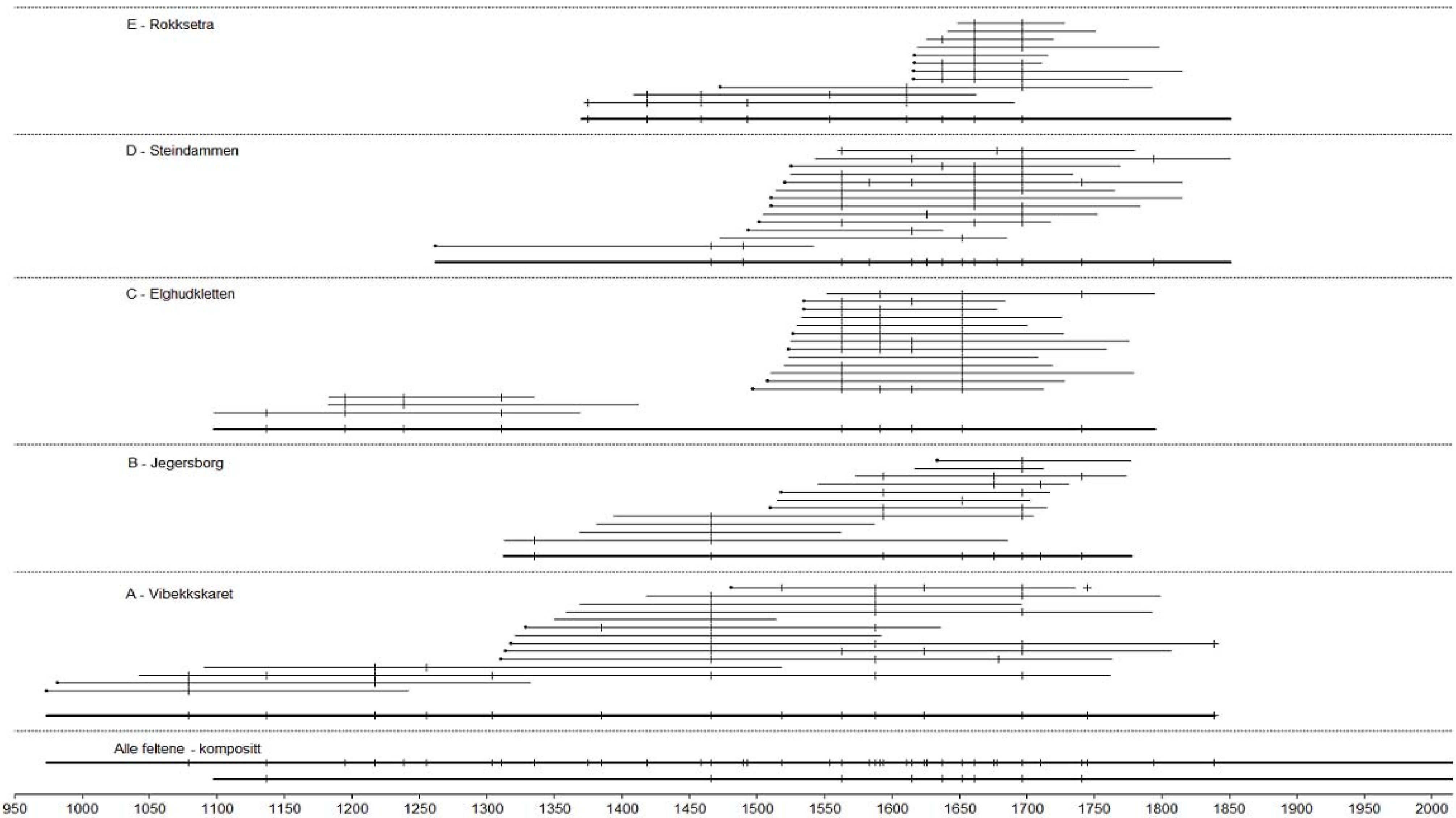

Figure 6: Time span (horizontal lines) and fire years (vertical marks) of all the dated samples. The two thick lines at the bottom, sums up the dating period, and fire years found in all sites (upper), and in two or more sites (lower). The samples are sorted by dating period within each site (A-E), and sites are divided by horizontal dotted lines. The dot illustrates that a pith was present in the sample

