Amount and distribution of macroscopic charcoal in soil within a Norwegian boreal forest landscape

Mengde og fordeling av makroskopisk trekull i jord i et borealt norsk skoglandskap

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PREFACE

This is my final 30 credits Master thesis from the Nature Management study at the Agricultural University of Norway.

The thesis is part of the project "Land-use and ecosystem function in Norwegian forest landscapes", which is funded by the Research Council of Norway.

The study area was situated within the forests managed by the commercial company Fritzöe Skoger, and the field work was approved by this company. Fritzöe Skoger was also very helpful in providing me with their maps of the area, general information and a cabin during field work.

I would like to thank my supervisor Mikael Ohlson for his interest in the subject and all advice and criticism during the work. I would also like to thank Carl Henrik Jensen who I shared time with during field work, laboratory work and while writing this thesis. Thanks a lot for the free expression of thoughts, comments and utter bullshit!

At last I would like to thank those who read through my thesis and commented my work: Jo Lian, Magnus Snøtun and Anders Nielsen.

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ABSTRACT

I have used the occurrence of macroscopic charcoal particles ((longest axis ≥ 0.5 mm) in forest soil samples to examine the impact of forest fire and the spatial distribution of past fires in a mixed coniferous forest landscape in the middle boreal zone in southeastern Norway. In total, the amount of macroscopic charcoal was determined in 100 soil samples from 20 10 × 5 m^2 sample plots.

Local impact of fire was registered in all twenty sample plots and 92 % of the examined soil samples contained macroscopic charcoal, which averaged a mass of 1576 kg/ha. I found no correlation between the mass of macroscopic charcoal and the present vegetation composition, or between the mass of macroscopic charcoal and the organic soil depth. Possible reasons for this are discussed. The spatial variation in the distribution of macroscopic charcoal was large both among and within sample plots, and this variability seemed random at small spatial scales, such as between neighboring samples only one meter apart. Differences in number and sizes of fires, fire behavior, fuel accumulation and charcoal sources are suggested as possible explanations for the observed spatial variation in the distribution and amount of macroscopic charcoal.

Both the estimated impact of fire on a landscape level and the estimated average mass of macroscopic charcoal are the largest that hitherto have been documented in Norway, and equaled levels found in Swedish pine forests, which are known to be heavily influenced by fire.

SAMMENDRAG

I denne studien har jeg undersøkt forekomsten av makroskopiske trekullpartikler (lengste akse $\geq$ 0,5 mm) i jordprøver for å finne brannpåvirkningen og utbredelsen av historiske skogbranner i et område med barblandingsskog i mellomboreal sone i Sørøst-Norge. Mengden av makroskopisk trekull ble bestemt i totalt 100 jordprøver, fra 20 prøveflater med størrelsen 10×5 m^2.

Det ble funnet spor av lokal brannpåvirkning i alle de tjue prøveflatene, og 92 % av de undersøkte jordprøvene inneholdt makroskopisk trekull. Den estimerte mengden av makroskopisk trekull var i gjennomsnitt 1576 kg/ha. Jeg fant ingen sammenheng mellom mengden av makroskopisk trekull og den nåværende sammensetningen av vegetasjonen innenfor prøveflatene, eller mellom mengden av makroskopisk trekull og tykkelsen på det organiske jordlaget. Mulige årsaker til den manglende korrelasjonen blir diskutert. Den romlige variasjonen i fordelingen av makroskopisk trekull var stor både mellom og innen prøveflatene, og denne variasjonen virket tilfeldig helt ned på en så liten romslig skala som mellom tilgrensende prøvepunkter, som bare lå en meter fra hverandre. Forskjeller i antall og størrelser på branner, brannforløp, brenselakkumulering og kilder for trekull blir foreslått som mulige forklaringer på den observerte romlige variasjonen i mengden og fordelingen av makroskopisk trekull.

Både den estimerte brannpåvirkningen av landskapet og den estimerte gjennomsnittlige mengden av makroskopisk trekull i området er de største som så langt har blitt registrert i Norge, og disse estimatene var jamførbare med nivåer fra svenske furuskoger, hvor det er kjent at skogbranner har hatt stor innvirkning.

CONTENTS

INTRODUCTION

Forest fires, windstorms, pathogens and individual tree-falls are all natural disturbance agents in forest ecosystems. The boreal forest is the world's largest continuous terrestrial biome, and forest fire has been a major disturbance factor in these systems (Bonan and Shugart 1989). In general, recurring fires are recognized as the most important disturbance factor maintaining forest succession cycles and various forest structures (Zackrisson 1977, Bradshaw et al. 1997). No fires are, however, identical (Schimmel 1993, Schimmel and Granström 1996). It is therefore difficult to generalize about fire impact, but some patterns still seems to exist (see Zackrisson 1977). For example, there is a high degree of variation, both in spatial and temporal perspectives, and fires in the boreal forests of Fennoscandia are often characterized by a small-scale mosaic of burned and unburned areas (Schimmel and Granström 1996, Schimmel and Granström 1997, Niklasson and Granström 2000, Pitkänen et al. 2003b). An observed continuity in the ectomycorrhizal fungal communities following forest fires also indicates the mosaic character and variable effect of fire (Jonsson et al. 1999). In a Norwegian perspective, there seems to be a decreasing fire impact with increasing latitude, but the fire impact and fire history in southern Norway has nevertheless been found to be very variable (Tryterud 2003).

The function of forest fires is both important and complex (Bonan and Shugart 1989). Over time, fire characteristics such as fire intensity, depth of burn, fire frequency, fire size and proximity to other burns constitutes a fire regime (Granström 2001), and differences in fire regimes have been important in maintaining biological diversity in boreal forests (Fries et al. 1997, Ohlson and Tryterud 1999, Granström 2001). Besides creating succession stages important for biodiversity, it has also been shown that the charcoal produced by fire has an important ecological effect due to their adsorptive capabilities (Zackrisson et al. 1996, Wardle et al. 1998, Nilsson et al. 2000, Pietikäinen et al. 2000, DeLuca et al. 2002). Furthermore, particle and gaseous emissions from forest fires may interact with climate dynamics and play an important role in atmospheric carbon cycles (Cofer et al. 1997).

Past forest fire occurrence and fire impact can be identified by analysis of different historical archives, i.e. written sources, fire scars and the presence of charcoal in peat, lake sediments and soil. Written sources are limited to historic time, and they are often short and incomplete (Clark 1988b). Fire scars on living and dead wood (dendrochronology) can be used to document the relative recent fire history with high spatial precision (Niklasson and

Granström 2000). Charcoal deposits in peat and lake sediments, on the other hand, contain information covering the whole Holocene (Patterson et al. 1987, Bradshaw et al. 1997). Though, the layered fire records in these deposits have a somewhat smaller degree of spatial precision as compared with fire scars (Clark 1988a, Clark 1988b, Pitkänen et al.2001). In addition, archives in fire scars, lake sediments and peat are spatially handicapped due to a limited and patchy distribution of useful records, i.e. old-growth forests, lakes and bogs.

The presence of macroscopic charcoal particles in forest soil, however, constitutes a long-term historical archive with high spatial precision (Clark et al. 1998, Ohlson and Tryterud 2000). Although the production and deposition of these particles by forest fires was highly variable at fine spatial scales, almost no macroscopic charcoal was distributed on the outside of burnt areas (Ohlson and Tryterud 2000). The macroscopic charcoal record in forest soils is easily accessible, and investigations can be performed at different spatial scales without being affected by the limitations that influence the availability of the other fire history archives. However, the macroscopic charcoal in forest soils is typically found at the boundary between the mineral and organic soil layers, and no layering occurs. This absence of layering makes identification of separate fire events impossible without the use of radiometric age determination.

The aim of this study is first to determine whether fire has been present or not, as indicated by the presence of macroscopic charcoal in the soil, in a mixed coniferous forest area in southeastern Norway. In addition I will try to uncover the spatial distribution of macroscopic charcoal on a small spatial scale. In order to do this, I have tried to answer the following questions:

- How large proportion of the investigated area has been affected by previous forest fire?
- How large is the estimated mass of macroscopic charcoal in the forest soil?
- Is there any correlation between the composition of the present vegetation and the amount of macroscopic charcoal in the soil?
- Is there any correlation between the depth of the organic soil layer and the amount of macroscopic charcoal in the soil?
- How is the amount of macroscopic charcoal distributed spatially, within sample plots of 5×10 m^2 and between such plots in a landscape perspective?

