

*Mastergradsoppg. 2013*

# **FIRE HISTORY AND ECOLOGY OF THE BOREAL FOREST NATURE RESERVE TRILLEMARCA-ROLLAGSFJELL**

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MASTER THESIS, DECEMBER 2013





## **PREFACE**

This document is my 60 credits Master thesis after my studies in General Ecology at the Department of Ecology and Natural Resource Management, Norwegian University of Life Sciences. Thanks be to God Almighty for the spiritual strength and inspiration to persevere to the final moment.

First, I am sincerely grateful to Mikael Ohlson, my supervisor, for his remarkable support and encouragement. I will always cherish your useful and insightful guidance throughout this project.

I thank my colleague Daniel Lossius for all the hard work on the field. Your assistance was invaluable. I am grateful to Brice Sone and Torbjørn Josefsson for your assistance.

I appreciate the love and support from my wonderful Evelyn and all the family. I also appreciate the cooperation from all the folks that made studying more interesting and gratifying.

15<sup>th</sup> December, 2013.

Joseph Nkrumah-Boakye.



## ABSTRACT

Macroscopic charcoal particles (axis  $\geq 0.5\text{mm}$ ) give an indication of local fire presence to a fine spatial accuracy. I have examined the history, distribution and impact of fires on the ecology of Trillemarka-Rollagsfjell boreal forest nature reserve, located in the south of Norway. Data were obtained from a total of 225 soil core samples from 15 macro sample plots measuring  $300 \times 300\text{m}^2$ .

There was macroscopic charcoal in 153 of the soil samples out of 225, giving an estimated burned area of 68%. The average mass of macroscopic charcoal was  $32.43 \text{ gm}^{-2}$  ( $324.3 \text{ kg ha}^{-1}$ ). The mass of macroscopic charcoal correlated with the component of dead trees in the macro sample plots as well as the combination of the proportion of Scots pine and the dead trees components (p-value  $\leq 0.05 > 0.036$ ; and p-value  $\leq 0.05 > 0.028$ ). However there was no correlation between the mass of macroscopic charcoal and Norway spruce, birch, aspen and rowan which formed the other components of the forest.

There were large variations in macroscopic charcoal mass between macro sample plots and within macro sample plots. These variations are consistent with findings from Norway and many other boreal forest zones. Variations result from the mosaic pattern of fire occurrence and spread through the boreal forest landscape. This fire pattern is influenced by climatic factors, vegetation composition and terrain conditions like rate of accumulation of suitable fuel load.

Overall, the results of this study indicate a moderate fire impact within Trillemarka-Rollagsfjell nature reserve which may not be as important presently as it were few centuries ago.

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## INTRODUCTION

Global warming has resulted in increasing average summer and winter temperatures throughout the Arctic and Subarctic regions. Globally temperatures rose between 0.10 to 0.16<sup>0</sup>C per decade in the last 50 years; twice the rate in the last 100 years (IPCC, 2007). The upper northern hemisphere is expected to experience significant temperature changes with the current trend. This area hosts the boreal forest ecosystem, the largest and most extensive of the earth's terrestrial biome, measuring in excess of 1.2 billion ha (~ 13.7 million km<sup>2</sup>) and covering 11% of the earth's terrestrial surface (Bonan & Shugart, 1989; Soja *et al.*, 2007). Two-thirds of this area of boreal forest is located in Eurasia which includes the Scandinavian boreal forest. The rest can be found in North America. This area lies between 45 and 70<sup>0</sup> N latitude and constitutes about 30% of the world's forested area (Conard & A. Ivanova, 1997).

The Scandinavian boreal forest mostly has a simple floral composition. Often dominated by two conifers, Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) and mixed sparsely with small deciduous populations of birch (*Betula* spp), aspen (*Populus tremula*), alder (*Alnus* spp), and goat willow (*Salix caprea*) (Dahlberg, 2002; Soja *et al.*, 2007). This simple vegetation composition, nonetheless results from complex climatic and geological interactions influenced significantly by disturbance factors including fires and infestations (Zackrisson, 1977; Bonan & Shugart, 1989; Soja *et al.*, 2007). The boreal regions have unique cold weather interactions, conditions that allow them to form the largest reservoir to global terrestrial carbon (C), estimated up to 50% of the global total (Turunen *et al.*, 2002; Deluca & Boisvenue, 2012). Most of this carbon is stored in upland soils and the boreal peatlands. Mass of carbon in the boreal soil is estimated at 1200 Pg C (1 Pg = 10<sup>15</sup>g) which forms about 80% of the total boreal carbon reservoir. Boreal forest biomass accounts for 60 – 80 Pg C (1 Pg = 10<sup>15</sup>g) of the carbon stock.

It has been reported that climatic warming may result in increasing frequency rate of wild or natural fires as well as expansion of area, in hectares, that is burned annually. In Canada, Russia and Alaska, the rate of burning and the size of forest burned in terms of area are expected to increase significantly by the 21<sup>st</sup> century (Flannigan *et al.*, 2009; Preston, 2009; Bergeron *et al.*, 2010). Fires have been a major factor that affects forest composition and structure as well as forest succession in the boreal forest (Zackrisson, 1977; Bonan & Shugart, 1989; Bond-Lamberty *et al.*, 2007). Annually an estimated 5 – 15 million hectares of forest burn, releasing between 1,000 – 2,000 g Cm<sup>-2</sup> of organic carbon as carbon dioxide (CO<sub>2</sub>) as reported by Ohlson *et al* (2009).

This raises a lot of concern because these reported levels of CO<sub>2</sub> released are significant contributions to the global challenge of atmospheric warming, having regard to the widely held



opinion that the boreal forest biome represents a carbon sink in the dynamics of global carbon cycle (Deluca & Boisvenue, 2012). Reducing the rate of burning within this ecosystem and preserving the natural integrity of the boreal forest biome seems to be an alternative approach to curtailing the trends in global climatic warming, to a globally significant extent (Flannigan *et al.*, 2009; Ohlson *et al.*, 2009; Preston, 2009).

Not all forests are vulnerable to the general increasing trend of fire occurrence. In Scandinavia, studies have shown considerable reduction in the frequency of fires and in some cases no incidence at all when Norway spruce replaced other tree species in the forest landscape (Ohlson & Tryterud, 1999; Ohlson *et al.*, 2011). In fact other authors have argued against the assertion of an increasing trend in fire frequency, size and impact on the boreal forest landscape (Bergeron & Flannigan, 1995; Flannigan *et al.*, 2000). Vegetation composition, climate and topography are some of the factors that account for the potency and distribution of fires within a particular forest landscape (Bonan & Shugart, 1989; Bergeron *et al.*, 2004; Aldersley *et al.*, 2011). It is important to study the fire history and composition of any particular forest landscape to be able to conclude on how the fire regime is likely to be influenced in the future, especially with regards to the reported current increasing trend.

One approach that has been quite commonly used in the last few decades is analyzing charcoal accumulated in the forest soil. Forest fires convert an estimated 1 – 3% of plant matter into charcoal. Charcoal persists in the soil for hundreds of years up to millennia (Ohlson & Tryterud, 2000; Preston, 2009). Analyzing the accumulated charcoal in soil sampled from burned areas should provide information about the role of fire in the development of the forest. Charcoal forms when fire incompletely combusts organic matter (Whitlock & Larsen, 2002). The presence of charcoal within the soil core often indicates past fire events. Macroscopic charcoal (charcoal with axis  $\geq 0.5\text{mm}$ ), has been established by a number of authors as good evidence of local fire to very fine spatial scales (Ohlson & Tryterud, 2000; Whitlock & Larsen, 2002).



## **OBJECTIVES**

I aim to identify the importance of fire to the development of the boreal forest nature reserve Trillemarka-Rollagsfjell; to understand the fire regime based on the evidence of macroscopic charcoal deposits.

I want to establish if there is a trend in fire regime at Trillemarka-Rollagsfjell based on trends, if any, in macroscopic charcoal data.

I will show the strength of correlation between forest landscape types and mass of macroscopic charcoal deposits and the probable influence of the forest landscape types on the fire regime.

## **MATERIAL AND METHODS**

### **Study area**

This study was conducted in the Trillemarka-Rollagsfjell Boreal Forest Nature Reserve located between Sigdal and Numedal in the County of Buskerud. Buskerud County comprise Sigdal, Rollag and Nore og Uvdal municipalities.

Trillemarka-Rollagsfjell has an area of 148km<sup>2</sup> and is the largest contiguous reserve of coniferous forest in the whole of Norway. It boasts of unique old growth natural forest and over 90 species in the Norwegian species red list. Trillemarka-Rollagsfjell located in central southern Norway, was established in December 2002. It has a varied landscape with stream gorges, plateau mountains and forests. The topography is characterized by large height differences which gives the area an outlook of varying climatic zones. The climate though, is typical of south Norway, with long, cold and snowy winters and relatively warm summers (Trønnnes, 2012).

The study area is located south of the reserve. The area has a long history of human influence ranging from man-made fires to logging. Logging began from about the 16<sup>th</sup> century and lasted until the 20<sup>th</sup> century, and was mainly for timber exploitation. In between, farming operations are believed to have existed from about the 18<sup>th</sup> to the 19<sup>th</sup> century and may have actually ceased about 100 – 150 years ago. Summer farms were also quite popular in the area during this period, and there are relics of these operations in the area presently.

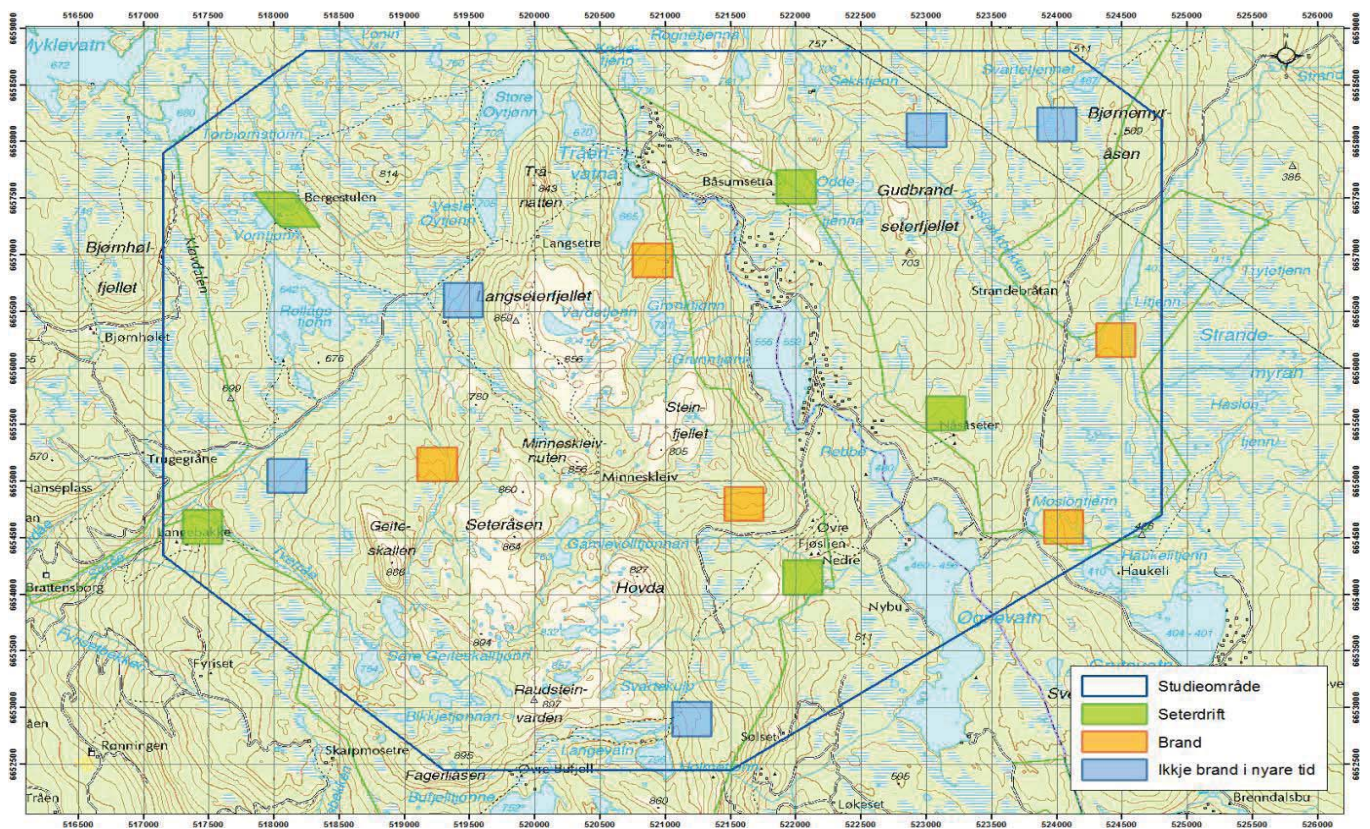


Figure 1: Map showing the study area with the macro sample plots. Colored spots green, orange and blue indicate landscape types SF, F and N respectively. Credit Trønnes 2012.