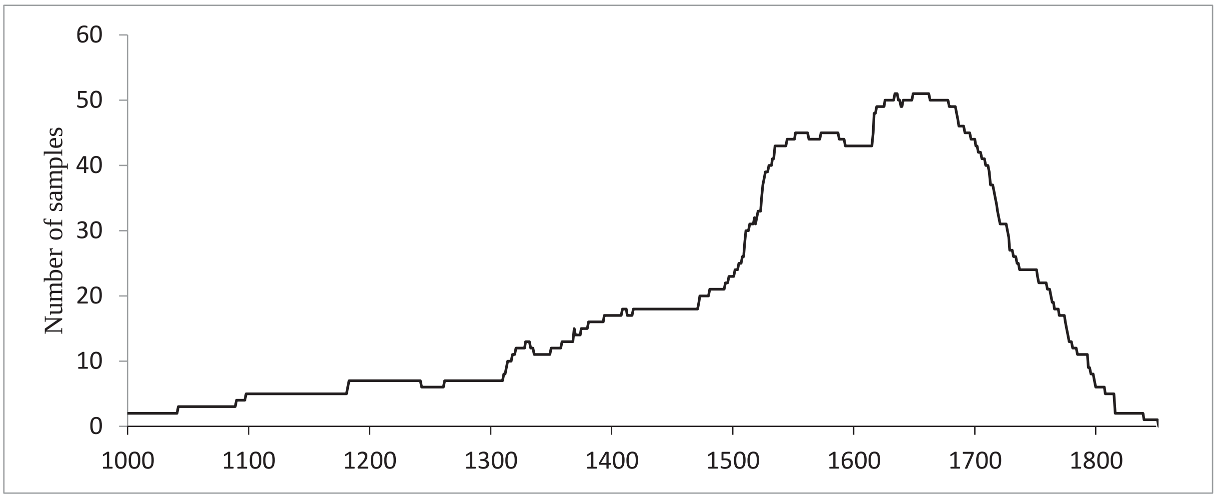

Figure 7: Timeline of number of samples dated.

