CARBON POOLS AND THEIR SPATIAL DISTRIBUTION IN FOUR SCOTS PINE FOREST ECOSYSTEMS, SOUTHEAST NORWAY

KSENIA METLYAEVA

Norwegian University of Life Sciences
Department of Ecology and Natural Resource Management
Master Thesis 60 credits 2009

PREFACE

This is a thesis in Ecology at the Department of Ecology and Natural Recourse Management, Norwegian University of Life Sciences (UMB). First I would like to thank my supervisor professor Mikael Ohlson for his valuable advices, comments and great support through all my work with this Master thesis. I would also like to thank PhD-student Terje Kristensen for his help and for his optimism and enthusiasm. Further, I would like to thank Sigurd Hoel and Honorata Gaida for the great help in field work and good company. Finally, thanks goes to my family for their patience and support, and especially to my grandmother Valenitina Opilatova who always said to me the words of Karl Marx:

"There is no royal road to science, and only those who do not dread the fatiguing climb of its steep paths have a chance of gaining its luminous summits"

Karl Marx, Das Kapital, Vol 1

Ås 15th December 2009

Ksenia Metlyaeva

SUMMARY

The main goal of my study was to examine above and below ground carbon pools and their variability across fine spatial scales in Scots pine (*Pinus sylvestris*) forests situated in the Aurskog – Høland county, southeast Norway.

Two methodological approaches for measuring carbon were applied: a systematic sampling scheme across the entire study sites (M1) and a tree centered sampling scheme around a set of randomly selected large trees (M2). The former sampling scheme was chosen in order to obtain a representative estimate of the amount of carbon in a common boreal forest type in Norway, whereas the other sampling scheme was chosen in order to investigate the influence of trees on soil carbon, as well as on carbon accumulated in the forest ground- and field layer vegetation. The carbon pools were calculated for the following compartments: field layer vegetation, trees, bryophytes and organic top-soil. The maximum depth for soil sampling was 15 cm in both methodological approaches (M1, M2). For M2 the effects of distance and direction from the trees on carbon pools were analyzed. The relationship between soil depth and carbon amount was also analyzed in M2. In this case the full length of the sample was taken, not only the top 15 cm. Totally, 1470 samples (bryophytes, field vegetation, soil and the different depths) were examined.

Using M1 I found significant differences in carbon pools between study sites, both with regard to the amount of carbon (quantitatively) and the carbon content (qualitatively). The average total amount of carbon over all study sites was 7,4 kg/m^2. The highest amount of carbon was accumulated in living vegetation (51%), mainly in trees (50%). The carbon pools for field layer vegetation and bryophytes were very small in comparison (1%). For below ground layers the carbon pool was distributed as follows: soil (32%), roots and stub (17%).

M2 gave lower carbon pool measurements than M1. The mean carbon values were 2,5 kg/m^2 for Method 1 and 1,0 kg/m^2 for Method 2 (trees excluded, including soil, field layer vegetation, bryophytes). The carbon amount in bryophytes and soil increased significantly with increasing distance from the tree, but the carbon amount in field layer vegetation showed no such relationship. The direction from tree effect was significant for bryophytes and field layer vegetation, but not significant for soil. The depth effect was non-significant for soil carbon, but a decreasing carbon trend with increasing soil depth was observed.

My results showed that the variation between the studied forests was small with regard to the average size of the carbon pool, although there was a considerable variation across fine spatial scales in all forests. The study also indicated that the carbon pools are structured by the large trees, mainly as a result of the distribution of organic mass in general, and not as a result of an effect on carbon amount in the soil.

CONTENT

1. INTRODUCTION

The CO_2 level is known to have a great influence on the climate of our planet. Fossil fuel is one of the largest sources of CO_2 emission (Cohen et al. 1996). The industrial revolution caused the concentration of atmospheric CO_2 to increase from the pre-industrial level of 280 ppm to 384 ppm in 2007, and it is still increasing at a rate of about 1,5 ppm per year (Malhi 1999; IPCC 2007). Another importance source of CO_2 is deforestation and land use that release big amounts of CO_2 into the atmosphere. These and other issues have resulted in an increased attention towards carbon pools and the carbon balance in forest ecosystems.