## **Sampling site**

Fifteen macro sample plots were chosen in a restricted random sampling procedure (Økland & Økland, 1996; Haugmo, 2004). Each macro sample plot measured 300m x 300m and the plots were selected to represent the following three main types of forest landscapes with different histories:

- ❖ Recent occurrence of wildfires (F - wildfire < 300 years ago).
- ❖ Historic occurrence of wildfires (N - wildfire > 300 years ago).
- ❖ Occurrence of historic summer farms (SF).

Knowledge about the recent and historic wildfires is premised on studies of tree rings in pine trees that have been damaged by fire over the years. Tree rings correspond to the age of trees because they occur in a pattern that shows the seasonal growth of trees. When fires damage trees at any stage in their development, the damage can be seen when one observes the rings. It is possible to estimate the years when fire damages occurred from the tree rings. Therefore, the history of fire occurrences can be quite accurately calculated from these analyses. I made use of findings from tree rings analyses that had been done earlier and used in other research projects preceding this project (Trønnnes, 2012). The dominant vegetation types were noted for all macro sample plots. These consisted mainly of the dominant tree species in order to allow for a subjective description of the forest composition within the macro sample plots.

## **Field work**

A grid size of 30m x 30m was used, yielding 121 sampling positions within each macro sample plot. Fifteen sampling positions were selected at random. Thus 15 soil samples were collected from each macro sample plot. This resulted in a total of 225 soil samples. The selected random sampling positions were located on the field with the aid of a GPS. The soil samples were collected with a steel cylinder (diameter 58mm). Each sample consisted of the entire organic top-soil and at least about 3cm of the underlying mineral soil, except for areas where rocks or boulders restricted deeper access into the mineral soil.

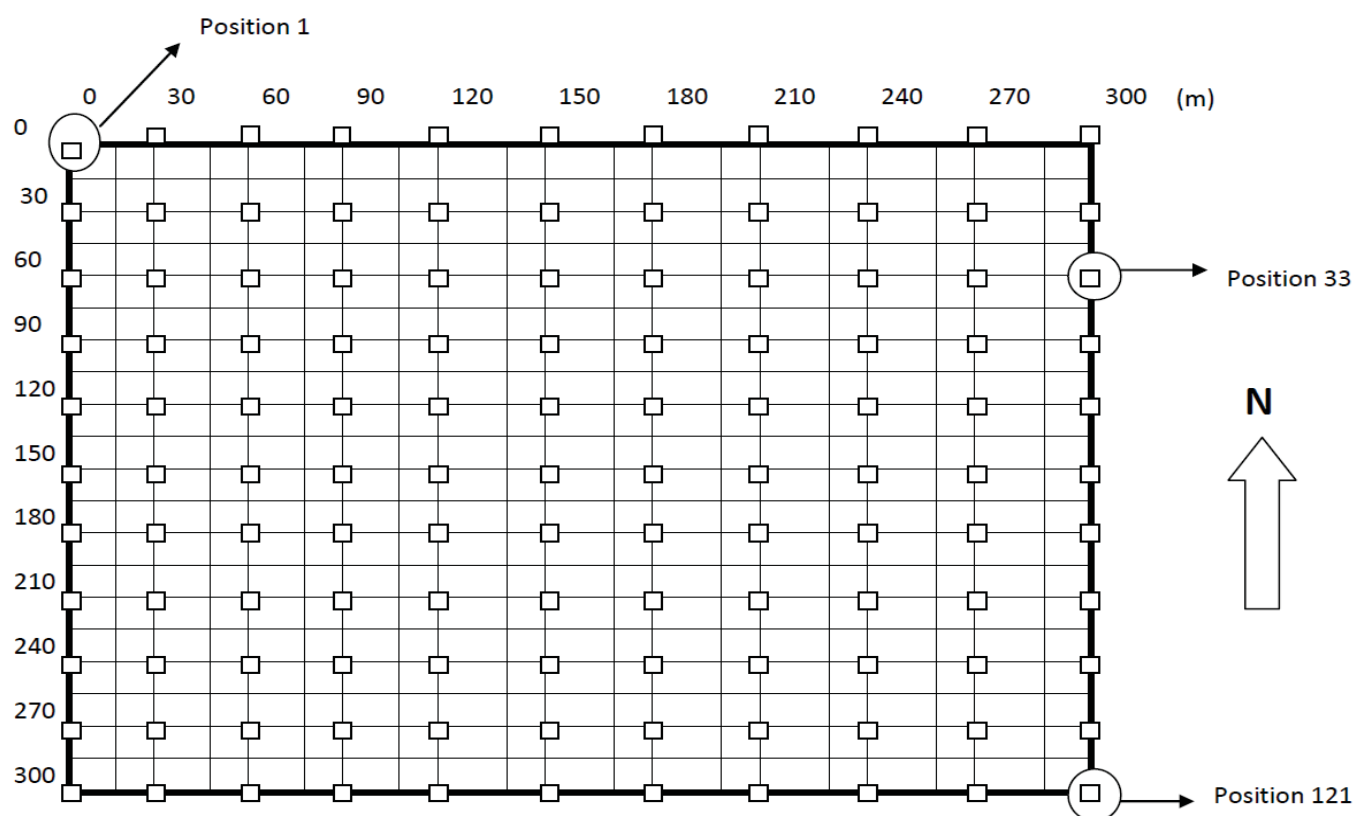


Figure 2: A graphical representation of the sampling procedure within a macro sample plot measuring 300m x 300m with a grid size 30m x 30m.

A tree-rod was used to press out the soil samples from the steel cylinder directly into marked plastic bags for safe carriage to the laboratory. The plastic bags were marked according to each macro sample plot and sampling position to allow for respective or accurate identification. For areas where there were physical obstacles to the sampling procedure; such as bare rocks, large stone boulders, peat soil deeper than 30cm, large tree trunks on the ground, large roots or water body; the position was rejected and the nearest position towards the north direction was selected.

**Table 1: Forest landscape type and name of macro sample plots.**

<b>RECENT WILDFIRES (F)</b>	<b>HISTORIC WILDFIRES (N)</b>	<b>SUMMER FARMS (SF)</b>
Moslontjenn	Gudbrandseterfjellet	Fjøslien
Litjenn	Langseterfjellet	Nåsåsetern
Steinfjellet	Geiteskallen	Båsumsetra
Grønlitjønn	Holmesjønn	Bergestulen
Seteråsen	Bjørnemyråsen	Langebakksetern

### **Laboratory procedure**

Laboratory work involved drying and sieving samples to obtain charcoal particles, preferably particles with axis  $\geq 0.5\text{mm}$ . This size range of particles allows for realistic estimates of persistent soil charcoal particles according to Ohlson and Tryterud (2000). These particles are referred to in previous studies as macroscopic charcoal particles (Wist, 2008; Ohlson *et al.*, 2011). Drying of the samples began shortly after collection from the field to reduce the tendency for oxidizing and darkening of the samples (Haugmo, 2004).

Evidence from previous studies show that macroscopic charcoal particles often appear black and completely opaque, with angular broken ends and usually have a silvery surface that reveals wood cell structures. Macroscopic particles are preferred because they are often from woody parts of plants that are burned and tend to provide better evidence of local presence of fires (Patterson *et al.*, 1987; Whitlock & Larsen, 2002). In an experiment to show the extent to which charcoal particles are distributed from burned spots, Ohlson and his colleagues found that no charcoal particles with axis  $\geq 0.5\text{mm}$  were distributed outside burn areas. They concluded that macroscopic charcoal is most reliable evidence of influence of fire within an area, and that the presence of macroscopic charcoal particles can be used to determine to a very high spatial precision, whether an area is fire-prone or otherwise (2009).



In contrast, portions of microscopic or smaller particles (below 0.5mm axis) can be distributed to other areas distant from burn areas, thus they can be found even in fire-free areas within or outside a forest where fire occurs.

The soil samples were dried in a drying oven (Termaks Series TS8000) at 70° C for 10-12 hrs. Dry soil samples were spread out on a platter and examined under a magnifier lamp (3x magnification). Macroscopic charcoal (axis  $\geq 0.5\text{mm}$ ) was hand sorted from the soil samples. Macroscopic charcoal samples were collected into glass vials and further dried to constant mass at 70° C for 20-24hrs (Termaks Series TS8000). These were then weighed (Precisa 205A SCS), and the mass of each charcoal sample recorded.

## Forest composition

**Table 2: Forest composition of the 15 macro sample plots in terms of basal area in  $\text{m}^2 \text{ha}^{-1}$**

Plots	Spruce	Pine	Birch	Aspen	Rowan	Dead	Total Basal Area	Landscape Type
Moslontjenn	7.5	10.7	12.0	0.0	0.0	2.5	32.7	F
Fjøslien	17.0	1.0	1.7	4.7	1.5	6.8	32.6	SF
Litjenn	7.3	14.5	1.5	0.0	0.0	1.5	24.8	F
Nåsåsetern	21.5	2.7	4.8	0.0	0.0	1.8	30.7	SF
Gudbrandseterfjellet	3.3	12.5	0.0	0.0	0.0	1.0	16.8	N
Steinfjellet	11.7	7.8	2.0	0.0	0.0	1.3	22.8	F
Grønlitjønn	16.8	4.0	2.2	0.0	0.0	1.2	24.2	F
Båsumsetra	14.7	4.0	1.8	0.0	0.0	2.0	22.5	SF
Langseterfjellet	13.2	2.7	2.0	0.0	1.0	3.2	22.0	N
Bergestulen	14.7	7.8	4.2	0.0	0.0	2.2	28.9	SF
Langebakksetern	22.0	5.0	5.4	0.0	1.0	1.5	34.9	SF
Geiteskallen	1.6	9.3	3.3	0.0	0.0	0.0	14.2	N
Seteråsen	5.4	6.8	4.0	0.0	1.0	3.0	20.2	F
Holmesjønn	15.7	4.0	2.3	0.0	0.0	2.8	24.7	N
Bjørnemyråsen	15.0	8.5	4.8	0.0	0.0	1.2	29.5	N

The composition of the forest from the 15 macro sample plots studied does not differ from the general composition of Trillemarka-Rollagsfjell nature reserve. The two main conifers dominate in an alternating pattern from one macro sample plot to another. A notable exception was Moslontjenn where birch dominated slightly with about 37% coverage (basal area –  $12.0\text{m}^2 \text{ha}^{-1}$ ), the rest of the plots had small proportions and Gudbrandseterfjellet had no birch at all. Aspen and rowan were absent from most of the plots except Fjøslien which had 14% aspen proportion. In fact, Fjøslien was

the only plot that registered the presence of aspen. Rowan was found in Fjøslien, Langseterfjellet, Langebakkesetern and Seteråsen in very small proportions (basal area 1 – 1.5m<sup>2</sup> ha<sup>-1</sup>). Over all Norway spruce was the most dominant with about 49% coverage and pine had 27%. The proportion of birch was just about half the proportion of pine at 13.6% while aspen and rowan represented just 1.23 and 1.18% respectively.