MATERIAL AND METHODS

Study area

This study was performed in a forest landscape situated in the district of Siljan in the county of Telemark, southeastern Norway (59°22′ N 9°44′ E) (Fig. 1).

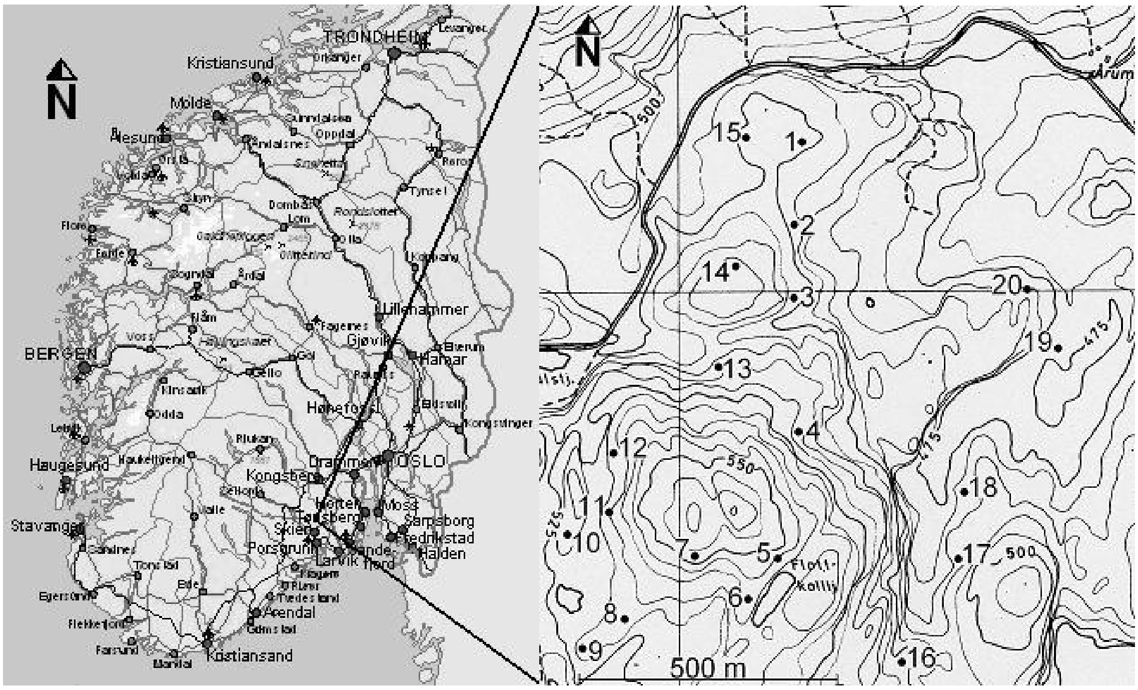

Fig. 1. Survey map of southern Norway showing the location of the study area and a detailed map of the area showing the location of the 20 macro sample plots.

Siljan lies in the southwestern part of the Oslo rift region, and the bedrock consists of intrusive rocks of Permian age, of which Larvikite and Syenite dominates (Pedersen et al. 1995). A thin layer of superficial deposits covers the bedrock (Moen 1999).

The topography within the study area is varied, ranging between 470 and 560 m above sea-level, and the climatic conditions are continental. The average monthly temperature is -5 °C in January and +16.5 °C in July, while the average annual temperature and average annual precipitation is 5.4 °C and 1120 mm respectively. Climate information was obtained from Siljan weather station 10 km south of the study area, at an elevation of 100 m above sea-level.

According to Moen (1999) the area is situated in the middle boreal vegetation zone. However, this part of Telemark is characterized by being a borderland where the transition from the middle boreal zone to the southern boreal and boreonemoral zones occurs over relatively short distances depending on local climatic conditions. The tree layer within the study area consisted mainly of a mixed coniferous forest, where Scots pine (*Pinus sylvestris*) dominated ridges and convex landscape forms, while Norway spruce (*Picea abies*) dominated depressions and concave landscape forms. Nomenclature for vascular plants follows Lid and Lid (1998), and that for bryophytes follow Hallingbäck and Holmåsen (1985). Small bogs were common in the largest depressions which were separated by areas of higher ground, and together this made the overall distribution of forest stands patchy. The forest is owned by the commercial company Fritzöe Skoger and selective cuttings have occurred in the study landscape during the 19th and 20th centuries. All of the sampled forest stands consisted of mature forest (maturity-class V according to the Norwegian silvicultural practice). However, the amount of dead wood within the forest was small (Tab. 1).

In the field layer, vegetation was dominated by *Vaccinium myrtillus*, but also *Deschampsia flexuosa* and other ericaceous dwarf shrubs such as *Calluna vulgaris* and *Vaccinium uliginosum* were frequent (Tab. 1). Vegetation in the ground layer consisted mainly of the mosses *Spaghnum* spp. and *Pleurozium schreberi* (Tab. 1).

Tab. 1. Main features of the study area based on observations from the 20 macro sample plots. Coverage in percent and standard error (SE) are given for dominating species.

Ground layer vegetation	% ± SE	Field layer vegetation	% ± SE	Trees > 1.5 m	% ± SE	Course woody debris	% ± SE
Spaghnum spp.	30.5 ± 5.1	*Vaccinium myrtillus*	27.8 ± 3.4	*Picea abies*	15.5 ± 3.0	*Picea abies*	0.5 ± 0.2
Pleurozium schreberi	13.5 ± 3.8	*Deschampsia flexuosa*	7.3 ± 1.5	*Pinus sylvestris*	2.9 ± 1.5	*Pinus sylvestris*	0.3 ± 0.2
Dicranum spp.	7.8 ± 2.0	*Calluna vulgaris*	6.0 ± 2.0	*Betula* spp.	0.5 ± 0.3		
Plagiothecium undulatum	2.0 ± 2.0	*Vaccinium uliginosum*	4.5 ± 1.5			**Standing dead wood**	**% ± SE**
Ptilium crista-castrensis	2.0 ± 1.6	*Cornus suecica*	1.4 ± 0.9			*Picea abies*	0.8 ± 0.2
Polytrichum spp.	1.7 ± 1.1	*Vaccinium vitis-idaea*	1.0 ± 0.6			*Betula* spp.	0.2 ± 0.1

Visible traces of past fire (charred tree-stumps) were only found in two locations in the southern part of the study area, but another trace was detected on a topographical map. A ridge approximately 2.5 km to the east of the study area is named “The Burned hills”, and this can possibly indicate that fire is not an unknown phenomenon in the region.

Sites for organic soil samples

Within the study area 20 macro sample plots were positioned using a restricted random sampling procedure as described by Økland (1996). Each plot, 5 x 10 m^2, was located according to the following criteria:

- In mature coniferous forest (forest maturity-class V).
- On flat terrain, or preferably on terrain with a slight southern aspect.
- Bog- and swamp-forest sites were rejected.

For all macro sample plots vegetation data and other environmental variables were registered (App. 1). Vegetation type was assigned by using the criteria of Fremstad (1997). The dominating ground layer and field layer species were noted, and their coverage was estimated subjectively. The species and number of all trees > 1.5 m within the macro sample plots were registered, and the total forest coverage over the plots was estimated subjectively. The same applied for dead wood within the plots. At last, each plot's direction of slope was measured with a compass and the slope itself with a clinometer.

Field and laboratory techniques

Within each 50 m^2 macro sample plot five squares of 1 m^2 were randomly chosen and one soil sample was removed from the middle of each square. Before a soil sample was removed, the dominating ground- and field layer species on the spot were noted (App. 2). The soil samples were taken with a steel cylinder, 5.6 cm in diameter, and entire cores from the soil surface down to the underlying mineral soil were sampled (Ohlson and Tryterud 1999). The cores were put in plastic bags in the field, and to avoid oxidizing and darkening they were stored in a freezer until further investigation (Kristoffersen 2002). The depth of the organic soil layer was measured to the nearest cm, by using a soil auger adjacent to all sample points (App. 2).