Forest's ecosystems function as "atmospheric filters" of CO_2 (Neilson et al. 2007). The CO_2 level is connected with carbon balance in the forest ecosystems. Globally, these systems are the most important terrestrial carbon sources in the world. Forest ecosystems cover 30% of land surface, but at the same time they contain more than 60% of global terrestrial carbon (Walle et al. 2000). The forest is a complex system. The carbon balance ecosystem is controlled by two opposite processes: 1) fixation of CO_2 into the ecosystem caused by photosynthesis, forest growth and soil carbon accumulation, and 2) release of CO_2 from the ecosystem caused by tree mortality, soil carbon and litter decomposition (Malhi 1999). A change in this balance caused by climate change, forest clearance, degradation, and other factors can entail fundamental consequences for the global carbon (C) cycle and the climate (Walle 2000; Powlson 2005; Kleja et al. 2008). It is important to keep in mind that the forest ecosystems have accumulated huge amount of C during long periods of time, but due to disturbances and misbalances in the ecosystems these huge quantities can be released within a very short period of time (Pregitzer 2004).

Boreal forests cover a large land-area of about 13,7 million km^2 and hold about 20% of global terrestrial C (Karjalainen 1996; Grace 2004). Within the boreal forest ecosystem the soil holds the majority of the carbon. In the study by Liski & Westman (1995) it was concluded that there is twice as much carbon stored in soil organic matter as in the atmosphere. Further, the study showed that about 15% of the global terrestrial carbon storage is contained in the soil of boreal forests (wetlands excluded).

Climate changes and increasing atmospheric temperature can influence the amount of soil carbon stored in the forest ecosystems in different ways. Lately, many studies have tried to suggest and model how an increasing temperature will influence the flux of carbon between the atmosphere and the forest ecosystem. For instance, Knorr et al. (2005) predict that higher temperature will increased microorganism activity in the soil and lead to the release of additional CO_2 in the atmosphere. As a result climate changes and temperature increase will be speeded up (Knorr et al. 2005). However, other scientists argue that the turnover time of the organic soil carbon pool is almost independent of mean annual temperatures (Giardina & Ryan 2000). Due to additional factors and complex interactions in soils it is difficult to predict soil responses. Therefore knowledge about carbon storage and dynamics in boreal forest is very important for obtaining reliable knowledge and getting more precise predictions about further global changes. To get better estimation of the amount of carbon in the world and in forest soils in particular, it is important to study the spatial patterns of carbon at fine spatial scales (Liski & Westamn 1997).

When it comes to the boreal forests in Fennoscandinavia there have been several studies aiming at calculating and analyzing carbon pools and fluxes. Numerous studies have been conducted in Finland. For instance, Ilvesniemi et al. (2002), and Finer et al. (2003) studied changes in carbon pool in Finnish boreal forest associated with clear cutting. They indicate significant effects of clear-cutting on C pools and fluxes. Liski & Westman (1995) analyzed carbon storage in forest soils of Finland. Kolari (2004) studied the carbon flux between the atmosphere and Finnish Scots pine forests of different age and did not find any evidence of carbon sink strength reduction in connection to increasing forest age. An interesting large scale stem-girdling experiment in boreal Scots pine forest in northern Sweden was done by Högberg et al. (2002). The experiment showed that flux of photosynthesis has big influence on soil respiration. In addition these processes were most controlled by seasonal patterns. A gap-type simulation model was applied to a Finnish forest to predict changes in C level storage in connection to different climate scenario. The experiment provided long-term predictions (100 year, 200 years), and the results showed decreasing C storage in response to climate warming. Net ecosystem production (NEP) had a complex response to climate change, specific to different tree species.

Some studies have been conducted in Norway as well. Clarke et al. (2007) studied the variation in the concentration of DOC (Dissolved organic carbon concentrations) in four Norway spruce stands at Nordmoen. The results showed significant effect of stand age on DOC concentration (throuhfall and O horizons) and DOC fluxes (only throughfall). Another study by Wit et al. (2006) estimated carbon budget in forest biomass in soils in the south-eastern part of Norway. The calculation involved forest resource data, biomass expansion and turnover factors and a dynamical soil model. Callesen et al. (2003) analyzed the relationship between 300 forest soil profiles and climate within the countries Sweden, Finland and Norway. The study showed a positive relationship between SOC (soil organic carbon) pools on one side and temperature and precipitation on the other. Despite several studies, including the above mentioned, it is still a demand for better knowledge about carbon patterns and polls in Norwegian boreal forest.