## **Data analysis**

Data on the quantities of macroscopic charcoal (mass of macroscopic charcoal in a sample in g m<sup>-2</sup>) was analyzed to identify the correlation between these values with variations in sample site properties. This was done to establish the strength of correlation between the amount of macroscopic charcoal found in a sample and the dominant tree species and type of forest landscape with regards to the criteria for selecting the various macro sample plots.

All statistical analyses were performed with Minitab statistical software (Minitab 16). A normality test showed that the data from macroscopic charcoal masses deviated from a normal distribution (Minitab 16 Normality test: p – value < 0.514). This is however quite consistent with regards to evidence from previous studies because data on macroscopic charcoal quantities often deviate from a normal distribution. (Ohlson & Tryterud, 2000; Wist, 2008). Tests for statistical difference between macro sample plots and forest landscape types with regards to the macroscopic charcoal obtained from the different sites were therefore performed using the Kruskal-Wallis one way Analysis of variance (ANOVA), because it is better suited for analysis of such non-parametric data. I also performed Mann-Whitney tests to identify any statistical differences between individual forest landscape types. Statistical tests were performed at a 5% level of significance (p-value ≤ 0.05).

Minitab 16 Statistical Software was used to make the box plot showing the variation between the mean values of macroscopic charcoal from the 15 macro sample plots. I also carried out regression analyses with scatter plots that show the strength of correlation between the mass of macroscopic charcoal and the basal area of the tree species and other components that constituted the forest.



## RESULTS

Out of a total of 225 sampling positions, 153 contained macroscopic charcoal. This is estimated to represent about 68% of the study area that has been burned or impacted by fire. All the 15 macro sample plots contained macroscopic charcoal. The maximum amount of macroscopic charcoal came from Fjøslien, where all the 15 sampling positions contained macroscopic charcoal. Holmesjønn had the least amount of  $2.15\text{gm}^{-2}$  whilst Geiteskallen had only six sampling positions with macroscopic charcoal.

**Table 3: Total and average mass of macroscopic charcoal ( $\text{gm}^{-2}$ ), and number of sample positions with macroscopic charcoal in all the macro sample plots.**

PLOT NUMBER	PLOT NAME	TOTAL CHARCOAL MASS ( $\text{gm}^{-2}$ )	AVERAGE CHARCOAL MASS ( $\text{gm}^{-2}$ )	NUMBER OF SAMPLES WITH CHARCOAL
1	Moslontjenn	52.56	4.78	11
2	Fjøslien	78.86	5.26	15
3	Litjenn	66.84	4.77	14
4	Nåsåsetern	15.8	1.98	8
5	Gudbrandseterfjellet	29.61	2.96	10
6	Steinfjellet	35.53	2.73	13
7	Grønlitjønn	31.38	2.85	11
8	Båsumsetra	48.33	5.37	9
9	Langseterfjellet	37.15	4.64	8
10	Bergestulen	14.23	1.58	9
11	Langebakksetern	28.55	3.17	9
12	Geiteskallen	12.58	2.1	6
13	Seteråsen	28.97	2.07	14
14	Holmesjønn	2.15	0.24	9
15	Bjørnemyråsen	3.89	0.56	7
<b>Total</b>		<b>486.43</b>		<b>153</b>

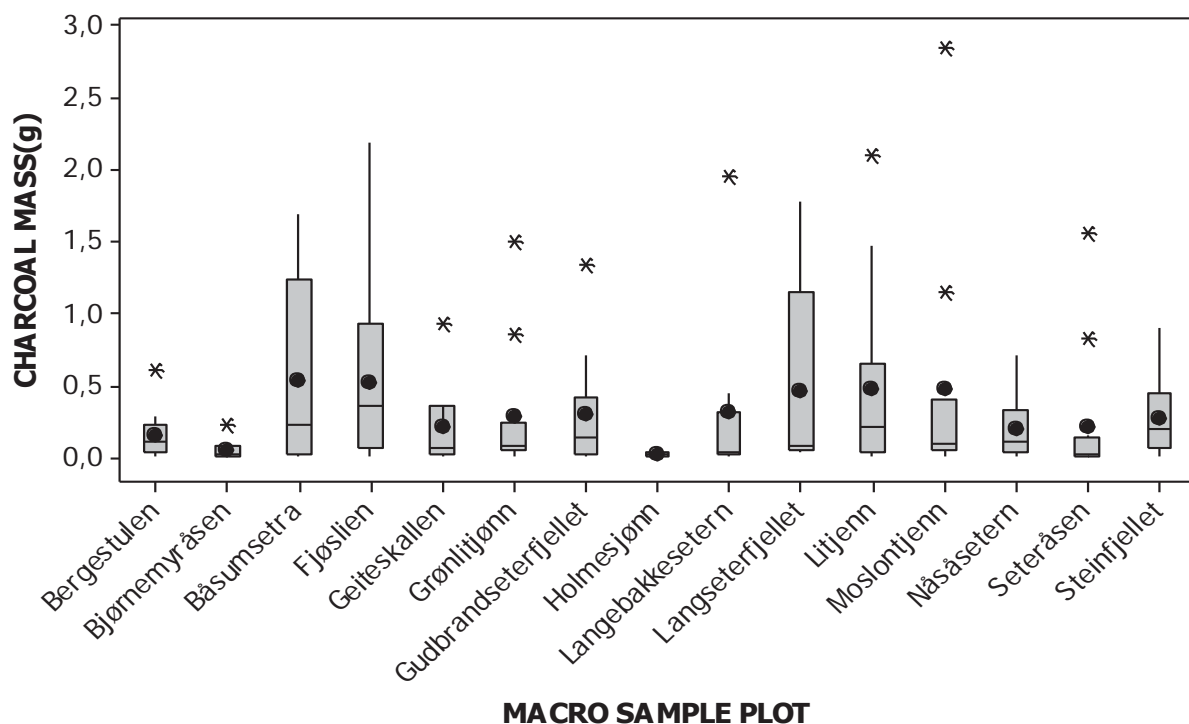
Average mass of macroscopic charcoal was calculated to be  $32.43\text{gm}^{-2}$  giving an estimated quantity of  $324.3\text{kg ha}^{-1}$  of macroscopic charcoal contained in the soil within the study area.

One consistent characteristic was the variation both spatial and quantitative, in the amounts and distribution of macroscopic charcoal within and between the 15 macro sample plots. Even though the total mass of macroscopic charcoal was more in the landscapes with recent fire occurrence, there seemed not to be an obvious trend in that regard. For example, Fjøslien which belonged to the landscapes with summer farm occurrence recorded the highest amount of macroscopic charcoal for all the macro sample plots (i.e,  $78.86\text{gm}^{-2}$ ). Gudbrandseterfjellet in the category of historic

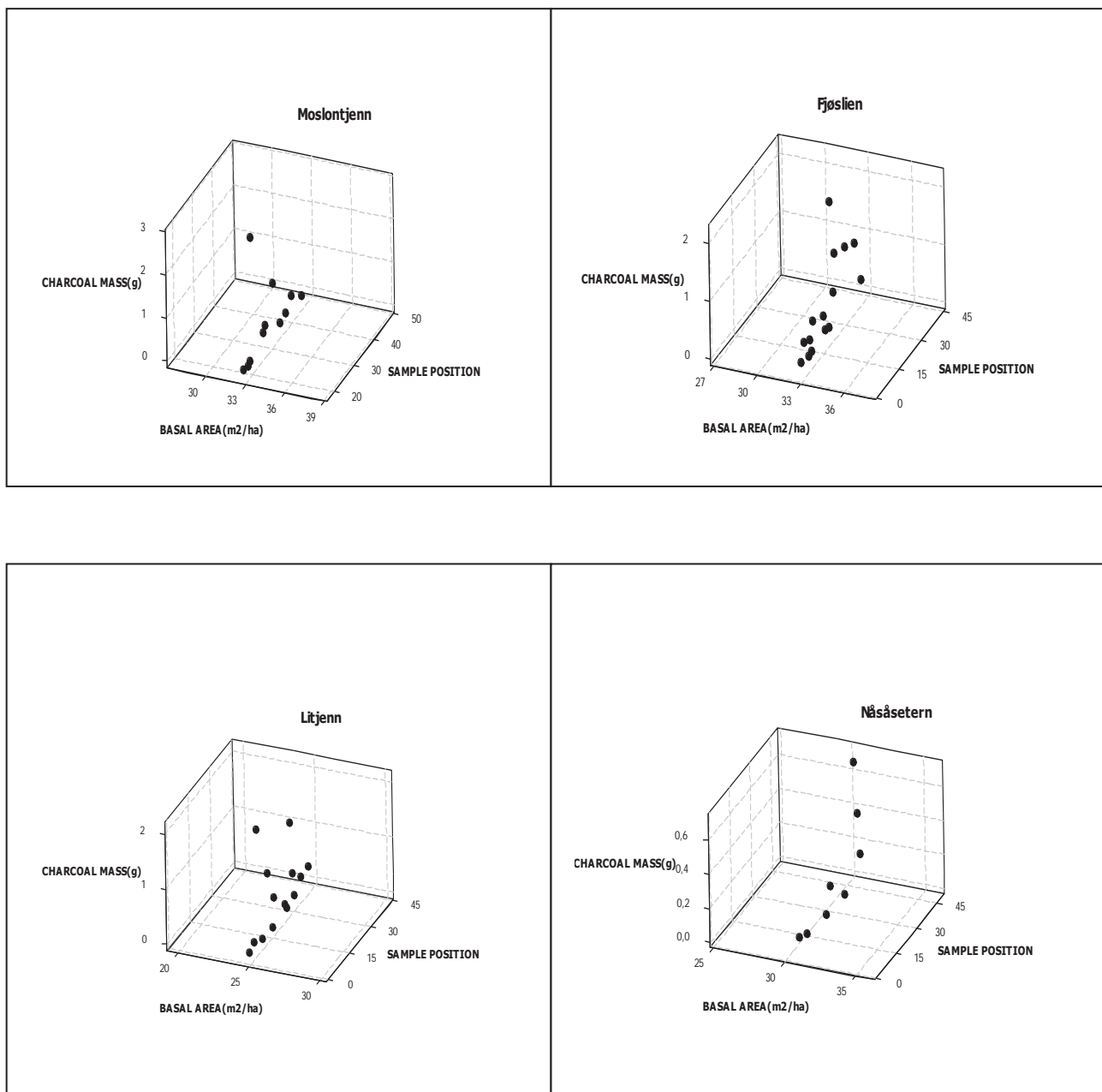
occurrence of fires recorded similar mass of charcoal as Seteråsen which was in the category of recent fire occurrence (i.e, 29.61 and 28.97gm<sup>-2</sup> respectively).