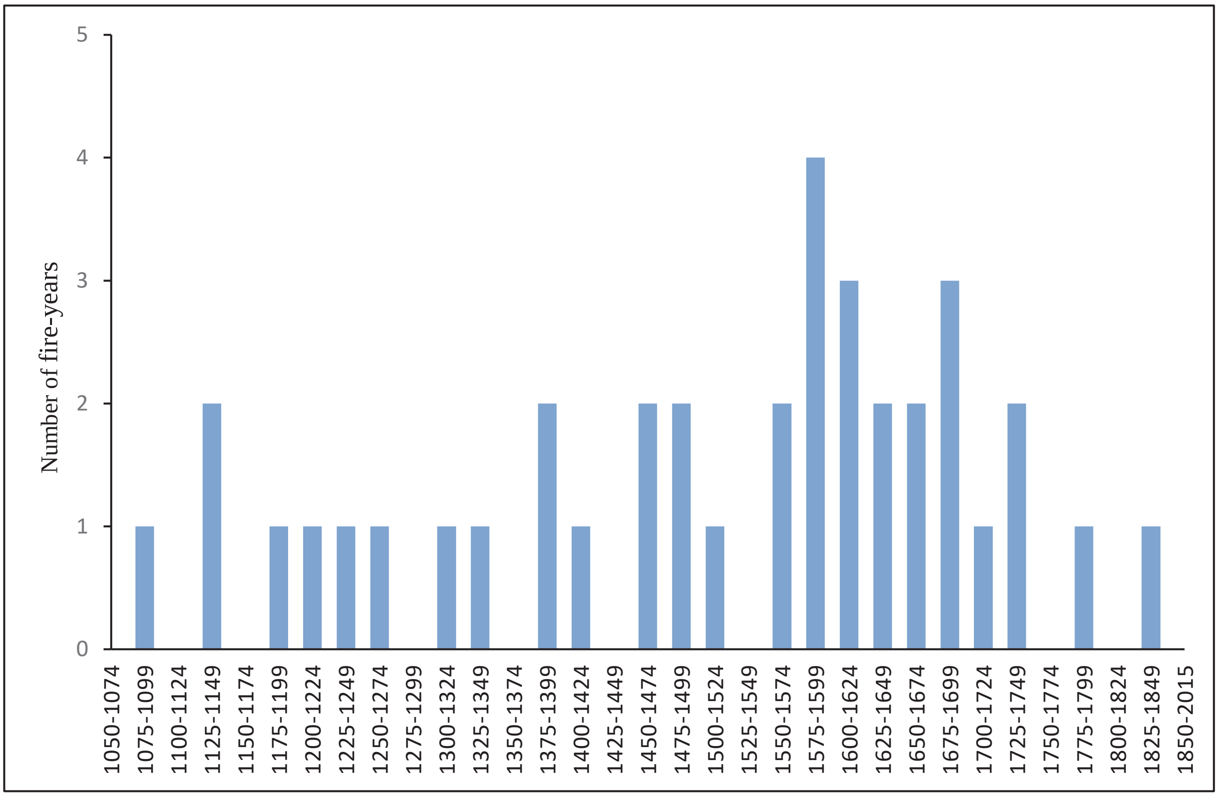

Figure 8: Total number of fires-years, divided in 25-years periods.

There is an uneven distribution of fires throughout the study period (Fig. 8), and it appears that there has been an increase in number of fires from the 1550s to the 1750s, this is however in accordance with the period with the highest number of samples (Fig. 7). The following years after that, the number of fires dropped, and there is only recorded one fire after 1800.

Fire years showing up in more than one site can indicate the extent of the fire. Out of all fire years dated, nine (24%) of these appeared in more than one sampling site. This indicates that there were larger fires those years, or that there were many fires that year. Four fire years were present in three different sampling sites, (1466, 1563, 1652 and 1741). Whereas the 1697 fire was found in four sites, (Tab. 2, Fig. 6). Most of the fire years occurring in several sites were also found in many of the individual samples, e.g. 1466, 1563, 1661 and 1697.

The fires recorded in multiple sampling sites were distributed through the whole-time period, with the oldest in 1137 and the most recent in 1741. In the 1600s there were five fires found in more than one sampling site, about every 15-20 years.

Table 2: Fire years recorded in more than one sampling site.

Fire-year	**A**	**B**	**C**	**D**	**E**
1137	X		X		
1466	X	X		X	
1563	X		X	X	
1615			X	X	
1637				X	X
1652		X	X	X	
1661				X	X
1697	X	X		X	X
1741		X	X	X	

5.1 Fire intervals

Single sample intervals show the years between two different fire scars in one sample. Samples with two or more scars are presented in Fig. 9 and Fig. 10. Fire interval is the number of years between two fires at a specific site or in a sample, and is a measure of how often a fire returns to the same area. There is a tendency of longer fire intervals in the data before 1575, with the highest number of intervals at 120-139 years (Fig. 9A). After 1575 (Fig. 9B), the fire intervals have shifted with the highest number between 20-39 years. However, these bars are strongly affected by one interval between two fire years being repeated in many samples, e.g. between 1661 and 1697 in sites D and E (Fig. 6).