Before examination the soil samples were thawed at room temperature and then partially dried in a drying oven (Termaks Series TS8000) at 90 ºC for 4-5 hrs. Thereafter, each core was spread out on a platter and thoroughly examined using a magnifier lamp (3× magnification). Macroscopic charcoal (longest axis ≥ 0.5 mm) was hand sorted from each sample. Only completely black and opaque particles with angular broken ends, often with a silvery surface showing wood-cell structures, were classified as charcoal (Ohlson and Tryterud 2000, Pitkänen et al. 2003b). Macroscopic charcoal has been shown to be a reliable evidence of local presence of past fires (Patterson et al. 1987, Hörnberg et al. 1995, Clark 1998, Ohlson and Tryterud 2000, Gardner and Whitlock 2001), even though some macroscopic particles can be transported for longer distances (Clark 1988a, Whitlock and Millspaugh 1996). Data from Pitkänen et al. (1999) suggest that such large particles are either very thin in relation to their largest dimensions or else elongated or even thread-like.

The macroscopic charcoal particles from each sample were collected on glass vials and dried to constant weight for 24 hours at 70 ºC (Drying oven: Termaks Series TS8000). Thereafter, the samples were weighted (Precisa 205 A SCS) to the nearest mg, and the size of the largest charcoal particle in each sample was measured to the nearest mm on a sheet of millimeter-paper (App. 2).

Vegetation classification and statistics

All statistical analyses were performed using the Minitab statistical software (Minitab Release 13.0), and Zar (1996) was used regarding statistical theory. As neither the charcoal weights nor their log-transformed values showed sign of following a normal distribution (Ryan-Joiner W-test for normality on the log-transformed data: p-value < 0.01), I have chosen to use nonparametric statistical methods for all statistical analyses, i.e. Mann-Whitney U-test, Kruskall-Wallis One way ANOVAs and Spearman's rank correlation. Unequal sample sizes and large variation were characteristic for the data material.

A substantial number of macro sample plots were characterized as vegetation types that were transitional forms, representing a total of eight different vegetation types according to Fremstad (1997) (App. 1). In order to perform statistics regarding the vegetation types I simplified the classification. By regrouping the plots using coverage of the field layer species as the separating criteria these eight classes were broken down to four, and as a consequence the number of observations within each vegetation type was raised.

One of the hundred soil samples was an obvious outlier as it contained more than four times as much macroscopic charcoal as the second largest sample (App. 2). This outlier was neither a result of errors done in the field nor in the laboratory, and it probably just reflected the variation regarding macroscopic charcoal distribution on the forest floor. Therefore, this sample was retained in all analyses. However, just to check the outlier's influence on the results the statistics were performed both with and without it, and it did not influence the outcome of any of the tests.

Multiple statistical tests were performed on the data material. This violates the assumption of sample independence. Since “it is generally invalid to employ multiple *t*-tests to examine the difference between all possible pairs of means” (Zar 1996), I have chosen to use a conservative significance criterion. The significance level for the Mann-Whitney U-test and Kruskall-Wallis One way ANOVAs in this study is thus set to $p \leq 0.001$.

RESULTS

All twenty macro sample plots contained macroscopic charcoal (Tab. 2). In total, macroscopic charcoal was found in 92 out of the 100 soil samples. Norway spruce was the most common tree species within the macro sample plots (Tab. 1). Macroscopic charcoal was found in 68 out of 75 sample points in spruce dominated macro sample plots, while 24 out of the 25 sample points in pine dominated plots contained charcoal. Yet, there was only a small difference between the estimated area burnt for plots dominated by Norway spruce and Scots pine, 90.7 % and 96 % respectively. Considering all macro sample plots the estimated area burned equaled 92 %.

Tab. 2. Average amount of macroscopic charcoal for each macro sample plot (Msp) and the minimum and maximum weights within each plot.

Msp	Average weight (g/dm^2)	Min - Max weight (g/dm^2)	Msp	Average weight (g/dm^2)	Min - Max weight (g/dm^2)
1	0.979	0.015 - 2.728	**11**	1.172	0.055 - 4.153
2	0.524	0.000 - 1.536	**12**	2.850	0.012 - 10.958
3	0.993	0.000 - 2.418	**13**	1.328	0.084 - 5.334
4	0.599	0.000 - 1.143	**14**	0.657	0.073 - 2.108
5	0.770	0.052 - 2.427	**15**	0.896	0.091 - 1.424
6	0.337	0.026 - 0.880	**16**	11.346	0.026 - 51.784
7	0.300	0.000 - 0.922	**17**	1.595	0.018 - 3.286
8	0.602	0.000 - 1.109	**18**	0.487	0.000 - 2.009
9	0.293	0.096 - 0.881	**19**	1.616	0.000 - 7.557
10	3.054	0.326 - 4.810	**20**	1.118	0.012 - 5.088

The average weight of macroscopic charcoal for all twenty macro sample plots were 1.576 g/dm^2, which gave an estimate of the total mass of macroscopic charcoal contained in the soil of 1576 kg/ha.

There was no significant relationship between the amount of macroscopic charcoal and any of the vegetation parameters: forest type, vegetation type, field layer- and ground layer vegetation. On average, the spruce dominated macro sample plots contained 1.7 g/dm^2 of macroscopic charcoal, while the pine dominated plots contained 1.1 g/dm^2 (Fig. 2). The difference in the average mass of charcoal in the two forest types was not significant (Tab. 3).

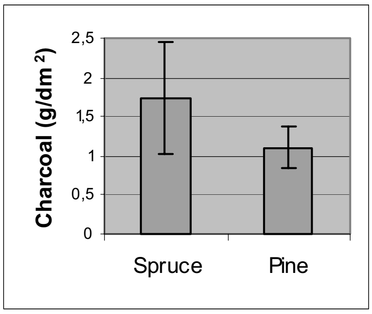

Fig. 2. Average amount of macroscopic charcoal in spruce- and pine dominated macro sample plots. Norway spruce plots: n=75. Scots pine plots: n=25. Vertical bars indicate ± 1 SE.

V. myrtillus-dominated spruce forest (A4a) was by far the most frequent vegetation type among the macro sample plots, but there were also plots categorized as *Vaccinium* spp. woodland (A2), *C. vulgaris – V. uliginosum*-dominated pine forest (A3a) and *V. myrtillus – C. suecica*-dominated spruce forest (A4b) (App. 1). The two *V. myrtillus*-dominated vegetation types contained the largest amounts of macroscopic charcoal, and the *Vaccinium* spp. woodland contained the least (Fig. 3). However, the observed differences in the amount of charcoal from macro sample plots in different vegetation types were not significant (Tab. 3). The regrouping procedure had no effect on the result.

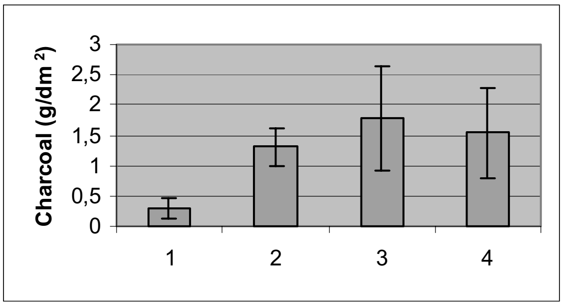

Fig. 3. Average amount of macroscopic charcoal from macro sample plots in different vegetation types (see text for explanations). 1=A2 (n=5), 2=A3a (n=20), 3=A4a (n=60), 4=A4b (n=15). Vertical bars indicate ± 1 SE.

Regarding the field layer vegetation, six species were registered on the sample points plus that there was no field layer vegetation on some spots (App.2). Three of the species (*Empetrum nigrum* ssp., *C. suecica* and *V. vitis-idaea*) were omitted from the statistical analysis because of small sample sizes (n ≤ 3). The sample points which were dominated by *V. myrtillus* contained the largest amount of macroscopic charcoal, while the points with no field layer vegetation contained the least (Fig. 4). Anyhow, the differences in charcoal weights from sample points dominated by unequal field layer vegetation were not significant (Tab. 3).

Tab. 3. Summary of results from statistical tests.