There was an apparent indication of greater fire impact towards the south-eastern side of the study area, going by the quantities of macroscopic charcoal recorded from macro sample plots situated around that area. But spatial variation could still be seen in the sharp declines in the amount of macroscopic charcoal recorded in Nåsåsetern – summer farm landscape (15.8gm<sup>-2</sup>) and Holmesjønn – historic fire landscape (2.15gm<sup>-2</sup>); both macro sample plots situated right within the south-eastern enclave of the study area where high macroscopic charcoal amounts had been recorded. See table 3 above.

A Kruskal-Wallis one-way ANOVA showed significant differences in the levels of macroscopic charcoal masses obtained from the various macro sample plots (Kruskal-Wallis one way ANOVA p-value > 0.033). The details of the analysis can be seen in appendix 1. This is a firm indication that the amount of macroscopic charcoal obtained was influenced by the macro sample plots. However, there was no obvious trend in the spatial distribution of macroscopic charcoal both within and between macro sample plots as illustrated in figure 4.



**Figure 3: A box plot showing total mass of macroscopic charcoal from the 15 macro sample plots. Black dots show the mean value per macro sample plot.**



**Figure 4: Spatial distribution of macroscopic charcoal within the 15 macro sample plots. The mass of macroscopic charcoal from the various sampling positions within the macro sample plots are depicted by the black dots. The figures above show the graphs for the first 4 macro sample plots (Moslontjenn, Fjøslien, Litjenn and Nåsåsetern).**

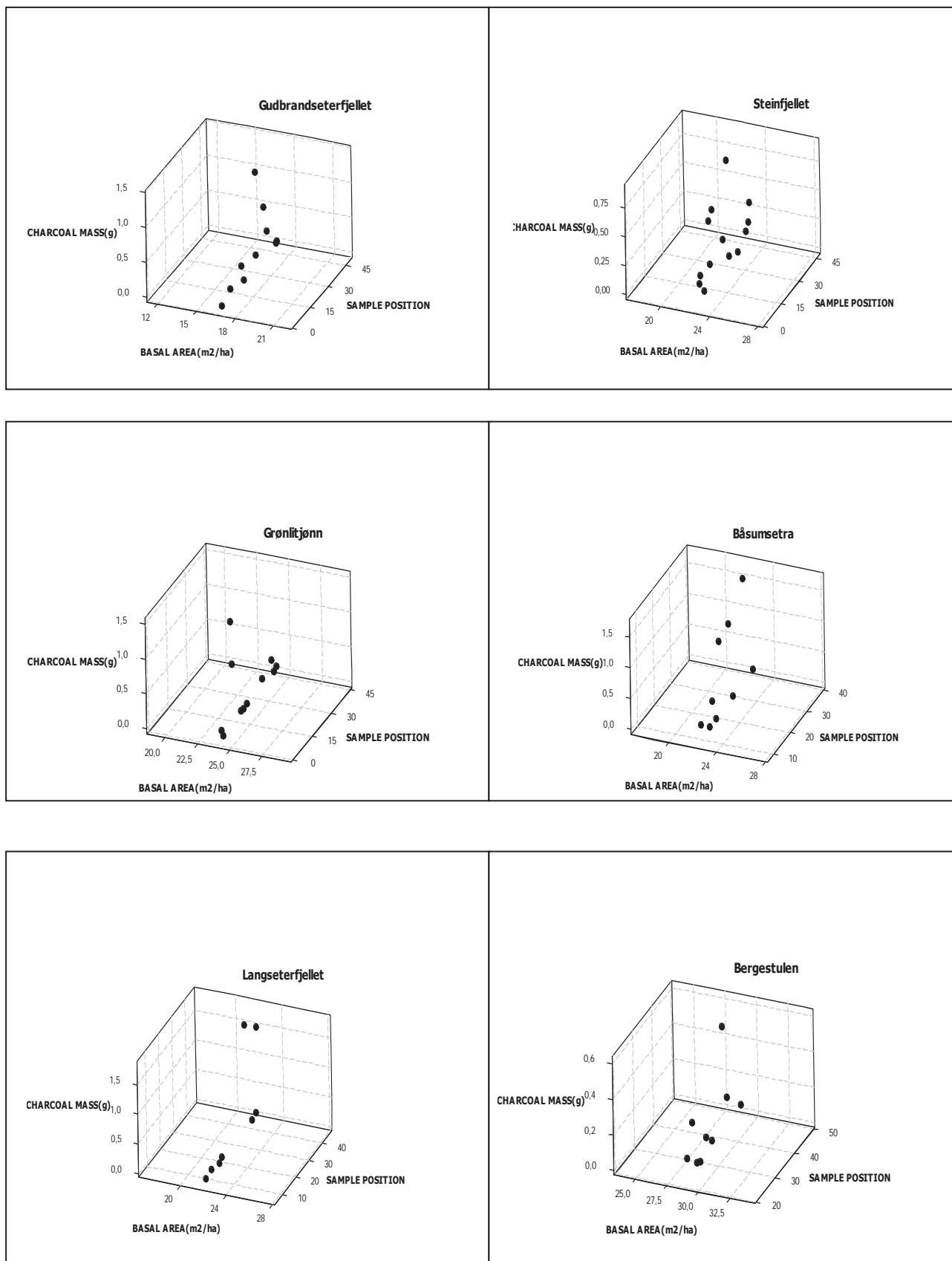


Figure 4 continued: Above are graphs from the next 6 macro sample plots (Gudbrandseterfjellet, Steinfjellet, Grønlitjønn, Båsumsetra, Lagseterfjellet, and Bergestulen).

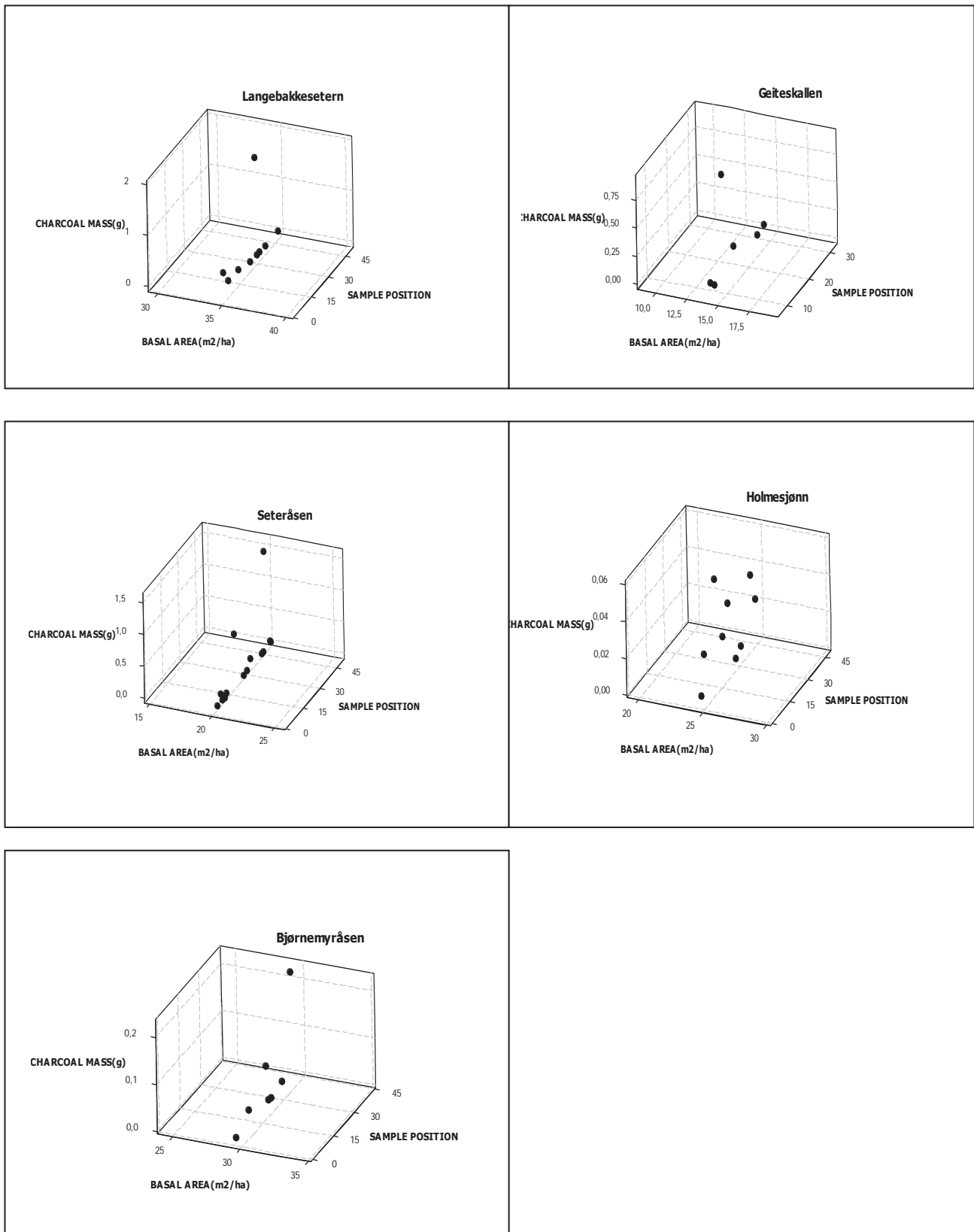


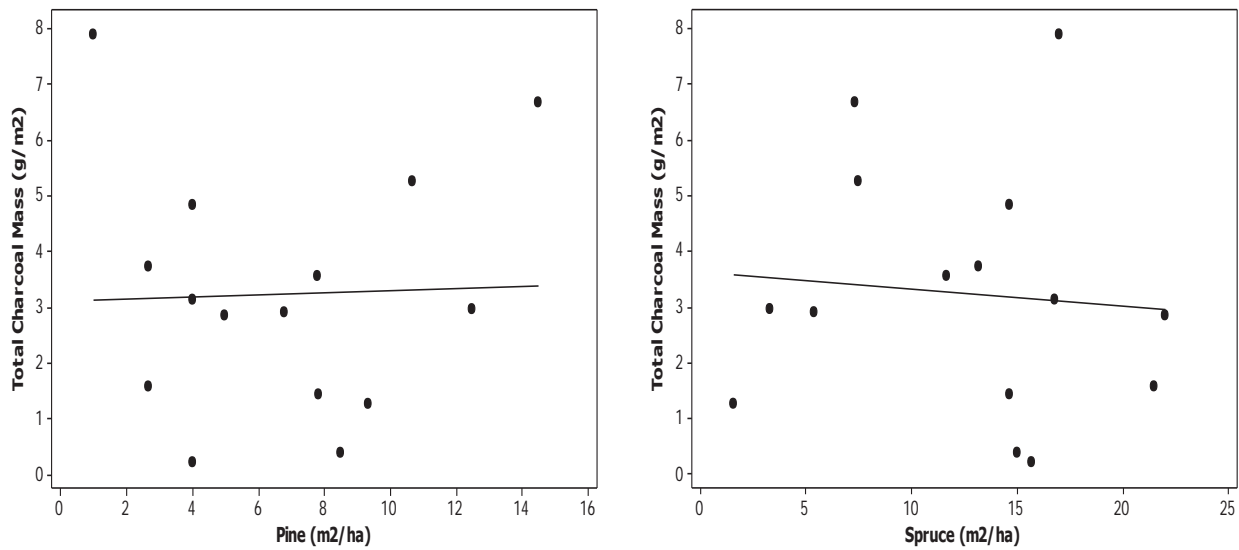
Figure 4 continued: Above are graphs of the last 5 macro sample plots (Langebakkesetern, Geiteskallen, Seteråsen, Holmesjønn, Bjørnemyråsen).