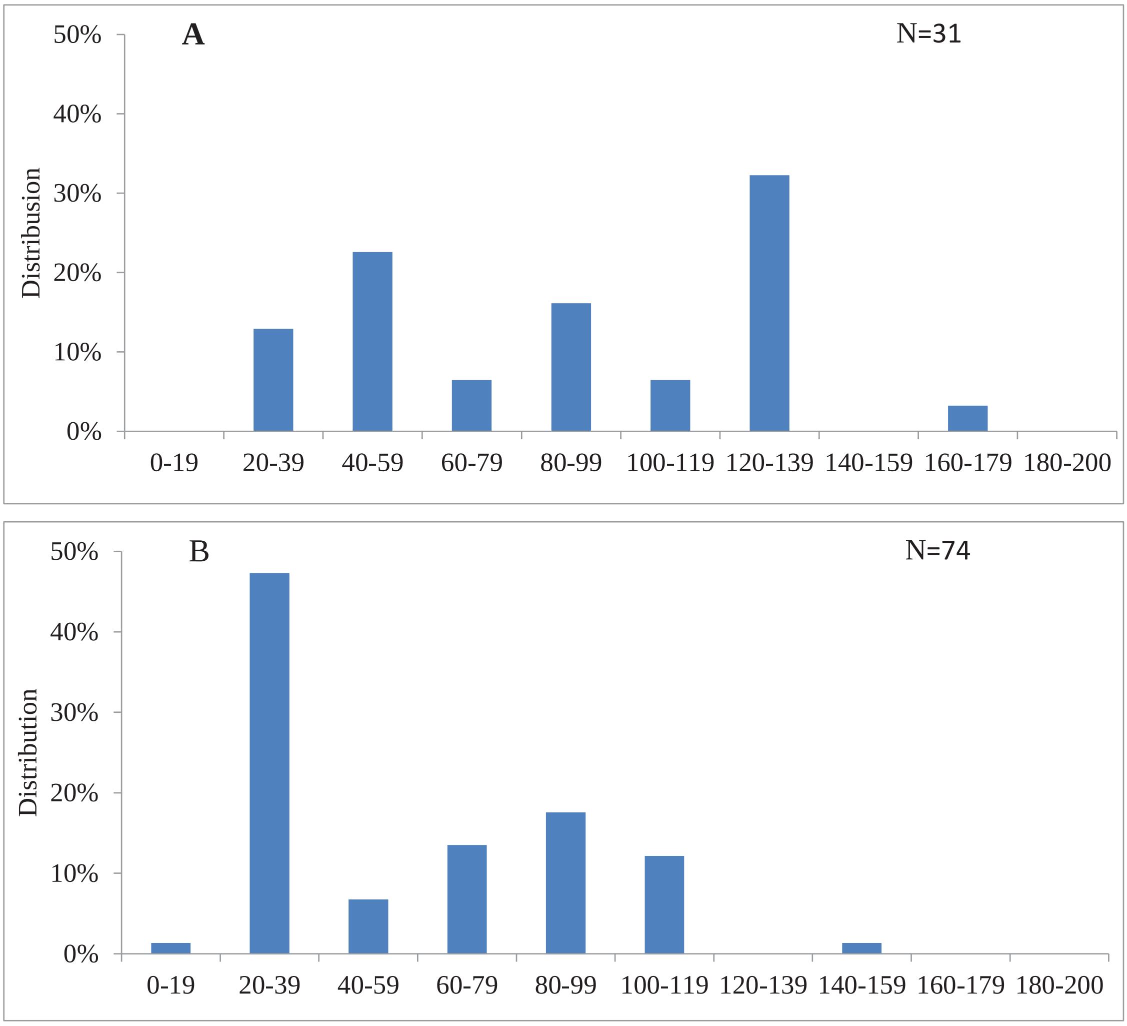

Figure 9: Distribution of fire intervals, (A) pre- 1575, and, (B) post 1575.

The trend in fire intervals over time show a moderate decline. After performing a simple linear regression, to see if there is a connection between the fire intervals over time, the results were: p = 0.073, β = -0,046, R^2 = 0.0308, n = 105. The MFI (mean fire intervals) went from ca. 80 years before 1550 to ca. 60 years after 1550.