Test	Method	P-value
Macroscopic charcoal vs. Forest type	Mann-Whitney U-test	0.25
Macroscopic charcoal vs. Vegetation type	Kruskall-Wallis One way ANOVA	0.24
Macroscopic charcoal vs. Field layer vegetation	Kruskall-Wallis One way ANOVA	0.34
Macroscopic charcoal vs. Ground layer vegetation	Kruskall-Wallis One way ANOVA	0.82
Organic soil depth vs. Macroscopic charcoal	Spearman's rank correlation	r= 0.196 p= 0.05

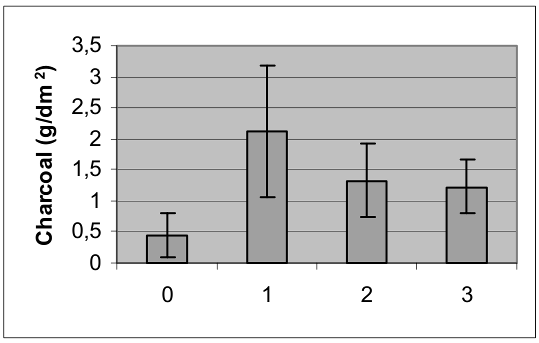

Fig. 4. Average amount of macroscopic charcoal from sample points with different field layer vegetation. 0=No vegetation (n=5), 1=*V. myrtillus* (n=49), 2=*C. vulgaris* (n=10), 3=*D. flexuosa* (n=27). Vertical bars indicate ± 1 SE.

In the ground layer, six mosses were registered on the sample points plus that there was no ground layer vegetation on some spots (App. 2). One of the mosses (*Hylocomium splendens*) was omitted because it was only growing on one of the sample points. Sample points dominated by *P. schreberi* contained the largest amount of macroscopic charcoal, while points dominated by *P. crista-castrensis* contained the least (Fig. 5). These were also the most and least frequent mosses on the sample points respectively. Furthermore, the samples from spots without any ground layer vegetation also contained much charcoal, but in total the differences among the unequal ground layer vegetation were not significant (Tab. 3).

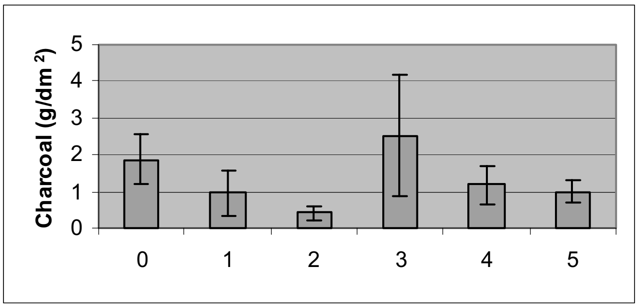

Fig. 5. Average amount of macroscopic charcoal from sample points with different ground layer vegetation. 0=No vegetation (n=12), 1=*Polytrichum* spp. (n=5), 2=*P. crista-castrensis* (n=5), 3=*P. schreberi* (n=31), 4=*Dicranum* spp. (n=22), 5=*Spaghnum* spp. (n=24). Vertical bars indicate ± 1 SE.

For all the soil samples, the amount of macroscopic charcoal was plotted against the depth of the organic soil layer (Fig. 6). Most of the samples were from thin soil and only a few were from soil with a deep organic layer, and due to the large variation in the mass of macroscopic charcoal there seemed to be no correlation between the two parameters (Fig. 6). However, a Spearman's rank correlation test indicated that there was a slight increase in the amount of charcoal with increasing organic soil depth (Tab. 3).

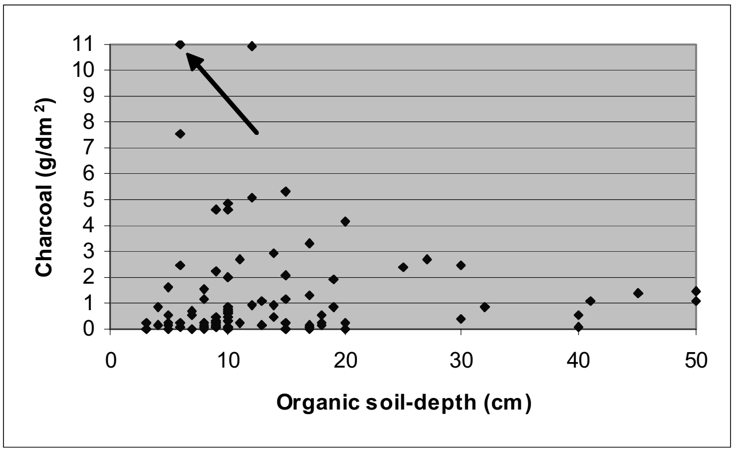

Fig. 6. Amount of macroscopic charcoal plotted against organic soil depth. The arrow marks a value that is out of scale (6 cm, 51.784 g/dm^2).

The most prominent feature concerning the macroscopic charcoal was the high degree of spatial variation regarding the distribution both between and within the macro sample plots (Tab. 2, Fig. 7). For instance, plots 17 and 18 were located in similar vegetation types and only separated by circa 200 meters. Even so, they contained very different amounts of macroscopic charcoal (Tab. 2). In spite of that, the variation within the macro sample plots was apparently even bigger, with the most extreme case in plot 16 where the charcoal weights from individual sample points varied from 0.026 to 51.784 g/dm^2 (Fig. 7). This spatial variation appeared on a small spatial scale, down to a distance of only one meter for neighboring samples. There seemed to be no obvious trend in this variation (Fig. 7)

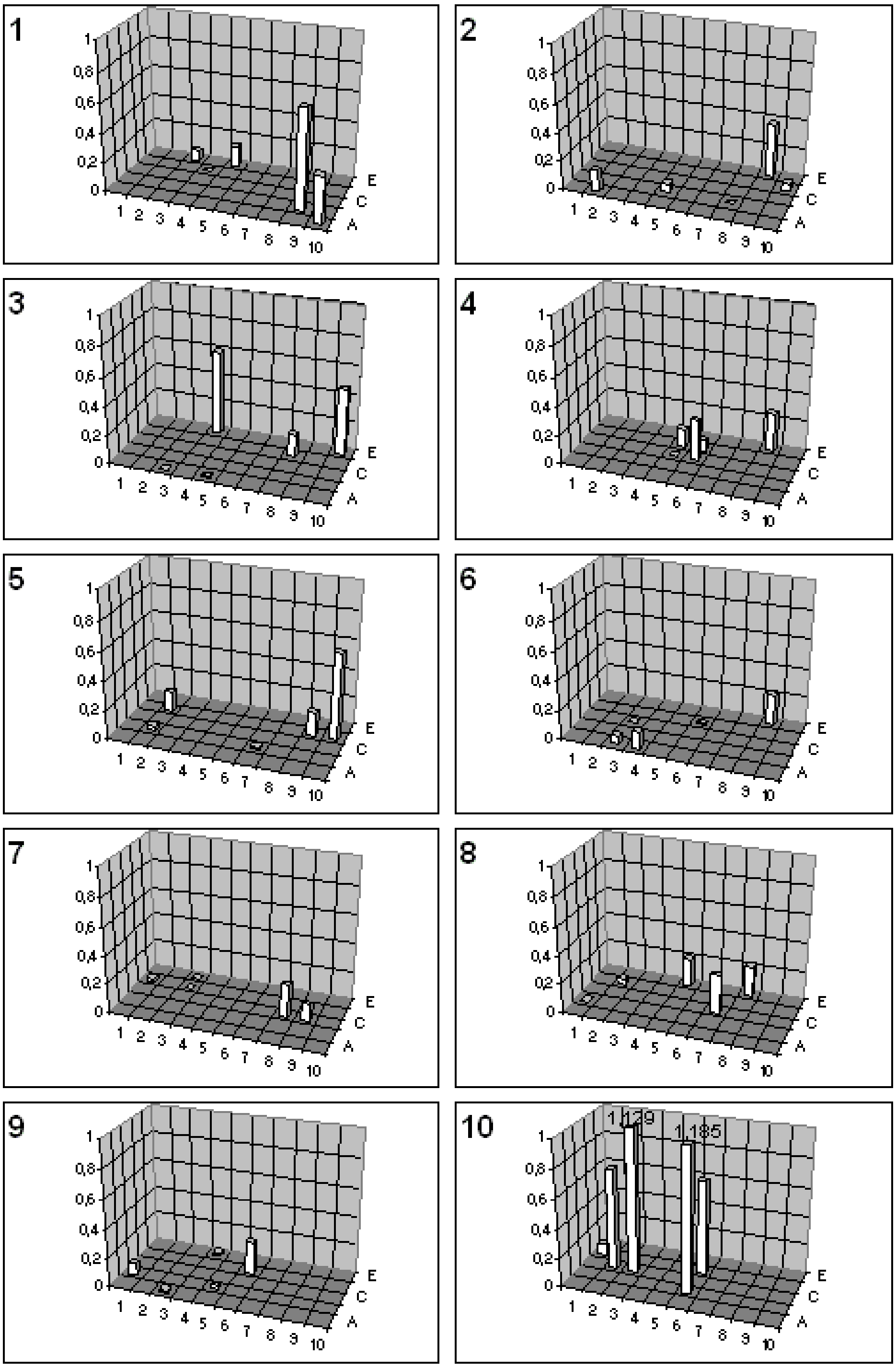

Fig. 7. Spatial distribution of macroscopic charcoal within the 20 macro sample plots (numbered 1-20). The X- and Y-axis (dark grey) represents the division of the sample plots. The Z-axis (light grey) displays the amount of macroscopic charcoal for each sample in grams. The diameter of the sampler (steel cylinder) was 5.6 cm.