Statistically, there was no significant difference in the amount of macroscopic charcoal in relation to the forest landscape types (p-value < 0.137, Kruskal-Wallis one way ANOVA). However, there was nearly three times as much macroscopic charcoal in the landscapes with recent 300 years of fire as there was in the landscapes with historic fires dating more than 300 years. Twice more was recorded in areas where summer farms occurred as against landscapes with historic fires. (See table 4 below).

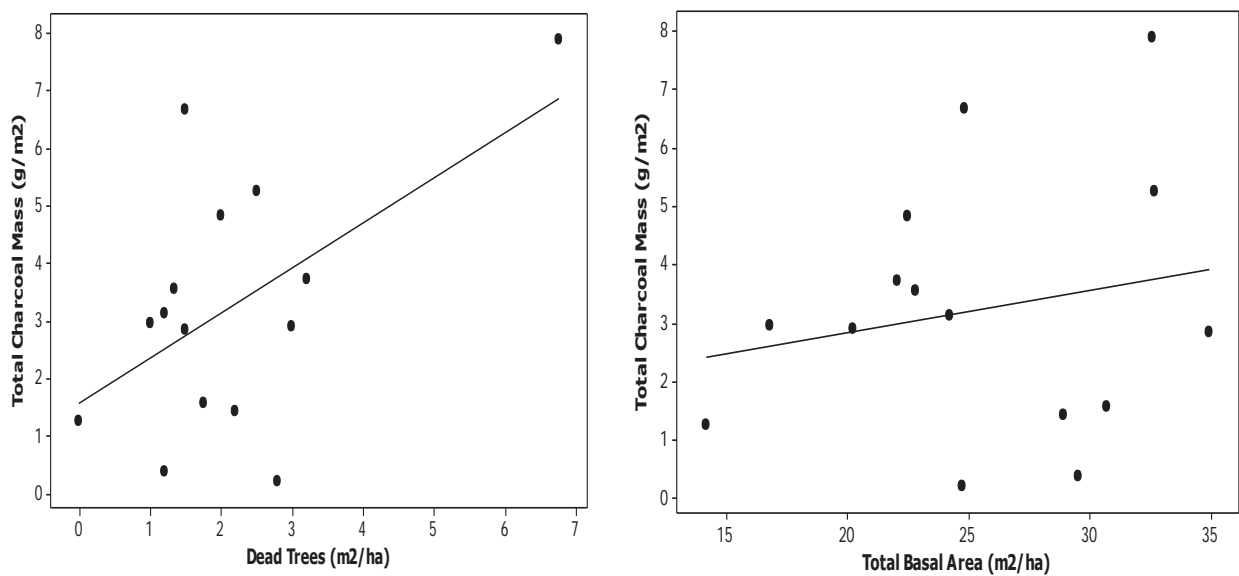
**Table 4: Total and average mass of macroscopic charcoal (gm<sup>-2</sup>) recorded in the forest landscape types.**

<b>PLOT TYPE</b>	<b>CHARCOAL MASS (gm<sup>-2</sup>)</b>	<b>AVERAGE MASS (gm<sup>-2</sup>)</b>
RECENT WILDFIRES	215.28	43.06
HISTORIC WILDFIRES	85.38	17.08
SUMMER FARMS	185.77	37.15

Regression analysis performed to identify the strongest correlation between the forest composition and the mass of macroscopic charcoal produced the best fitted model from the proportion of pine and dead tree components of the forest by the size of their basal areas (p-value > 0.028). Individual regression analyses showed that the proportion of dead trees with regards to the basal area correlated quite strongly with mass of macroscopic charcoal (p-value > 0.036). However the basal areas of pine or Norway spruce alone showed no significant correlation with macroscopic charcoal mass (p-value < 0.901 and p-value < 0.76 respectively). Basal areas of all the other tree components of the forest; birch, aspen and rowan had no significant correlation statistically with macroscopic charcoal mass. Appendix 2 contains the detailed regression analyses and fitted line plots that illustrate the strength of correlation between the species, dead tree components and macroscopic charcoal mass. See also figure 5 below.



**Figure 5: Scatter plots showing the correlation between mass of macroscopic charcoal and basal area of pine trees compared with the correlation between mass of macroscopic charcoal and basal area of Norway spruce trees. (Mass of macroscopic charcoal is in gm<sup>-2</sup> and basal area is in m<sup>2</sup>ha<sup>-1</sup>).**



**Figure 5 continued: Scatter plots showing the correlation between mass of macroscopic charcoal and basal area of dead trees as compared to correlation between mass of macroscopic charcoal and total basal area. (Mass of macroscopic charcoal is in gm<sup>-2</sup> and basal area is in m<sup>2</sup>ha<sup>-1</sup>).**



## DISCUSSION

Trees bearing fire scars and the presence of macroscopic charcoal constitute reliable evidence that fires have been a part of the history of Trillemarka-Rollagsfjell Nature Reserve. From the results recounted, I draw three inferences for subsequent discussion in this section. These are:

- Fire impact on the development of the forest landscape
- Relationship between forest composition and fire regime
- Spatial variability in the distribution and abundance of macroscopic charcoal.

### Fire impact on the forest

The extent of fire impact varied with respect to forest landscape type and site conditions as evident from the distribution of macroscopic charcoal. There was a higher average mass of macroscopic charcoal obtained from the forest landscapes with recent fire history and least average from the landscapes without recent fires. But this could be a reflection of fire frequency and effect on biomass within the various landscape types other than merely the time record of fires considering forest composition and production rate of combustible biomass as fuel. This is because recent impact of fires may have to be thoroughly investigated before the distribution of macroscopic charcoal can explain the differences between the various landscape types (Bergeron & Archambault, 1993). It is interesting to note that the forest landscape types were statistically no different despite the marked variation in the amounts of macroscopic charcoal obtained from each.

The estimated burned area of 68% indicates a relatively moderate fire impact as compared to estimates from previous studies conducted in Norway (Haugmo, 2004; Wist, 2008). Kristoffersen recorded a far less impact of 38% in 2002 from the boreal forest of Reisa National Park in northern Norway (Kristoffersen, 2002). Again, the estimated area burned can be compared to studies from other boreal forest zones including Russia and North America. Wallenius estimated around 65% of fire impact in a study from north-western Russia within a natural *Picea abies* (Norway spruce) dominated landscape in the Onega peninsula (Wallenius, 2002). There were markedly high estimates of areas burned from a boreal forest-tundra zone across Hudson Bay in northern Canada measuring about 95 to 97% in a study reported by Payette and colleagues (Payette *et al.*, 2001). North American boreal forest tend to experience higher intensity fires, (Logan & Powell, 2001; Payette *et al.*, 2001; Wallenius *et al.*, 2005) as compared to Fennoscandia and Russia where low intensity surface fires often characterize the fire regime (Conard & A. Ivanova, 1997; Wallenius *et al.*, 2002).

The average mass of macroscopic charcoal obtained from the 15 macro sample plots was  $32.43\text{gm}^{-2}$  - (corresponding to  $324.3\text{kg ha}^{-1}$ ). Zackrisson *et al* (1996) quantified the mass of charcoal from twelve locations within the boreal forest zone of northern Sweden dominated mainly by pine (*Pinus sylvestris*), and established the mass of charcoal to range between 984 to  $2074\text{kg ha}^{-1}$ . They suggested that these levels would be sufficient for charcoal to have significant ecological impact through its sorptive abilities. If the mass of charcoal obtained from Trillemarka in this study is to be considered in the light of these levels, then it can be stated that the soil charcoal may have had a very modest ecological effect, if any, within the boreal forest landscape of the study area.



**Figure 6: A Pine tree in the sample plot Seteråsen bearing fire scar at the base. Photo: Author.**

Ohlson and Tryterud recorded an average charcoal production of  $235\text{kg ha}^{-1}$  by trapping charcoal from three experimental burns conducted on two sites in east and south-east Norway and one site in eastern Sweden. The experimental burns covered between 40% to 95% in area across the three sites. They also recorded a maximum mass per trap of  $6800\text{kg ha}^{-1}$  (2000). Depending on their intensity and the abundance of fuel from suitable biomass, single fire events can produce high levels of charcoal mass. In an experiment to trap airborne particles after high intensity fire in a pine forest in west-central Siberia, Clark and colleagues recorded a mass of  $729\text{kg ha}^{-1}$  (Clark *et al.*, 1998).

This study recorded an average mass of charcoal identical to Kristoffersen's  $360\text{kg ha}^{-1}$  from a pine-dominated forest in northern Norway, considering that Trillemarka is slightly dominated by Norway spruce. However, there exists the probability that the impact of fires on the landscape by way of percentage coverage could have been exaggerated. The restricted sampling method used, involved targeted selection of landscape types with recent or historic evidence of fire scars – based on

evidence from tree rings (Trønnnes, 2012). This ensured that a proportion of the macro sample plots were situated within sites where it was most likely to register fire occurrence. Also sampling was as a principle shifted where the grid fell in areas where it was practically impossible to retrieve the soil sample. These areas such as extensive bogs, large rocks, and water bodies tend to restrict fire spread and may not contain macroscopic charcoal (Engelmark, 1984). It is thus concluded that the impact of fire on the development of the forest may have been quite modest.

### **Forest composition and fire regime**

Vegetation structure and functioning are shaped by disturbance events (natural or human-induced), in combination with climate, terrain or site conditions (Bonan & Shugart, 1989; Thonicke *et al.*, 2001). Fire is a primary disturbance factor in most forest ecosystems (boreal forests included). This is evidenced by charcoal deposits within the forest soil and fire scars on living trees (Bonan & Shugart, 1989; Marlon *et al.*, 2006). The floral diversity and mosaic patterns within the boreal forest have been attributed to recurring fires by several authors (Bonan & Shugart, 1989; Thonicke *et al.*, 2001; Bergeron *et al.*, 2004). Previously ignited by lightning, man seems to be the main agent for forest fires since humans appeared on the scene (Rowe & Scotter, 1973). In fact the contribution of man as a forest fire agent is estimated at about 65% where as lightning is 17% (Conard & A. Ivanova, 1997). Fires consume the forest floor and exert direct impact on soil moisture, soil temperature, biomass accumulation and regeneration of vegetation. This places fire as a key disturbance factor within the boreal forest ecosystem on a global scale, influencing biogeochemical cycling, energy flow and productivity (Bonan & Shugart, 1989; Zackrisson *et al.*, 1996; Thonicke *et al.*, 2001).

The extent of fire impact depends on the severity, intensity and frequency of fires (also expressed as the fire return interval – FRI) (Payette, 1992). Tree species that take many years to either reproduce or develop resolute physical features to survive fires, may consequently require longer fire return intervals to complete key successional processes (Schimmel & Granström, 1996). This has obvious implications regarding which species survive in any landscape with reference to the relative FRI. This is evidenced by the patterns of past fires that dominate the vegetation in many landscapes (Conard & A. Ivanova, 1997).