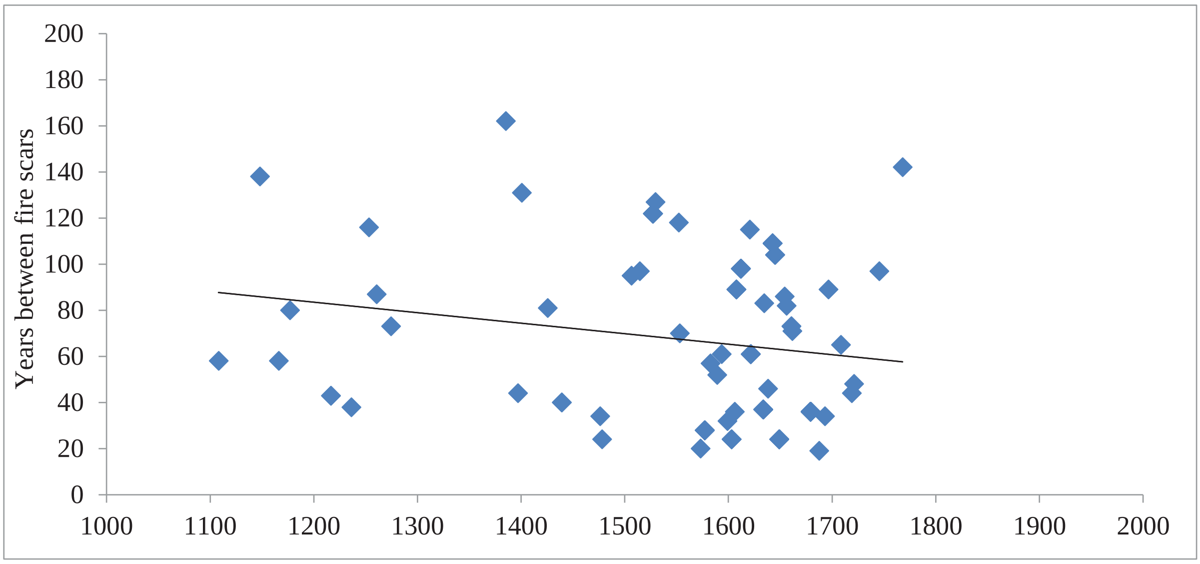

Figure 10: Intervals between fire scars in individual samples over time.

5.2 Season

91 of the fire scars were dated to season (54%), the oldest from 1137 and the most recent from 1697. There were fires during the whole growing season (Fig. 11), however the majority occurred in middle early (ME) and late early (LE). Only two fires were dated to the dormant (D) season (Fig. 12).

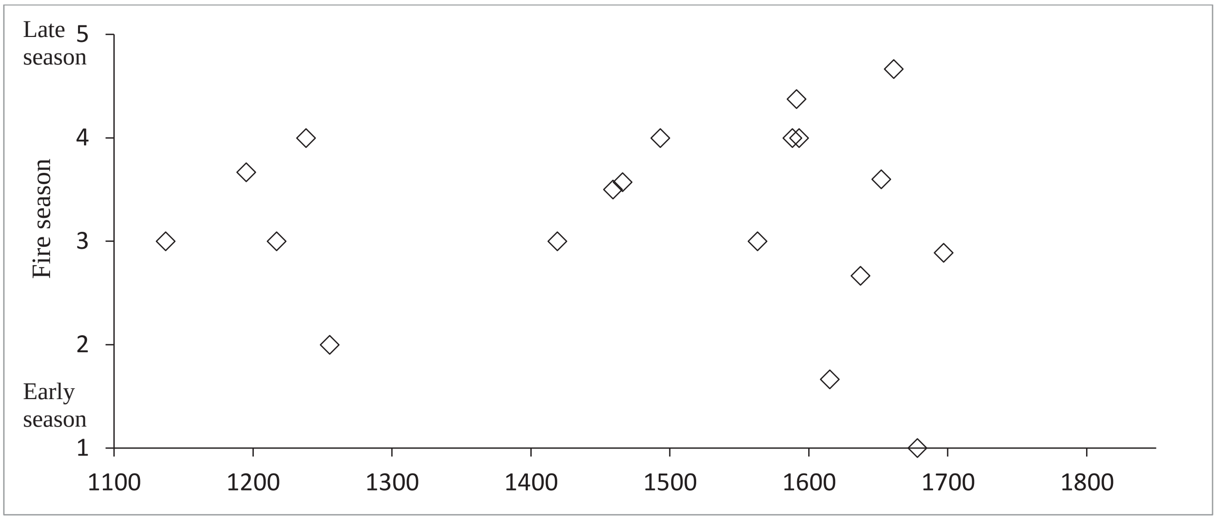

Figure 11: Fire season index values (1 corresponds to dormant season and 5 corresponds to latewood season) for each individual fire that was season dated (n = 19).

There was no clear trend in fire season over time (p = 0.90, β = -0,00015, R^2 = 0.0009, n = 19. (fig. 12)), however a slightly wider distribution of fire seasons were present after 1575. Between 1255 and 1419 only five fires were recorded, of which none were dated to season.