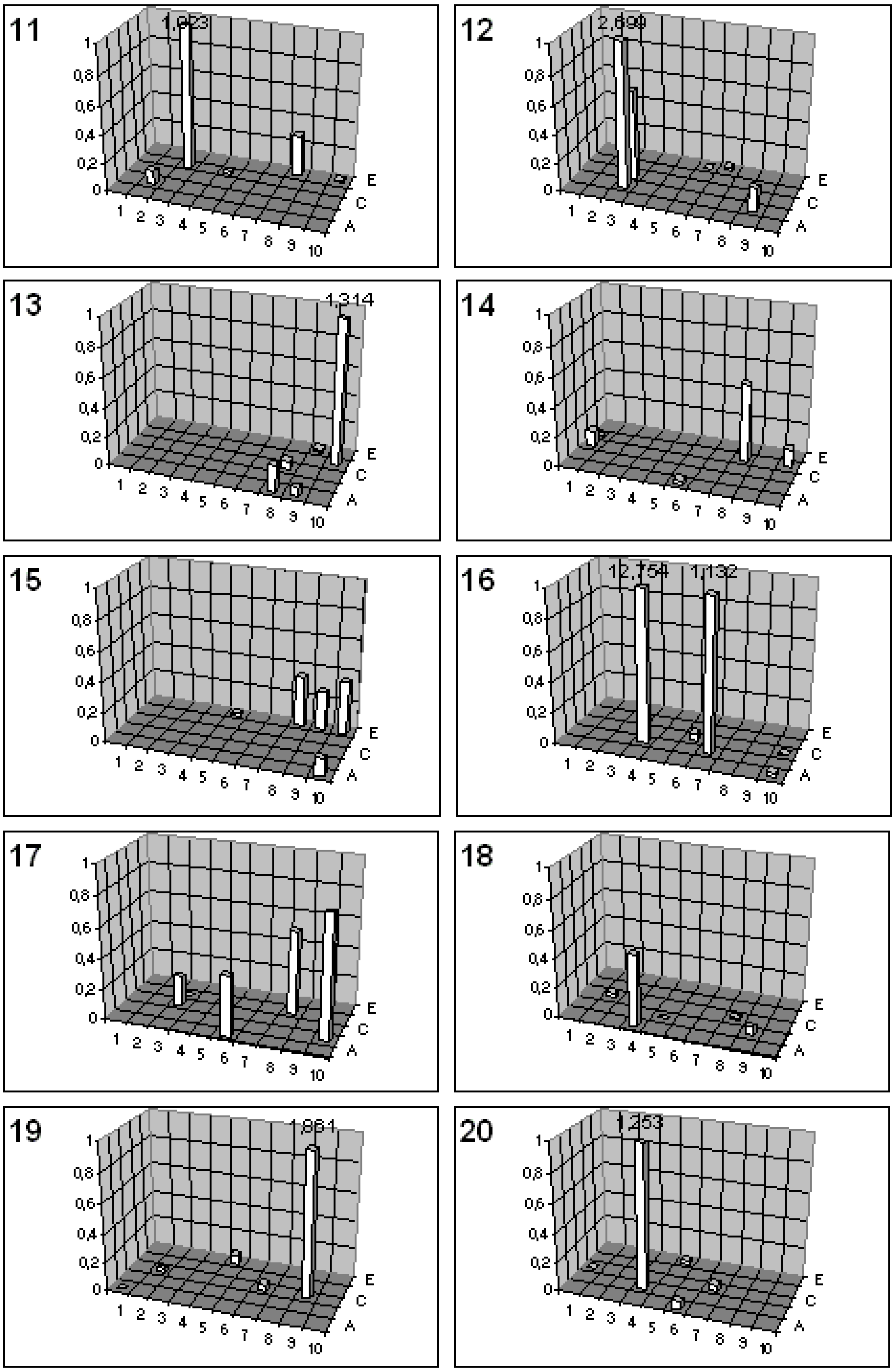

Fig. 7. Continues.

DISCUSSION

In the discussion I focus on the four following results of this study:

1. Forest fire has been a major disturbance factor in the study area.
2. There was no correlation between the amount of macroscopic charcoal in the soil and the composition of the vegetation.
3. There was no clear relationship between the organic soil depth and the amount of macroscopic charcoal in the soil.
4. There was a high degree of spatial variation both between and within the macro sample plots regarding the distribution and amount of macroscopic charcoal.

Forest fire impact

All 20 macro sample plots contained macroscopic charcoal, and it was estimated that 92 % of the studied mixed coniferous forest landscape was affected by previous fire (Tab. 2). A study from northwestern Russia in a natural middle boreal landscape dominated by *P. abies*, found traces of past fires in 65 % of the studied plots (Wallenius 2002); while in the northern boreal landscape of Reisa National park in northern Norway, 38 % of the investigated area was affected by fire (Kristoffersen 2002). Wallenius (2002) distributed the study plots randomly, while Kristoffersen (2002) used a method identical to the restricted random sampling procedure in this study, though with more general criteria regarding positioning of the macro sample plots.

Compared to these earlier findings this implies that forest fire has been a major disturbance factor in the study area. In fact, even more than 92 % of the area may have been affected by fire, because an absence of large charcoal particles does not necessarily mean that an area has not burned (Ohlson and Tryterud 2000). Ohlson and Tryterud (2000) documented that 14 % of the charcoal traps within a burn-area did not contain macroscopic charcoal. However, the area affected by fire was probably an overestimation in the first place; as the location of the macro sample plots was done following a set of criteria, which would exclude the areas least possible to be affected by fire. Zackrisson (1977) found that the hydrological conditions were very important in relation to fire frequency, and that forest stands on convex landscape features or south-facing slopes burnt more frequently than those on concave ones or on north-facing slopes. Therefore, I probably have an over-representation of burnt plots in my selection, which possibly may explain some of the difference between my estimate and the estimates of Wallenius (2002) and Kristoffersen (2002). Nonetheless, forest fire has been present almost everywhere in the studied landscape.

The mass of macroscopic charcoal averaged a value of 1576 kg/ha. Kristoffersen (2002), in her study from northern Norway, found the mass of macroscopic charcoal to be 360 kg/ha in pine dominated forest and 180 kg/ha in birch (*Betula* spp) dominated forest. Zackrisson et al. (1996) documented the mass of charcoal on an area basis in twelve natural pine stands within the northern boreal zone of Sweden. They found that the mass of charcoal from these sites was in the interval from 984 to 2074 kg/ha. The results from Kristoffersen (2002) and Zackrisson et al. (1996) included all charcoal within soil samples, but it has also been shown that single fire events can produce massive amounts of charcoal. An experimental high-intensity stand-replacing fire in a pine forest in west-central Siberia produced an estimated amount of 729 kg/ha of airborne particles (Clark et al. 1998). Ohlson and Tryterud (2000) estimated the average fire-specific production in three quite high-intensity experimental forest fires in representative boreal forests, and found that the production of charcoal ≥ 0.5 mm was 207, 257 and 163 kg/ha respectively. In addition, Ohlson and Tryterud (2000) found that the weight of macroscopic charcoal gave a good estimate of the total amount of charcoal in the soil, since 94 % of the mass of charcoal in the experimental burns were contained in charcoal larger than 2.0 mm.