Fire return intervals vary from place to place within the boreal forest zone depending on local climatic and site conditions. They are observed to be longer in most well watered sites near rivers and also in landscapes with forest patches interspersed by wet and extensive bogs (Conard & A. Ivanova, 1997). The Yukon Flats and Porcupine Plateau regions in Alaska have the most extreme fire climate (short FRI) because of low precipitation and high summer temperatures. They (FRIs)

also decrease from north to south across the latitudinal scale. (Yarie, 1981; Bonan & Shugart, 1989). Fire return intervals are affected by forest composition dynamics. Korovin, identified longer FRI for forest stands dominated by *Picea abies* (Norway spruce) – dark coniferous boreal forest – and shorter intervals in light coniferous pine and larch dominated stands (1996). Ohlson and his team showed that the invasion of pine and birch dominated stands by Norway spruce altered the fire regime and significantly reduced fire activity at a sub-continental scale (Ohlson *et al.*, 2011). There seem to be an apparent or indirect interdependent relationship between fires and forest vegetation composition dynamics where both phenomena influence the dynamics of each.

Studies of FRI from Russia showed variation from as low as 10 years in a few areas to between 25 and 100 years across much of the landscape (Conard & A. Ivanova, 1997). Reported FRIs from North American boreal forests range from an average of 50 to 200 years, to an extreme of 500 years in wet regions of eastern Canada (Foster, 1983). In northern Sweden they range from 50 to 270 years and average between 110 to 155 years (Engelmark, 1984). FRI can be altered considerably by management interventions within the landscape. Evidence from Ontario, Canada, indicates extension of FRI from 65 to 580 years due to fire suppression (Ward & Tithecott, 1993). There are examples again from north-western Minnesota reported by Clark (1988).

Fire intensity as described by Byram is the energy output rate per unit length of fire front (1959). It is particularly important in determining the proportion of plant parts above ground that may survive a fire occurrence. Above-ground vegetation in the under-storey and forest floor are usually destroyed even in low-intensity fires because they normally grow at lower heights compared to the trees, and often lack the morphology –like thick bark – that protects against fires (Schimmel & Granström, 1996). The survival of under-storey plants is often achieved where plants possess underground meristems (rhizomes, root corms) or seeds in the soil which are mostly insulated from variations in fire intensity (Schimmel & Granström, 1996). The thick organic layer that covers the boreal forest floor restricts the penetration of heat down the soil during fires.

The severity of fire has been described in terms of the degree of removal of this organic material leading to heating of soil down the core. It is therefore a rating of the effect of the fire rather than its behavior (Schimmel & Granström, 1996). It may also be expressed in terms of tree mortality in forest ecosystems, and the consumption of above-ground vegetation. Severity depends on the duration of burning, the rate of energy output (intensity), thermal capacity and conductivity of the soil (Rowe & Scotter, 1973). The amount of organic matter consumed in the fire is influenced by the site conditions. Wet organic layers are less readily consumed than are dry layers and many fires have little effect on the forest floor because they occur when the ground is wet or frozen



(Zackrisson, 1977; Thonicke *et al.*, 2001). Direct soil heating during burning is minimal and has little long-lasting effect on soil temperature because mineral soil and organic matter are poor conductors of heat energy. Therefore, the lower portion of the thick forest floor layer often remains moist during burning (Bonan & Shugart, 1989).

### **Spatial variability in the distribution and abundance of macroscopic charcoal**

The high level of variation in the occurrence and quantities of macroscopic charcoal within and between macro sample plots seems to correspond with the characteristic mosaic behavior of fires within the boreal forest landscape. Many authors who have studied charcoal deposits within the boreal forest have expressed similar trends in the distribution of charcoal (Patterson *et al.*, 1987; Ohlson *et al.*, 2009). Variation occurs in charcoal deposits both in lake sediments and peat (Preston, 2009). Lake sediment charcoal variations are explained by the varied pathways through which they are transported and deposited. These include direct deposition from spreading near-by fires, transport by runoffs into lakes and transport of airborne charcoal particles by wind (Long & Whitlock, 2002).

Within peat or soil core variation in charcoal distribution reflects macro and microclimatic differences, as well as vegetation and terrain complexities. There were marked differences in the three main forest landscape types selected. Forest landscapes types assessed to have fire occurrence within the recent 300 years, recorded higher mass of charcoal as compared to the rest. However, there were no obvious similarities in the charcoal mass quantities from the five macro sample plots in this category. Similarly, landscapes with no fire in the recent 300 years, and landscape types associated with historic summer farms showed no obvious trends in the charcoal amounts.

Trillemarka-Rollagsfjell is an old growth mixed coniferous forest landscape and the portion where this study was carried out was not typically homogenous landscape. The observed differences in specific local vegetation composition and basal area indicate possible variations in local terrain conditions and microclimatic conditions. For instance, dominance of Norway spruce and pine trees alternated among the macro sample plots. The proportions of these species have been shown to influence the fire regime significantly to a landscape scale (Korovin, 1996; Ohlson & Tryterud, 1999; Ohlson *et al.*, 2011). Basal area per hectare varied from a low of 14.2 to 34.9, but there was no correlation between total basal area alone and mass of macroscopic charcoal. Basal area of dead trees component correlated significantly with mass of macroscopic charcoal obtained from the macro sample plots. This supports the argument that fires tend to be more frequent with abundance of readily combustible fuels, given other suitable macroclimatic conditions and ignition factors. Dead trees would normally contribute more suitable biomass fuel than living trees (Johnson, 1996;

Thonicke *et al.*, 2001; Bergeron *et al.*, 2004). There were charcoal deposits in all the macro sample plots selected but whereas every soil sample from Fjøslien had charcoal, only six samples produced charcoal in Geiteskallen. Over all, the macro sample plots were not significantly different with regards to the number of sampling positions that produced macroscopic charcoal but were significantly different in terms of the quantities of macroscopic charcoal that were obtained from each. Terrain conditions such as topography, physical differences in the geology of sites like the soil moisture content from one macro sample plot to the other and the distribution and condition of organic material, may all influence the fire regime at a landscape scale regarding variations in macro sample plots (Zackrisson, 1977; Bonan & Shugart, 1989).



**Figure 7: Variation in the distribution of macroscopic charcoal between macro sample plots illustrated here by photographs of samples from Gudbrandseterfjellet (landscape type N) and Moslontjenn (landscape type F). Photo: Author.**

Each of the 15 macro sample plots measured about 90 ha on the average and presented relatively more similar landscape within than when comparing between different macro sample plots. In contrast, variations in macroscopic charcoal quantities obtained from the sampling positions were consistently evident throughout the macro sample plots and were just as pronounced. This has often been reported in previous studies about soil charcoal deposits. Ohlson and Tryterud documented variation at fine spatial scales in an experiment to quantify the production and distribution of charcoal inside and outside burn areas in boreal Scandinavia (Ohlson & Tryterud, 2000). Kristoffersen and Haugmo also reported similar variations at very fine spatial scales in studies from northern and southern Norway (Kristoffersen, 2002; Haugmo, 2004).

Within macro sample plots, the mosaic pattern of boreal forest fires seems to be legitimate explanation for the variations reflected in the amount of macroscopic charcoal obtained. Fires in the

boreal forest are noted for spatial and temporal variations in pattern that result in a mosaic of burned and unburned patches after many fire incidents. These patterns are often explained to reflect the dynamics in the microclimatic conditions of the sites and vegetation composition effects to fine spatial and temporal scales (Morgan *et al.*, 2001). The level of fuel accumulated within the forest influences the start and spread of fire. Fuel accumulation is affected by the composition and rate of productivity of the vegetation. To start a fire, Thonicke and colleagues explain that fuel load requires a minimum temperature threshold to allow successful ignition. This is determined by the climate. There need also to be a minimum threshold of moisture content within the fuel load beyond which fire ignited will be extinguished or prevented from spreading. This they termed 'moisture of extinction'. Perhaps more specific to the site is the fuel load required to sustain a fire and its spreading within the site. Thonicke and colleagues, citing Schultz, reported that fuel load must reach a minimum of  $200\text{gm}^{-2}$  below which fire spread is almost impossible regardless of favorable climatic conditions at the site. (Schultz, 1988). They observed that many ecosystems that experience discontinuous fuel load at some point in their successional processes are characterized by little or no fire occurrence during those periods (Thonicke *et al.*, 2001; Long & Whitlock, 2002). This means that fire can only spread when the minimum fuel load threshold is exceeded regardless of favorable climate and other conditions. However, where the fuel load is above the threshold, climatic conditions can be considered as the most important factor for fire ignition and spread (Schimmel & Granström, 1997; Thonicke *et al.*, 2001). This relates that microclimatic conditions may be as important as regional or national conditions as far as the fire regime is concerned and are important in explaining fire behavior even to very fine spatial scale.



**Figure 8: Variation within a macro sample plot shown here by photographs of two macroscopic charcoal samples, both from Moslontjenn (F). Photo by Author.**



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## APPENDIX 1

### Kruskal-Wallis Test: CHARCOAL MASS versus LANDSCAPE TYPE

Since the normality test on my data showed that it deviates from normality, I used this Kruskal-Wallis one way ANOVA non-parametric statistical software to analyze the charcoal mass data. I set the significance level for these analyses at  $p\text{-value} \leq 0.05$ .

#### Kruskal-Wallis Test on CHARCOAL MASS

LANDSCAPE TYPE	N	Median	Ave Rank	Z
HISTORIC WILDFIRES	5	12,58	5,0	-1,84
RECENT WILDFIRES	5	35,53	10,6	1,59
SUMMER FARMS	5	28,55	8,4	0,24
Overall	15	8,0		
H = 3,98 DF = 2 P = 0,137				

### Kruskal-Wallis Test: CHARCOAL MASS(g) versus SAMPLE PLOT

#### Kruskal-Wallis Test on CHARCOAL MASS(g)

SAMPLE PLOT	N	Median	Ave Rank	Z
Bergestulen	9	10,500	76,1	-0,06
Bjørnemyråsen	7	1,700	43,9	-2,03
Båsumsetra	9	22,400	85,7	0,61
Fjøslien	15	35,500	101,1	2,21
Geiteskallen	6	6,550	67,9	-0,51
Grønli tjønn	11	7,700	80,0	0,24
Gudbrandseterfjellet	10	14,200	76,5	-0,04
Holmesjønn	9	2,300	33,2	-3,06
Langebakksetern	9	3,800	69,3	-0,54
Langseterfjellet	8	8,450	88,3	0,74
Litjenn	14	21,100	91,8	1,31
Moslontjenn	11	9,400	84,9	0,61
Nåsåsetern	8	11,150	79,0	0,13
Seteråsen	14	2,350	55,7	-1,89
Steinfjellet	13	19,600	91,5	1,24
Overall	153	77,0		

H = 25,16 DF = 14 P = 0,033

H = 25,16 DF = 14 P = 0,033 (adjusted for ties)

### Mann-Whitney Test and CI: RECENT WILDFIRES; HISTORIC WILDFIRES

I performed the Mann-Whitney test to compare the landscape types for differences with regards to the amount of macroscopic charcoal (p-value  $\leq 0.05$ ).