My study aimed at providing detailed information about carbon pools in a common Norwegian boreal forest type. The main aim of my study was to estimate the distribution of carbon and biomass on fine spatial scales in Norwegian boreal Scots pine forests. For this purpose four study sites located in Aurskog-Høland municipality were analyzed. Two methods for measuring carbon both above ground and below ground were applied: a systematic sampling scheme across the entire study sites and an alternative sampling scheme around a set of the ten biggest trees from every study site. The former sampling scheme was chosen in order to obtain a general picture of the carbon level in a common boreal forest type in Norway, whereas the other sampling scheme was chosen in order to investigate the influence of trees on soil carbon, as well as on carbon accumulated in bryophytes and in other field layer vegetation. I will later refer to these methods as Methods 1 and 2 or abbreviated as M1 and M2, respectively. During the research the following tasks were defined in relation to the two methodologies M1 and M2:

Specific aims for the systematic sampling across the study sites (M1):

- Calculate biomass/amount of carbon in all living components and organic top-soil
- Analyze biomass/carbon variation across study sites
- Compare the findings with those from other studies

Specific aims for the sampling around large trees (M2)

- Calculate biomass/amount of carbon in living components (bryophytes, field layer vegetation) and organic top-soil.

- Analyze tree influence on spatial soil carbon distribution with a main focus on relationship between amount of carbon and the factors distance and direction from the tree in addition to the depth.

Aim for both M1 and M2:

- Calculate carbon content in soil

- Compare the results from the two methods.

Based on previous studies and during the fieldwork, I formulated the following hypotheses and expectations, which I wanted to test:

For method 1

-Amount of biomass/carbon will vary between sites, and the expected amount of carbon will be different between study sites due to site-specific conditions.

- The trees and organic soil accumulate the most carbon/biomass.

For Method 2

- Distance and direction from big trees and the soil depth will significantly correlate with the amount of carbon for different compartments (field layer vegetation, bryophytes, organic soil).

For Method 1 and Method 2

- The expected amount of carbon around trees will be different from the general expectation level of carbon across the study sites.

2. METHODS

2.1 Study area

The study sites were located in a forest area in the Aurskog - Høland municipality in the eastern part of Akershus county, south-eastern part of Norway (59° 50′ 0″ N, 11° 34′ 0″ E) (Fig. 1). The county borders to Sweden in the east, Hedmark county in the north and Østfold county in the south (www.ahk.no). The study area has an altitude ranging from 184 to 305 m.a.s. With regard to the bedrock, this mainly consists of gneiss, granite and quartzite of Precambrian origin (Moen 1999). The territory is situated in the Boreonemoral region characterized by both boreal and nemoral features, and is a transitional zone between the nemoral deciduous forest areas and the boreal coniferous areas. According to Moen (1999) the zone consists mainly of coniferous, birch and grey alder forests.