I have found an amount of macroscopic charcoal that is comparable to the amount found in Swedish pine forests, which are known to be heavily influenced by fire (Zackrisson 1977). The findings also correspond well with the opinion that forest fire has been of greater impact in the southern part of the boreal zone than in the northern part (Sarmaja-Korjonen 1998, Tryterud 2003). The amount of macroscopic charcoal was large both in a Norwegian and Scandinavian perspective. Considering that most of the forest fires investigated in Fennoscandian boreal forest have been relatively small ground-fires of low and medium intensity (Zackrisson and Östlund 1991, Schimmel 1993, Schimmel and Granström 1997, Niklasson and Granström 2000) and that Ohlson and Tryterud (2000) estimated an average charcoal production of 235 kg/ha in their three experimental fires, it is very likely that forest stands within the study area have experienced more than one fire during the Holocene. Although the charcoal production estimate of Ohlson and Tryterud (2000) only was an example of the production of charcoal during fires in boreal forests, the difference between this figure and the amount of macroscopic charcoal found in the study area is so large that I think it is legitimate to assume that multiple fires have occurred.

Charcoal, vegetation and soil depth

I found no correlation between vegetation and the mass of macroscopic charcoal, neither regarding ground layer vegetation, field layer vegetation, vegetation type nor forest type, and the Spearman's rank correlation test indicated a slight increase in the amount of charcoal with increasing depth of the organic soil layer (Tab. 3). Zackrisson (1977) documented that forest of lichen – *Calluna* type burnt more frequent than forests of *V. vitis-idaea* and *V. myrtillus* type, and all of these forest types burnt much more frequent than mesic forest. According to this most of my macro sample plots were situated in rather fire exposed vegetation and they did not reflect a dry – wet gradient. Furthermore, long-term fire history studies covering the whole Holocene have revealed that both climate and vegetation have changed multiple times during this period, and that fire regimes have not been constant (Segerström et al. 1996, Segerström 1997, Pitkänen 2000, Granström 2001, Pitkänen et al. 2001, Pitkänen et al. 2002, Pitkänen et al. 2003a). One obvious indication of this is the well defined change in fire frequency that occurred following spruce establishment in Norwegian sites. An abrupt decline in fire frequency has been documented in conjunction with the local establishment of Norway spruce in investigated areas (Smedstad 1997, Ohlson and Tryterud 1999, Korbøl 2000, Tryterud 2000, Tryterud 2003). With respect to this, and since charcoal probably is very persistent in the forest soil (Zackrisson et al. 1996, Cofer et al. 1997); there was no surprise that a correlation between macroscopic charcoal and vegetation could not be detected from the soil samples, which actually may cover a substantial part of the Holocene fire history.

Regarding the correlation between macroscopic charcoal and organic soil depth I expected to find that the amount of macroscopic charcoal should decrease with an increasing organic soil depth, indicating increasing humidity, production and accumulation of organic material. This was not the case, and there can be several explanations for the lack of correlation. Firstly, there were few samples from deep soil, and these therefore had a major influence on the result of the correlation. In addition, most of the study area was only covered with a thin layer of superficial deposits; and as I tried to stay out of the bogs and swamps, the samples from deep soils came from small patches within an area of predominately shallow soils. Pitkänen et al. (2001) found that large bogs only burn over during extremely dry periods, while the areas closer to the edges experiences the same fires as the surrounding forest. Consequently, the areas with deep soil in this study may have experienced the same fire events as the areas with shallow soil; and with respect to this, I could not expect to find any decrease in the amount of macroscopic charcoal with increasing soil depth. It has also been suggested that fires consumes some of the charcoal from previous fire events (Ohlson and Tryterud 2000), and if dry shallow soil was more influenced by fire this might also explain why there was no reverse trend between the mass of macroscopic charcoal and the organic soil depth. Another possibility is that the charcoal has been protected from physical fragmentation, such as freezing and thawing, in the deep soil, and thus has been preserved in the soil (M. Ohlson, pers. comm.). At last, it might be that measuring the depth of the organic soil layer was not a good method to estimate the amount of organic material in the soil; as this method does not take into account the effects of compaction and decomposition, which are fundamental determinants of organic soil accumulation (Økland and Ohlson 1998). It was also difficult to acquire accurate estimates of the organic soil depth by using a soil auger, as it removed quite poor samples from the different soil layers. Therefore, it may be that measures of loss-on-ignition would be a more appropriate method.

I suggest that there was no correlation between vegetation composition and the amount of macroscopic charcoal on a long-term time-scale because climate, vegetation and ultimately fire impact have changed during the Holocene. I also suggest that a possible reverse correlation between the mass of macroscopic charcoal and organic soil depth will not be detected by investigations on as small spatial scales as this. In addition, there are methodological problems with the technique that I have used to estimate the amount of organic material in the soil. Granström (2001) reached a similar conclusion. He concluded that differences in fire frequency between regions typically were much larger than between forest types within a region and that past fire frequencies could not be deduced from the present vegetation types.

Still, some general patterns regarding fire and vegetation composition has been detected on larger spatial scales. Zackrisson (1977) concluded that the forest ground-flora, reflecting the hydrological conditions, appeared to be very important in relation to fire frequency, and that forest fires have had a substantial impact on the vegetation successions occurring in the boreal forests of northern Sweden. Schimmel and Granström (1996) showed that variation in depth of burn had large consequences for the initial succession in typical boreal forest vegetation, and that the effects persisted for many years after a fire. Fire-driven successions have also been documented on historical data from peat and sediment deposits (Franklin and Tolonen 2000, Jasinski and Angelstam 2002). However, these studies focused on the vegetation successions following in a relatively short time-span after fire. Zackrisson

(1977) used a dendrochronological method which only covers a short time-span compared with soil samples, and Schimmel and Granström (1996) investigated the vegetation successions a few years after a fire incident.

It has also been documented that Scots pine has an extraordinary capacity to survive forest fires as compared to Norway spruce, and pine dominated forests generally have been more fire influenced than spruce forests (Zackrisson 1977, Bonan and Shugart 1989, Zackrisson and Östlund 1991, Jasinski and Angelstam 2002). Tryterud (2003) found that the amount of charcoal in pine bog sites showed a figure more than ten times higher than spruce bog sites, indicating that different site types have been influenced by different fire regimes. Some spruce forests, i.e. the spruce swamp forests, have even been considered to be fire-free refugia (Zackrisson and Östlund 1991). However, this view has been modified, because it has been shown that many spruce swamp forests have burnt one or several times (Hörnberg et al 1995, Segerström et al. 1996, Ohlson et al. 1997, Segerström 1997, Korbøl 2000, Tryterud 2003). Moreover, in Finland estimates of average fire interval in pine dominated dry sites and more mesic spruce dominated sites have been found to be fairly similar under natural conditions, contrary to the result of Zackrisson (1977) (Pitkänen 2000, Pitkänen and Grönlund 2001).

Spatial variation in the distribution of macroscopic charcoal

The spatial variation in the distribution of macroscopic charcoal was large both among and within macro sample plots (Tab. 2, Fig. 7), even though the study was performed within a rather limited area (ca 60 ha). This was in accordance with the findings of Kristoffersen (2002) and Jensen (2004) who also documented large spatial variation in the macroscopic charcoal distribution. Ohlson and Tryterud (2000) registered a highly variable number of macroscopic charcoal particles in traps on the inside of newly burnt areas, and the variation occurred at fine spatial scales. Large spatial variation in the amount of charcoal has also been documented on small spatial scales in both peat (Smestad 1997, Korbøl 2000, Tryterud 2000, Pitkänen et al. 2001) and lake sediments (Whitlock and Millspaugh 1996).

On a regional scale, the spatial variation has been shown to be even more pronounced. For instance, the charcoal record in Norway show large latitudinal variation with small fire impact in central and northern Norway and a highly variable influence in the southern part of the country (Tryterud 2003). The same tendency with decreasing amount of charcoal with increasing latitude has also been documented in Finland (Sarmaja-Korjonen 1998). This registered spatial variation has three implications. First of all, multiple fires probably have affected different parts of the study area. Second, fire probably has occurred in a mosaic pattern on small spatial scales; and third, there has probably been spatial variation in both fuel accumulation and charcoal sources.

Between macro sample plots

Although, no correlation between neither forest type nor vegetation type and the mass of macroscopic charcoal was found, there was substantial variation regarding the average mass of macroscopic charcoal among macro sample plots (Tab. 2). The longest distance between any two macro sample plots was just about 1.1 km, and when comparing the average weight of macroscopic charcoal per dm^2 for the separate plots, there was considerable variation over short distances (Fig. 1, Tab. 2).