	N	Median
RECENT WILDFIRES	5	35,53
HISTORIC WILDFIRES	5	12,58

Point estimate for ETA1-ETA2 is 26,82

96,3 Percent CI for ETA1-ETA2 is (-1,63;54,25)

W = 36,0

Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at **0,0947**

### Mann-Whitney Test and CI: RECENT WILDFIRES; SUMMER FARMS

	N	Median
RECENT WILDFIRES	5	35,53
SUMMER FARMS	5	28,55

Point estimate for ETA1-ETA2 is 13,17

96,3 Percent CI for ETA1-ETA2 is (-43,32;38,34)

W = 32,0

Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at **0,4034**

### Mann-Whitney Test and CI: HISTORIC WILDFIRES; SUMMER FARMS

	N	Median
HISTORIC WILDFIRES	5	12,58
SUMMER FARMS	5	28,55

Point estimate for ETA1-ETA2 is -13,65

96,3 Percent CI for ETA1-ETA2 is (-66,30;15,37)

W = 21,0

Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at **0,2101**

## APPENDIX 2

**Regression analyses were performed to show the relationship between the mass of macroscopic charcoal and the forest components (p-value  $\leq 0.05$ ) .**

### Regression Analysis: Total Charcoal Mass versus Spruce; Pine; ...

The regression equation is

$$\text{Total Charcoal Mass} = -0,76 + 0,030 \text{ Spruce} + 0,304 \text{ Pine} - 0,033 \text{ Birch} \\ + 0,604 \text{ Aspen} + 0,56 \text{ Rowan} + 0,626 \text{ Dead}$$

Predictor	Coef	SE Coef	T	P
Constant	-0,759	3,658	-0,21	0,841
Spruce	0,0301	0,1342	0,22	0,828
Pine	0,3038	0,2514	1,21	0,261
Birch	-0,0327	0,2118	-0,15	0,881
Aspen	0,6041	0,8709	0,69	0,508
Rowan	0,561	1,576	0,36	0,731
Dead	0,6257	0,7956	0,79	0,454

S = 2,06310 R-Sq = 49,9% R-Sq(adj) = 12,4%

### Analysis of Variance

Source	DF	SS	MS	F	P
Regression	6	33,939	5,657	1,33	0,345
Residual Error	8	34,051	4,256		
Total	14	67,990			

Source	DF	Seq SS
Spruce	1	0,504
Pine	1	0,099
Birch	1	0,131
Aspen	1	28,525
Rowan	1	2,048
Dead	1	2,633

### Unusual Observations

Total Charcoal	St
Obs	Spruce Mass Fit SE Fit Residual Resid
2	17,0 7,886 7,886 2,063 0,000 * X

X denotes an observation whose X value gives it large leverage.



### Regression Analysis: Total Charcoal Mass versus Spruce; Pine; ...

The regression equation is

$$\text{Total Charcoal Mass} = -0,69 + 0,026 \text{ Spruce} + 0,294 \text{ Pine} + 0,643 \text{ Aspen} \\ + 0,56 \text{ Rowan} + 0,593 \text{ Dead}$$

Predictor	Coef	SE Coef	T	P
Constant	-0,695	3,432	-0,20	0,844
Spruce	0,0256	0,1238	0,21	0,841
Pine	0,2941	0,2299	1,28	0,233
Aspen	0,6434	0,7864	0,82	0,434
Rowan	0,563	1,488	0,38	0,714
Dead	0,5931	0,7244	0,82	0,434

S = 1,94801 R-Sq = 49,8% R-Sq(adj) = 21,9%

#### Analysis of Variance

Source	DF	SS	MS	F	P
Regression	5	33,837	6,767	1,78	0,212
Residual Error	9	34,153	3,795		
Total	14	67,990			

Source	DF	Seq SS
Spruce	1	0,504
Pine	1	0,099
Aspen	1	28,587
Rowan	1	2,103
Dead	1	2,544

#### Unusual Observations

Total Charcoal		St			
Obs	Spruce	Mass	Fit	SE Fit	Residual
2	17,0	7,886	7,886	1,948	-0,000
					* X

X denotes an observation whose X value gives it large leverage.

### Regression Analysis: Total Charcoal Mass versus Pine; Aspen; Rowan; Dead

The regression equation is

$$\text{Total Charcoal Mass} = -0,12 + 0,260 \text{ Pine} + 0,646 \text{ Aspen} + 0,51 \text{ Rowan} \\ + 0,587 \text{ Dead}$$

Predictor	Coef	SE Coef	T	P
Constant	-0,120	1,918	-0,06	0,951
Pine	0,2604	0,1541	1,69	0,122
Aspen	0,6455	0,7477	0,86	0,408
Rowan	0,512	1,396	0,37	0,721
Dead	0,5873	0,6883	0,85	0,413

S = 1,85244 R-Sq = 49,5% R-Sq(adj) = 29,3%

### Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	33,675	8,419	2,45	0,114
Residual Error	10	34,315	3,432		
Total	14	67,990			

Source	DF	Seq SS
Pine	1	0,084
Aspen	1	29,102
Rowan	1	1,990
Dead	1	2,498

### Unusual Observations

Total Charcoal	St
Obs Pine Mass Fit SE Fit Residual Resid	
2 1,0 7,886 7,886 1,852 -0,000 * X	

X denotes an observation whose X value gives it large leverage.

### Regression Analysis: Total Charcoal Mass versus Pine; Aspen; Dead

The regression equation is

$$\text{Total Charcoal Mass} = -0,11 + 0,249 \text{ Pine} + 0,667 \text{ Aspen} + 0,686 \text{ Dead}$$

Predictor	Coef	SE Coef	T	P
Constant	-0,108	1,841	-0,06	0,954
Pine	0,2493	0,1451	1,72	0,114
Aspen	0,6672	0,7155	0,93	0,371
Dead	0,6862	0,6080	1,13	0,283

$$S = 1,77810 \quad R\text{-Sq} = 48,8\% \quad R\text{-Sq}(\text{adj}) = 34,9\%$$

### Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	33,212	11,071	3,50	0,053
Residual Error	11	34,778	3,162		
Total	14	67,990			

Source	DF	Seq SS
Pine	1	0,084
Aspen	1	29,102
Dead	1	4,026

## Unusual Observations

Total Charcoal				St		
Obs	Pine	Mass	Fit	SE Fit	Residual	Resid
2	1,0	7,886	7,886	1,778	-0,000	* X

X denotes an observation whose X value gives it large leverage.

## Regression Analysis: Total Charcoal Mass versus Pine; Dead

The regression equation is

$$\text{Total Charcoal Mass} = -0,94 + 0,261 \text{ Pine} + 1,14 \text{ Dead}$$

Predictor	Coef	SE Coef	T	P
Constant	-0,940	1,602	-0,59	0,568
Pine	0,2607	0,1438	1,81	0,095
Dead	1,1381	0,3652	3,12	0,009

S = 1,76841 R-Sq = 44,8% R-Sq(adj) = 35,6%

## Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	30,463	15,231	4,87	0,028
Residual Error	12	37,527	3,127		
Total	14	67,990			

Source	DF	Seq SS
Pine	1	0,084
Dead	1	30,379

## Unusual Observations

Total Charcoal				St		
Obs	Pine	Mass	Fit	SE Fit	Residual	St Resid
2	1,0	7,886	7,003	1,497	0,883	0,94 X

X denotes an observation whose X value gives it large leverage.

## Regression Analysis: Charcoal Mass versus Dead

The regression equation is

$$\text{Charcoal Mass} = 1,58 + 0,782 \text{ Dead}$$

Predictor	Coef	SE Coef	T	P
Constant	1,5772	0,8664	1,82	0,092
Dead	0,7824	0,3340	2,34	0,036

S = 1,91765 R-Sq = 29,7% R-Sq(adj) = 24,3%

## Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	20,184	20,184	5,49	0,036
Residual Error	13	47,806	3,677		
Total	14	67,990			

## Unusual Observations

	Charcoal					
Obs	Dead	Mass	Fit	SE Fit	Residual	St Resid
2	6,75	7,886	6,859	1,621	1,027	1,00 X
3	1,50	6,684	2,751	0,538	3,933	2,14R

R denotes an observation with a large standardized residual.  
X denotes an observation whose X value gives it large leverage.

## Regression Analysis: Charcoal Mass versus Spruce

The regression equation is

$$\text{Charcoal Mass} = 3,62 - 0,0305 \text{ Spruce}$$

Predictor	Coef	SE Coef	T	P
Constant	3,623	1,356	2,67	0,019
Spruce	-0,03048	0,09784	-0,31	0,760

S = 2,27843 R-Sq = 0,7% R-Sq(adj) = 0,0%

### Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0,504	0,504	0,10	0,760
Residual Error	13	67,486	5,191		
Total	14	67,990			

Unusual Observations

Charcoal

Obs	Spruce	Mass	Fit	SE Fit	Residual	St Resid
2	17,0	7,886	3,105	0,736	4,781	2,22R

R denotes an observation with a large standardized residual.

### Regression Analysis: Charcoal Mass versus Pine

The regression equation is

$$\text{Charcoal Mass} = 3,11 + 0,020 \text{ Pine}$$

Predictor	Coef	SE Coef	T	P
Constant	3,108	1,212	2,57	0,023
Pine	0,0199	0,1567	0,13	0,901

S = 2,28550 R-Sq = 0,1% R-Sq(adj) = 0,0%

### Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0,084	0,084	0,02	0,901
Residual Error	13	67,906	5,224		
Total	14	67,990			

Unusual Observations

Charcoal

Obs	Pine	Mass	Fit	SE Fit	Residual	St Resid
2	1,0	7,886	3,128	1,077	4,758	2,36R

R denotes an observation with a large standardized residual.

## Regression Analysis: CHARCOAL MASS versus Total Basal Area

The regression equation is

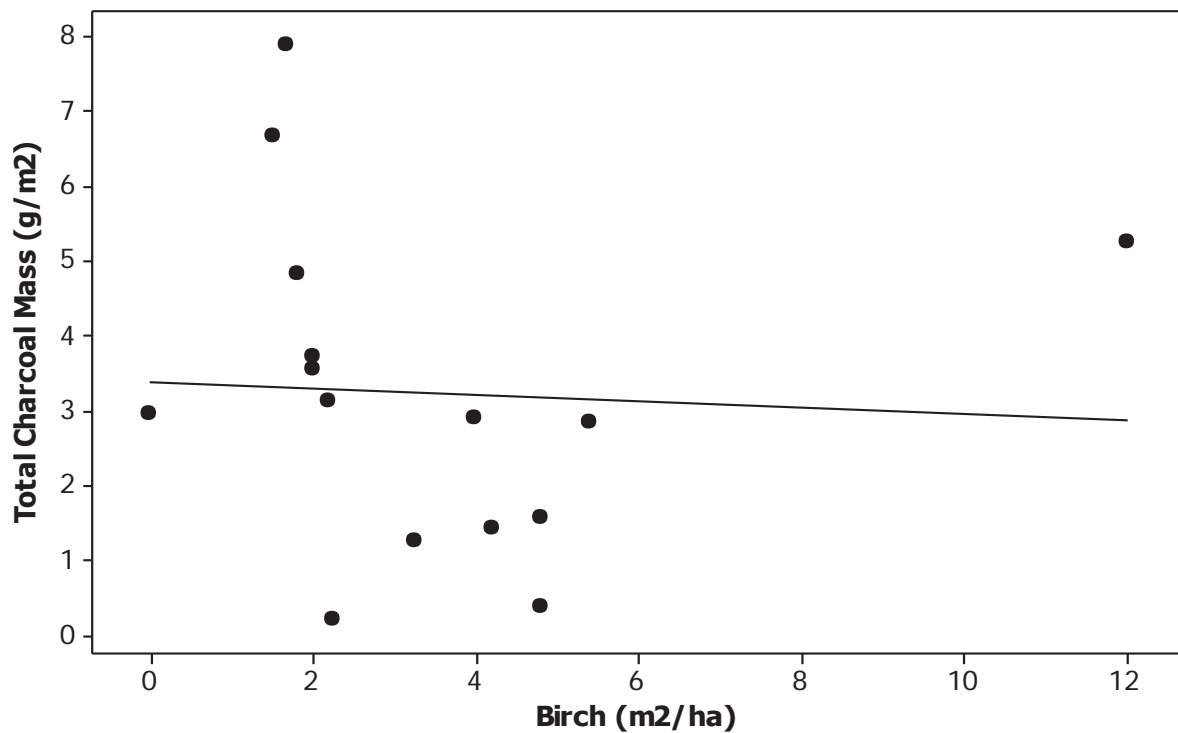
$$\text{CHARCOAL MASS} = 13.87 + 0.7299 \text{ Total Basal Area}$$