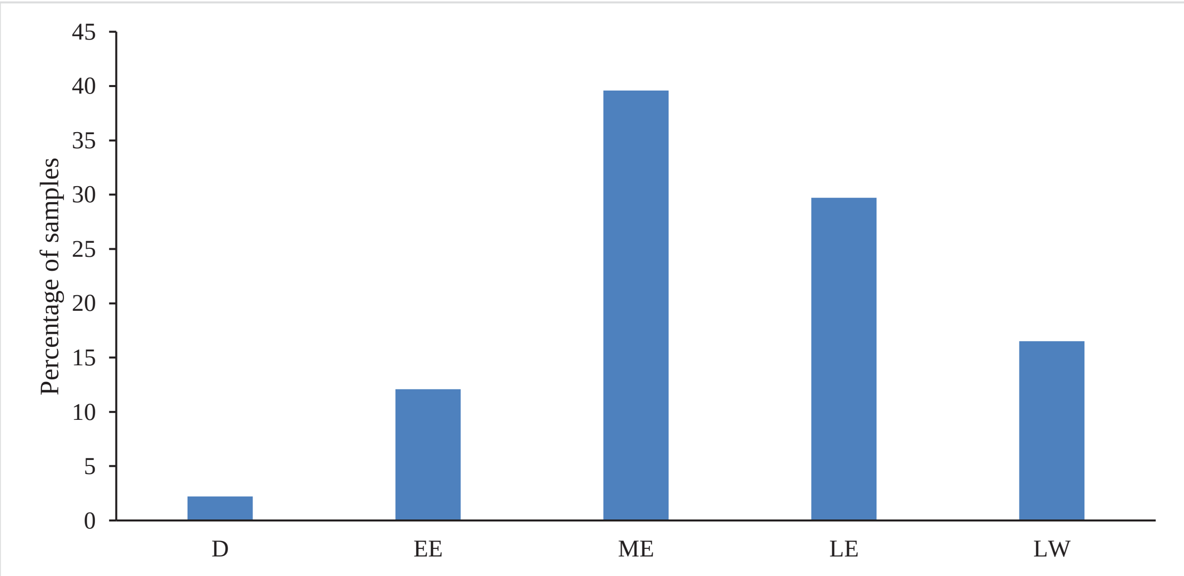

Figure 12: Percentage of fire scars in different season categories (n = 91).

6.0 Discussion.

This study documents forest fire history and fire regime in the Tresdalen area over a time span of >1000 years. The study shows that forest fires have occurred on a regular basis in the Tresdalen area since the oldest fire documented in 1079 and that fires have been a major factor forming the forested landscape. The data collected gives the possibility to reconstruct fire frequency and to some degree fire extent. There are some limitations to the dataset as there are few samples collected dating after 1800. This limits the interpretation to some extent, but some logical conclusions can be made. The fires have varied both in size and season throughout the period. Fire frequency increased somewhat from about 1575 to the 1700s. However, most of the data collected fell within this period, indicating that the increase in fire frequency partly is a result of the increased sample size.

6.1 Fire frequency

The major causes of change in fire regime are human activity (e.g. Lehtonen & Huttunen 1997) and climatic variation (e.g. Swetnam 1993). In this study, the results are not conclusive to neither. There are no clear signs of fire regime shifts being caused by human interference.

Natural fire regimes are dominated by few fires that burn over large areas with higher intensity (Johnson 1992). Human set fires on the other hand, tend to be smaller in scale, possibly due to more moist weather conditions, less fuel on the ground in the form of dry vegetation, and active fire suppression (Granström & Niklasson 2008).

Several studies (Lehtonen & Huttunen 1997; Niklasson & Granström 2000; Rolstad et al. 2017; Storaunet et al. 2013) have showed a connection between fire frequency and human settlements in Fennoscandia. The general pattern, being a shift from larger, fewer, natural driven fires before the 1600s, to an increased number of smaller fires between the 1600-1800s, and with almost no fires from the 1800s to present day, though these years differ some in the different studies. This however is not apparent in the data as the fires are more evenly distributed throughout the whole period (Fig. 8). It also appears that larger fires have occurred throughout the period.

6.2 Fire intervals

Fire interval is the number of years between fires at a specific site, and is a measure of how often a fire returns to the same area. There is an apparent shift in the fire intervals from ca. 1575 (Fig. 9), with longer intervals before 1575, and shorter intervals after 1575. However, many of the individual samples had the same two fires recorded, thereby causing them to be overrepresented in the chart.

The results display small gradual decline in the fire intervals over time. However, the sample size is smaller before 1550 compared to after 1550 and this affects the outcome. The results indicate that fire intervals have shortened some over time, but there is no clear sign indicating human influence, compared to other studies where fire intervals have been very different before and after the 1600s (e.g. Rolstad. et al 2017).