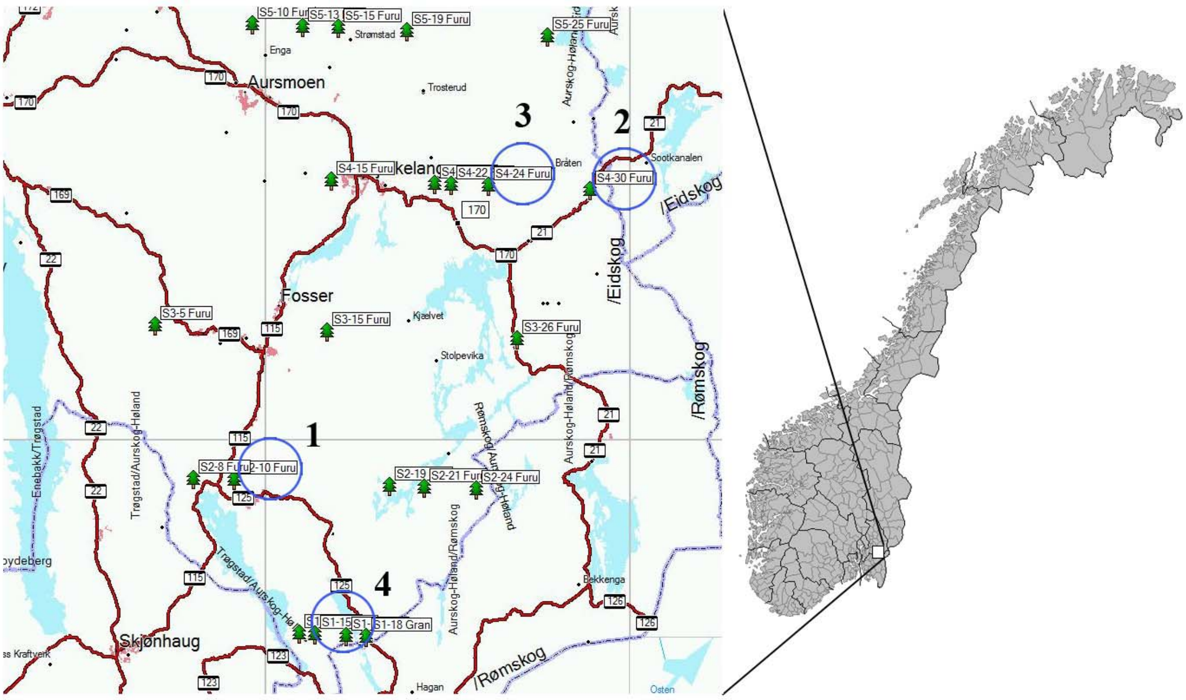


Fig. 1. Survey map showing the location of the study area (right). Location map for the four study sites (left). Green trees show all sites established in the Project. Blue circles show the study sites chosen for this research. Information in the squares explained project number for site and dominated tree species.

All study sites were situated in mature, mixed coniferous stands with Scots pine (*Pinus sylvestris* L.) as dominating species (materials from project "WoodWisdom - IRIS: New Technologies to Optimize the Wood Information Basis - Developing an Integrated Resource Information System"). Norway spruce *(Picea abies)* and birch *(Betula* spp*)* were also present in smaller numbers. Four earlier established sites (S2.10, S4.30, S4.24, and S1.15) were chosen for this study. They are hereafter referred to as study sites 1, 2, 3 and 4. Sites 1 and 4 had 49 and 57 trees respectively, while sites 2 and 3 counted higher values: 113 trees at each study site (Table 1). The field layer vegetation was dominated by bilberry (*Vaccinium myrtillus*) and the ground vegetation was dominated by featherbryophytes, mainly *Pleurozium schreberi* and *Hylocomium splendens.*

Table 1. Main characteristics for study sites

Site Nr.	Altitude (m)	Main tree species	Development class	Tree N	Age
1	185	Scots pine	5	49	120
2	279	Scots pine	3	113	65
3	306	Scots pine	3	113	55
4	230	Scots pine	4	57	85

According to Norwegian Meteorological Institute the average monthly temperature is -5,5 (°C) in January and 15 (°C) in July, while the average annual temperature is 4,5 (°C) in the area where the study sites are located. Regarding precipitation this varies from maximum 86 mm (September, October) to minimum 36 mm in February, with average total annual value of 735 mm. Reports from Fosser weather station was used for climate information for the study areas. The station is located 128 m.a.s. 11,7 km away from Fosser. The station is located 9 and 18 km northwest from study sites 1 and 4, and 19,8 and 15 km southwest from study sites 2 and 3, respectively (http://kart.statkart.no; eklima.no).

2.2 Collection of materials

The fieldwork took place during the summer 2008. Firstly, 12 previously established (project materials) study sites were inspected for the criteria for best suitability for soil sampling. The two main criteria for study site selection were: availability of soil and suitability for sampling (i.e. sites with an abundant occurrence of rock outcrops and boulders were rejected) (Fig. 2).