Positioning of all macro sample plots followed the same criteria that should make them comparable, and therefore differences in physical properties between sample plots were an improbable explanation for the variation between plots. For example, the only macro sample plot that stood out with respect to exposition was plot 20, which had a quite steep north-westerly angle of slope. However, the average amount of macroscopic charcoal in this plot did not stand out from the rest. I think it is most likely that the difference in the amount of macroscopic charcoal among macro sample plots was due to the study area having experienced multiple small-scale fires. These may not have affected all plots equally, because the varied topography might have created fire-breaks. It has been shown that both landscape depressions, bogs, watercourses and previous burnt areas can act as fire-breaks (Schimmel and Granström 1997, Niklasson and Granström 2000, Pitkänen et al. 2003b).

Within macro sample plots

The spatial distribution of macroscopic charcoal within the macro sample plots seemed even more pronounced than between plots. Up till now, little is known about the distribution of macroscopic charcoal on as small spatial scales as this, but the few studies that have been done have all concluded that the spatial variation was large. This has been investigated both on newly burnt sites (Ohlson and Tryterud 2000) and historical data (Kristoffersen 2002, Jensen 2004). Kristoffersen (2002) worked with the same spatial resolution as in this study, while Jensen (2004) documented considerable spatial variation in the amount of macroscopic charcoal on an even smaller spatial scale. He sampled a random selection of some of the sample points used in this study, but removed nine soil samples on a straight line from each sample point. The distance between each soil sample was 15 cm, and there was substantial spatial variation in the amount of charcoal on a decimeter scale (Jensen 2004).

Because the distribution of macroscopic charcoal in forest soil can be used to distinguish between fire-prone and fire-free areas with high spatial precision (Ohlson and Tryterud 2000), one possible explanation for the observed variation might be that fires have been highly mosaic at point scale. Forest fires might possibly have affected some areas and missed other at distances of less than a meter, due to for example micro-topographic and micro-climatic differences (Ohlson and Tryterud 2000). This explanation is supported by Jonsson et al. (1999) who found that low-intensity wildfires in Swedish boreal forest had less effect on the ectomycorrhizal fungal species composition than the effect caused by spatial variation. Moreover, most of the common ectomycorrhizal fungal species tended to be found at all sites affected by fire independent of the time since the last fire, and species-richness did not seem to be affected by wildfire (Jonsson et al. 1999). Another possible explanation is that the large variation on small spatial scales is caused by differences in fuel accumulation and charcoal sources. Burnt wood produce much more charcoal than for instance grass, lichen and mosses (Patterson et al. 1987). In addition, the vegetation composition greatly influences the fire behavior (Schimmel 1993, Schimmel and Granström 1997). Ohlson and Tryterud (2000) suggested that a combination of small amount of fuel, fuel that produced no charcoal and low fire intensity could explain the observed small-scale variability in the amount of charcoal, since the relationship between fuel accumulation and fuel consumption was the key determinant of charred particle production (see Clark et al. 1998). I suggest that a combination of the two presented explanations likely may have caused the observed spatial variation in the distribution of macroscopic charcoal within the macro sample plots.

Even though the spatial variation in the amount of macroscopic charcoal was large on different spatial scales, the general impression of the studied landscape was that fire has had a major impact on this forest. In fact, the amount of macroscopic charcoal and estimated impact of fire, found in this study, are the largest that have been registered in Norway, up till now.

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Appendix 1. Data material from the 20 macro sample plots(Msp) (see text for further explanations).

Msp	Vegetation type (Fremstad 1997) (1)	Ground layer						Field layer								Trees > 1.5 m						Dead wood								Spatial position		
		Dominant species (2)						Dominant species (3)								Norway Spruce		Scots Pine		Birch		Coarse debris				Standing				Axis of length	Slope	Aspect
		1	2	3	4	5	6	1	2	3	4	5	6	7	8							Spruce		Pine		Spruce		Birch				
		%	%	%	%	%	%	%	%	%	%	%	%	%	%	Nr.	%	Nr.	%	Nr.	%	Nr.	%	Nr.	%	Nr.	%	Nr.	%	(˚)	(˚)	(˚)
1	A4a/ A3a	20	20	20	20	0	0	40	10	5	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	10 - 190	3	190
2	A4a	0	50	0	0	0	0	50	5	5	0	0	0	0	0	1	15	1	5	0	0	0	0	0	0	1	1	0	0	130 - 310	10	130
3	A4a	30	10	10	0	0	0	50	0	0	5	0	0	0	0	4	40	0	0	0	0	0	0	0	0	2	1	0	0	120 - 300	8	120
4	A4b	0	50	0	0	40	0	20	0	0	10	15	0	0	0	1	25	0	0	0	0	1	1	0	0	0	0	1	2	104 - 284	4	104
5	A4a	70	0	0	0	0	0	40	0	0	10	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	132 - 312	8	132
6	A4a/ A4b	0	50	0	0	0	0	25	0	0	15	0	0	0	0	2	40	0	0	0	0	1	3	0	0	0	0	0	0	12 - 192	2	192
7	A4a	20	0	10	3	0	0	10	0	0	25	0	0	0	0	3	30	1	10	0	0	0	0	1	2	0	0	0	0	150 - 330	6	150
8	A3a	10	15	10	0	0	0	10	25	15	0	0	0	0	0	2	3	2	2	2	2	0	0	0	0	0	0	2	1	16 - 196	1	196
9	A2/ A3a	20	30	0	0	0	0	20	20	20	0	0	0	0	0	4	15	4	15	2	5	1	1	0	0	1	1	0	0	46 -226	0	
10	A3a	20	0	20	0	0	0	25	20	20	0	0	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10 -190	2	190
11	A4b/ A4a	0	60	0	10	0	0	25	0	10	2	2	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	40 - 220	1	40
12	A4b	5	45	10	0	0	0	10	0	0	10	10	0	0	0	3	30	0	0	0	0	1	1	0	0	0	0	0	0	70 - 250	4	250
13	A4a/ A4b	5	40	5	0	0	10	20	2	0	15	0	4	0	0	2	10	0	0	1	1	0	0	0	0	3	2	1	1	125 - 305	3	305
14	A3a	20	20	20	0	0	0	5	20	5	0	0	0	2	0	1	10	2	25	0	0	0	0	0	0	0	0	0	0	40 - 220	2	40
15	A3a/ A4a	0	50	0	0	0	0	25	15	10	10	0	0	0	0	4	15	0	0	0	0	0	0	0	0	1	1	0	0	174 - 354	1	174
16	A4a/ A4b	10	10	10	0	0	0	65	0	0	5	0	0	0	0	0	0	0	0	1	1	0	0	0	0	2	2	0	0	130 - 310	2	310
17	A4a/ A4b	30	0	30	0	0	30	20	0	0	15	0	0	0	5	4	35	0	0	0	0	0	0	0	0	3	2	0	0	24 - 204	3	180
18	A4a	0	70	10	0	0	0	30	0	0	10	0	0	0	0	2	5	0	0	0	0	1	1	0	0	1	4	0	0	45 - 225	0	
19	A4a	10	50	0	0	0	0	35	2	0	4	0	10	0	0	6	20	0	0	0	0	0	0	1	4	0	0	0	0	158 - 338	2	338
20	A4a	0	40	0	0	0	0	30	0	0	10	0	0	0	0	1	4	0	0	0	0	3	2	0	0	1	2	0	0	148 - 328	10	310

(1) V. type	Description
A2/ A3a	*Vaccinium* spp. dom. forest/ *C. vulgaris* - *V. uliginosum* dom. forest
A3a	*C. vulgaris* - *V. uliginosum* dom. forest
A3a/ A4a	*C. vulgaris* - *V. uliginosum* dom. forest/ *V. myrtillus* dom. forest
A4a/ A3a	*V. myrtillus* dom. forest/ *C. vulgaris* - *V. uliginosum* dom. forest
A4a	*V. myrtillus* dom. forest
A4a/ A4b	*V. myrtillus* dom. forest/ *V. myrtillus* - *C. suecica* dom. forest
A4b/ A4a	*V. myrtillus* - *C. suecica* dom. forest/ *V. myrtillus* dom. forest
A4b	*V. myrtillus* - *C. suecica* dom. forest

(2) Ground layer	
Nr.	**Species**
1	*Pleurozium schreberi*
2	*Spaghnum* spp.
3	*Dicranum* spp.
4	*Polytrichum* spp.
5	*Plagiothecium undulatum*
6	*Ptilium crista-castrensis*

(3) Field layer	
Nr.	**Species**
1	*Vaccinium myrtillus*
2	*Calluna vulgaris*
3	*Vaccinium uliginosum*
4	*Deschampsia flexuosa*
5	*Cornus suecica*
6	*Vaccinium vitis-idaea*
7	*Empetrum nigrum* ssp.
8	*Poaceae nemoralis*

Appendix 2.