6.3 Season

The results showed no clear trend in fire season over the time period. There is however a slightly wider variation of fire seasons in the 1600s compared to the previous centuries.

Number of lightning strikes is highest in south-eastern Norway in June-August, with the majority in July and August (Rokseth et al. 2001), i.e. late in the growing season. Niklasson and Drakenberg (2001) discuss that fires in spring and early summer were more likely to have been anthropogenically caused. This is possibly due to fires being more easily controlled this early in the season. The results from other studies on fire -history in Fennoscandia show a relatively sudden appearances of numerous early season fires in the 1600s (e.g. Rolstad et al. 2017; Storaunet et al. 2013). Niklasson and Drakenberg (2001) found the same pattern in the 1700s as did Groven and Niklasson (2005) for the 1500s. In this study however, most of the fires throughout the period were in middle or late season.

It is possible that the fires that occurred in the Tresdalen area were for the most part natural. This is most likely the case with the fires before the 1600s, as the area was poorly populated. There is no clear shift in fire season after 1600s, even though people have been using the area for forestry, summer farms, and pastures for centuries. Thus, the results of this study show no clear trend toward a significant human influence.

6.4 Possible causes for lack of fires after 1800.

There has been a lack of fires from the 1800s up to present day, as we found only one sample with a fire scar from after 1800, dating to 1839.

The area has been influenced by commercial forestry since the 1600s (Brænd 2016), and we found many remains of cut trees and stumps. From historical records, it appears that the local farmers did their outmost to prevent forest fires from the early 1700s (Fosvold 1936). This could be an explanation as to why few samples were found and subsequently few fires from the 1700-1800s. Another reason could be that the logging in the area may have caused a landscape with little fuel in the form of flammable material on the ground, as this may have reduced the risk of fires. Active fire suppression could be a cause, but in remote areas without the help of motorized equipment this seems unlikely, and if a big fire would occur, there was probably little one could do but wait it out (Wallenius 2011).

There is however a possibility that trees with more recent fire scars have been cut and the stumps have disappeared due to decay. Older trees with multiple fire scars are probably more resilient to rot because of the high amount of resin in the wood, created by the fire events. Younger trees with only one or two scars do not have the same amount of resin and is therefore not as resilient against rot and decay as older trees with multiple scars (K. O. Storaunet, pers. medd. 2017). Another explanation may be that many of the samples did not have the sapwood and bark still present, and many of the outmost rings have decomposed resulting in less information from the later period.

The 1697 fire and possibly also the 1741 fire, seems to have been large fires, as they appeared in 4 and 3 sites, respectively. This could partially explain why the sampling size decreased rapidly from about the 1700. There is a possibility that these fires made way for new growth and regeneration, and that logging in the following centuries left few fire scarred stumps behind that lasted through the centuries without decaying.

There has been some historical documentation of forest fires from the 1800 and 1900s, but no literature or data was found for the same fire years discovered in the field data of this study. In 1882, an area of 30 ha burned between the river Rokka and Tresa (Sæter, Ivar 1908), where two of our sites are located (D and E). There are other fires of varying sizes recorded from the middle of the 1800s as well. There was also a larger fire in 1902 which burned about 230 ha.

In the early 1900s, 25 fires were recorded over a period of 10 years, however most of them were of little significance. Out of the 25 fires,10 were ignited by lightning (Sæter, Ivar 1908). The two first fire-outpost stations in the country were constructed in Stor Elvdal municipality in 1905 and one of them was located in the center of our study area at Månseterkletten 871 a.s.l. (Sæter, Ivar 1908). This indicates that people were actively trying to prevent forest fires, as fires obviously was a threat in the region.

7.0 Conclusion

Dendroecological cross dating of fire scarred samples reveals that fires have been burning regularly in the Tresdalen area. There is most likely a natural fire regime in the area up to the 1800s as there is no clear shift in fire season or fire frequency, although the increase in fire frequency and decrease in fire intervals might indicate a slight human influence from the late 1500s. From the historical records, it's clear that the area was being repopulated in the years following the Black Death, and that the local forest areas were being used as pastures and for logging. There is however no clear connection between human settlements and frequency of fires. There are few records of fires after 1800, possibly due to a combination of legislation, increased logging activity and active fire suppression.

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