$S = 22.4097$   $R\text{-Sq} = 4.0\%$   $R\text{-Sq}(\text{adj}) = 0.0\%$

### Analysis of Variance

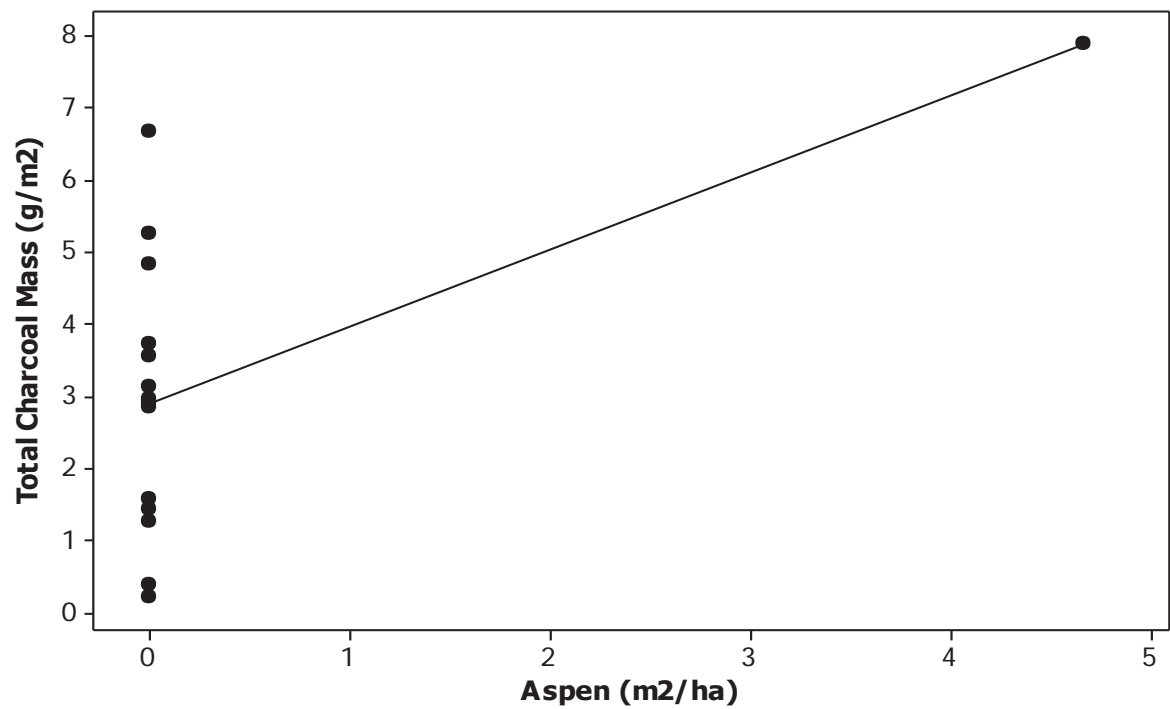
Source	DF	SS	MS	F	P
Regression	1	270.47	270.472	0.54	0.476
Error	13	6528.55	502.196		
Total	14	6799.02			

### Scatterplot of Total Charcoal Mass (g/m<sup>2</sup>) vs Birch (m<sup>2</sup>/ha)

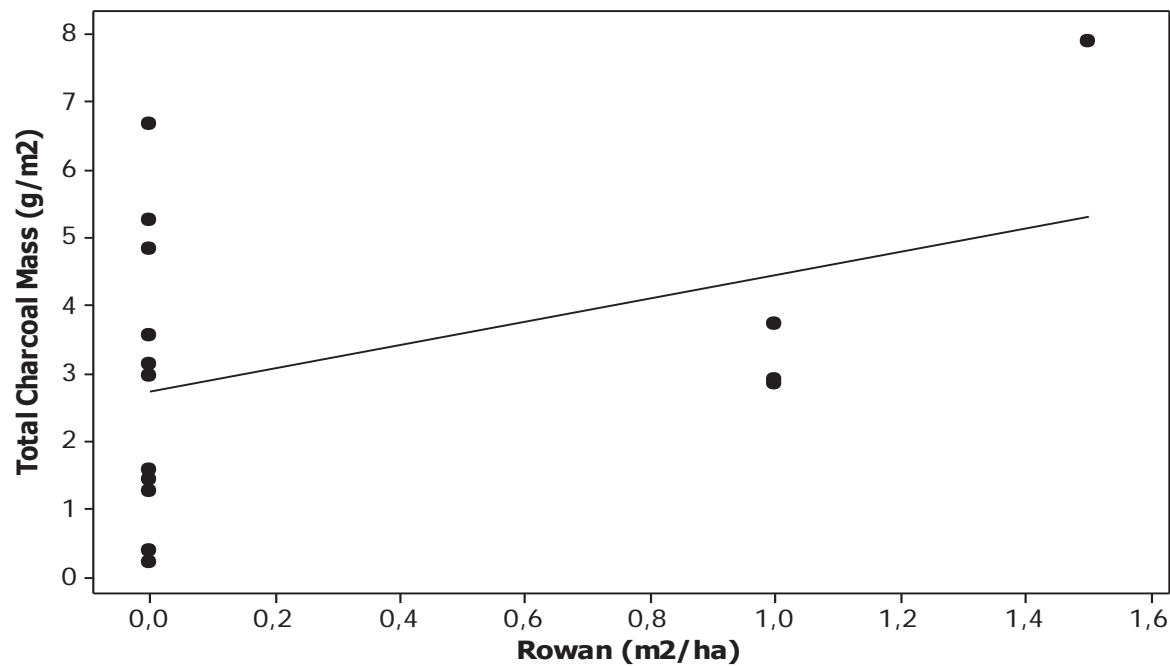




Scatterplot of Total Charcoal Mass (g/m2) vs Aspen (m2/ha)



Scatterplot of Total Charcoal Mass (g/m2) vs Rowan (m2/ha)



### APPENDIX 3

#### Forest composition and macroscopic charcoal mass data (g).

	Logging	Basal area											
Name	Cut stumps/ha	Total	Spruce	Pine	Birch	Aspen	Rowan	Willow	Deciduous tot	Dead	Height	Volume tot	Mean age
Bergstulen	38.8	28.9	14.7	7.8	4.2	0.0	0.0	0.0	4.2	2.2	16.8	229.3	166.1
Bjørnemyråsen	49.2	29.5	15.0	8.5	4.8	0.0	0.0	0.0	4.8	1.2	17.5	241.8	135.3
Båsumsetra	36.3	22.5	14.7	4.0	1.8	0.0	0.0	0.0	1.8	2.0	14.5	135.5	120.2
Fjøslien	16.7	32.6	17.0	1.0	1.7	4.7	1.5	0.0	7.8	6.8	19.4	238.8	112.8
Geiteskallen	55.8	14.2	1.6	9.3	3.3	0.0	0.0	0.0	3.3	0.0	13.6	86.7	134.7
Gudbrandseterfjellet	7.5	16.8	3.3	12.5	0.0	0.0	0.0	0.0	0.0	1.0	10.3	85.8	163.3
Grønnlitjønn	62.5	24.2	16.8	4.0	2.2	0.0	0.0	0.0	2.2	1.2	13.2	131.2	172.2
Holmesjønn	2.9	24.7	15.7	4.0	2.3	0.0	0.0	0.0	2.3	2.8	11.9	137.2	140.7
Langebakksetern	58.8	34.9	22.0	5.0	5.4	0.0	1.0	0.0	6.4	1.5	15.8	237.2	93.2
Langseterfjellet	15.8	22.0	13.2	2.7	2.0	0.0	1.0	0.0	3.0	3.2	15.1	149.8	151.4
Litjenn	68.8	24.8	7.3	14.5	1.5	0.0	0.0	0.0	1.5	1.5	16.6	187.7	219.8
Moslontjenn	76.3	32.7	7.5	10.7	12.0	0.0	0.0	0.0	12.0	2.5	15.8	179	121.1
Nåsåster	46.7	30.7	21.5	2.7	4.8	0.0	0.0	0.0	4.8	1.8	19.8	263.2	94.4
Seteråsen	14.2	20.2	5.4	6.8	4.0	0.0	1.0	0.0	5.0	3.0	8.8	88.7	177.6
Steinfjellet	20.8	22.8	11.7	7.8	2.0	0.0	0.0	0.0	2.0	1.3	15.6	150.3	153.5
MEDIAN	40.3	24.8	12.0	6.7	3.5	0.3	0.3	0.0	4.1	2.0	14.8	164.4	140.9
SE	6.38	1.65	1.64	0.97	0.70	0.30	0.13	0.00	0.75	0.41	0.77	16.11	8.93
STDV	24.71	6.41	6.34	3.77	2.71	1.17	0.52	0.00	2.89	1.58	3.00	62.41	34.60

<u>Moslont</u>	<u>Fjøl</u>	<u>Litje</u>	<u>Nåsåset</u>	<u>Gudbrands</u>	<u>Steinfj</u>	<u>Grønlit</u>	<u>Båsum</u>	<u>Langsete</u>	<u>Bergest</u>	<u>Langeba</u>	<u>Geiteska</u>	<u>Seterås</u>	<u>Holmes</u>	<u>Bjørne</u>
0.061	0.025	0.002	0.05	0.003	0.029	1.503	0.022	0.08	0.047	0.174	0.029	0.147	0.023	0.008
0.094	0.044	0.017	0.715	0.712	0.003	0.054	1.202	0.059	0.032	0.014	0.031	0.009	0.037	0.035
0.002	0.355	0.036	0.089	0.01	0.2	0.005	1.267	0.089	0.282	0.453	0.1	0.008	0.006	0.011
1.144	0.527	0.14	0.022	0.177	0.196	0.862	0.224	1.788	0.12	1.958	0.169	0.027	0.025	0.225
0.409	0.097	0.282	0.012	0.016	0.088	0.055	0.368	0.042	0.607	0.002	0.924	0.827	0.059	0.007
0.05	0.252	0.031	0.393	0.315	0.147	0.044	1.69	0.045	0.105	0.022	0.005	0.062	0.002	0.017
0.288	1.207	1.063	0.165	0.018	0.901	0.044	0.006	0.11	0.039	0.038		0.004	0.005	0.086
0.294	0.059	0.13	0.134	0.258	0.053	0.137	0.047	1.502	0.181	0.163		0.02	0.021	
2.855	2.199	1.47		1.345	0.142	0.247	0.007		0.01	0.031		0.015	0.037	
0.045	0.164	2.097		0.107	0.265	0.11						0.014		
0.014	0.372	0.105			0.645	0.077						0.008		
	0.559	0.293			0.299							0.142		
	0.937	0.501			0.585							0.051		
	1.08	0.517										1.563		
	0.009													