Data-material from the 100 sample points (see note 1 – 4 and text for further explanations).

Msp	Sample point (1)	Veg. type (2)	Dominating species		Organic soil depth (cm)	Charcoal weight (g)	Mass of charcoal (g/dm^2)	Largest charcoal particle		
			Ground layer (3)	Field layer (4)				Length (mm)	Width (mm)	Area (mm^2)
1	A10	4	1	1	17	0,324	1,315	5	4	20
	B9	4	6	1	27	0,672	2,728	11	9	99
	D4	4	4	1	5	0,004	0,015	5	1	5
	E3	4	3	1	5	0,064	0,260	6	4	24
	E5	4	3	1	7	0,142	0,576	7	4	28
2	A2	5	0	1	10	0,157	0,637	10	5	50
	B5	5	4	0	8	0,061	0,247	6	3	18
	B8	5	6	3	5	0,000	0,000			0
	D10	5	6	1	8	0,050	0,202	8	5	40
	E9	5	6	1	8	0,378	1,536	11	3	33
3	A3	5	4	0	15	0,000	0,000			0
	A5	5	3	0	15	0,009	0,035	5	2	10
	D8	5	5	5	10	0,155	0,629	7	7	49
	E4	5	4	1	25	0,596	2,418	8	7	56
	E10	5	0	0	19	0,464	1,885	6	6	36
4	C5	8	6	4	20	0,000	0,000			0
	C6	8	6	5	15	0,282	1,143	9	4	36
	D5	8	6	5	18	0,129	0,522	9	4	36
	D6	8	5	4	9	0,064	0,261	6	4	24
	E9	8	6	5	13	0,263	1,069	8	6	48
5	B2	5	0	1	4	0,031	0,127	6	3	18
	B7	5	4	5	6	0,013	0,052	7	3	21
	D2	5	5	1	5	0,139	0,564	5	4	20
	D9	5	4	1	7	0,167	0,678	6	4	24
	D10	5	4	1	6	0,598	2,427	8	3	24
6	A3	6	6	5	15	0,066	0,266	5	1	5
	A4	6	5	1	10	0,119	0,481	6	4	24
	C3	6	6	5	15	0,008	0,030	4	3	12
	D6	6	6	5	17	0,006	0,026	6	1	6
	E9	6	0	1	10	0,217	0,880	7	3	21
7	C8	5	0	1	14	0,227	0,922	6	5	30
	C9	5	4	1	9	0,116	0,471	6	3	18
	D1	5	4	1	8	0,026	0,106	7	5	35
	D3	5	4	5	8	0,000	0,000			0
	E3	5	4	5	10	0,000	0,000			0
8	B1	2	4	3	20	0,000	0,000			0
	C7	2	3	1	41	0,273	1,109	13	7	91
	D2	2	4	3	18	0,045	0,184	6	1	6
	E5	2	5	3	19	0,204	0,829	9	2	18
	E8	2	5	1	12	0,219	0,890	5	4	20
9	A3	1	1	2	10	0,015	0,061	4	2	8
	B1	1	5	1	10	0,081	0,329	5	4	20
	B5	1	4	1	17	0,024	0,096	5	3	15
	D6	1	0	1	32	0,217	0,881	11	3	33
	E4	1	4	2	9	0,024	0,098	3	2	6
10	B6	2	0	3	10	1,185	4,810	8	3	24
	C2	2	4	2	14	0,712	2,889	10	4	40
	C3	2	0	3	10	1,129	4,585	15	12	180
	D1	2	5	1	9	0,080	0,326	6	5	30
	D6	2	4	1	11	0,655	2,658	9	3	27
11	B2	7	4	1	30	0,094	0,380	7	4	28
	D3	7	4	1	20	1,023	4,153	10	6	60
	D5	7	5	1	10	0,021	0,086	4	2	8
	E8	7	5	1	8	0,292	1,185	8	5	40
	E10	7	1	1	40	0,014	0,055	3	2	6

App. 2. Continues.

Msp	Sample point (1)	Veg. type (2)	Dominating species: Ground layer (3)	Dominating species: Field layer (4)	Organic soil depth (cm)	Charcoal weight (g)	Mass of charcoal (g/dm^2)	Largest charcoal particle: Length (mm)	Largest charcoal particle: Width (mm)	Largest charcoal particle: Area (mm^2)
12	B3	8	5	5	12	2,699	10,958	11	9	99
	B9	8	6	4	10	0,164	0,665	4	4	16
	C3	8	5	5	30	0,611	2,480	10	3	30
	E6	8	4	5	7	0,003	0,012	4	1	4
	E7	8	6	5	17	0,033	0,134	6	3	18
13	A8	6	6	1	10	0,181	0,736	6	3	18
	A9	6	6	6	20	0,058	0,237	7	4	28
	C8	6	6	1	18	0,061	0,249	5	3	15
	D10	6	6	1	15	1,314	5,334	9	8	72
	E9	6	6	1	17	0,021	0,084	7	4	28
14	A6	2	6	1	13	0,031	0,126	7	4	28
	C1	2	5	3	14	0,110	0,448	11	3	33
	D1	2	0	3	17	0,018	0,073	5	4	20
	D8	2	4	3	15	0,519	2,108	11	5	55
	D10	2	4	1	7	0,130	0,529	7	3	21
15	A10	3	4	1	40	0,123	0,500	7	5	35
	E5	3	1	1	10	0,022	0,091	6	5	30
	E8	3	4	1	45	0,346	1,404	10	2	20
	E9	3	4	1	50	0,261	1,059	11	4	44
	E10	3	6	1	50	0,351	1,424	10	4	40
16	A10	6	0	1	5	0,032	0,129	6	2	12
	B4	6	4	1	6	12,754	51,784	25	12	300
	B7	6	5	1	9	1,132	4,597	10	7	70
	C6	6	5	5	6	0,047	0,192	7	2	14
	C10	6	2	1	3	0,006	0,026	4	1	4
17	A6	6	4	5	5	0,396	1,607	8	4	32
	B10	6	1	5	17	0,809	3,286	13	8	104
	C3	6	5	5	4	0,203	0,825	8	3	24
	D3	6	4	5	3	0,004	0,018	4	2	8
	D8	6	4	5	9	0,551	2,238	7	6	42
18	A4	5	6	5	10	0,495	2,009	8	6	48
	B5	5	6	5	10	0,000	0,000			0
	B9	5	5	5	3	0,058	0,235	8	4	32
	C2	5	5	6	4	0,033	0,134	9	4	36
	C8	5	5	1	8	0,014	0,057	7	2	14
19	A1	5	0	1	10	0,000	0,000			0
	C2	5	5	0	9	0,022	0,091	5	3	15
	C7	5	5	3	8	0,042	0,171	9	4	36
	C9	5	0	1	6	1,861	7,557	19	5	95
	E5	5	6	6	9	0,064	0,261	7	3	21
20	A6	5	5	5	11	0,058	0,237	6	4	24
	B4	5	6	5	12	1,253	5,088	11	6	66
	C1	5	4	5	7	0,003	0,012	4	2	8
	C7	5	4	5	9	0,045	0,183	5	4	20
	E5	5	3	1	10	0,017	0,069	3	2	6

(2) V. type

Code	Type
1	A2/ A3a
2	A3a
3	A3a/ A4a
4	A4a/ A3a
5	A4a
6	A4a/ A4b
7	A4b/ A4a
8	A4b

(3) Ground layer

Code	Species
0	No vegetation
1	*Polytrichum* spp.
2	*Hylocomium splendens*
3	*Ptilium crista-castrensis*
4	*Pleurozium schreberi*
5	*Dicranum* spp.
6	*Spaghnum* spp.

(4) Field layer

Code	Species
0	No vegetation
1	*Vaccinium myrtillus*
2	*Empetrum nigrum* ssp.
3	*Calluna vulgaris*
4	*Cornus suecica*
5	*Deschampsia flexuosa*
6	*Vaccinium vitis-idaea*

(1) Sample point

Code	Description
A-E:	Highest point of the plot, from left to right.
1-10:	Downwards from the highest point.