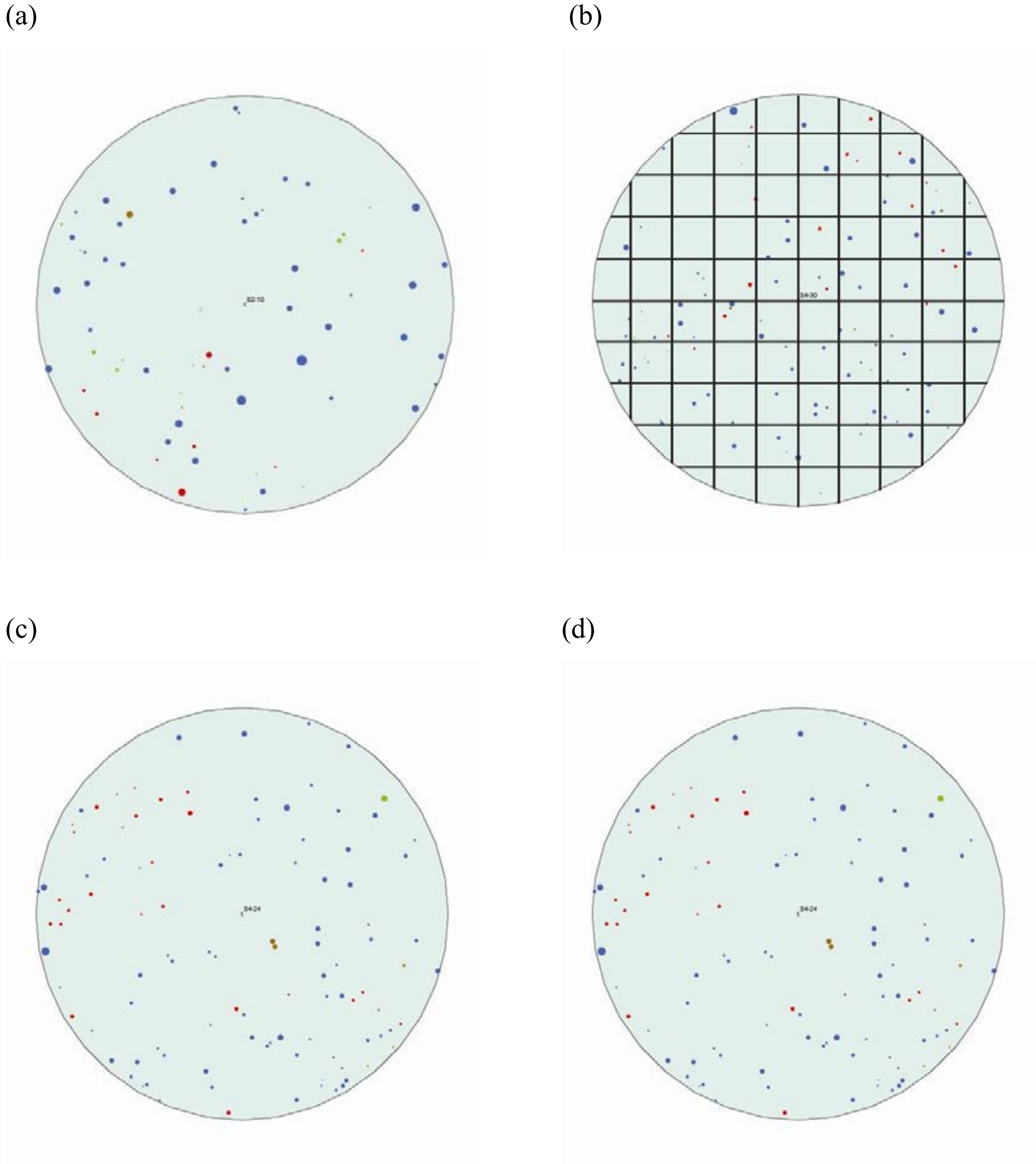


Fig. 2. Study sites maps with trees locations. Figures a, b, c, d show study sites 1,2,3,4 respectively. Figure b demonstrates example of how the sites were divided for the systematic sampling. The center of every study site is marked with a number. The spots mark the trees situated at the study sites and the spot sizes are reflecting tree sizes and colors represent tree types (blue – Scots pine, green - deciduous trees, brown - dead trees, red – Norway spruce, grey - Common Juniper (*Juniperus communis*).

During the fieldwork two sampling methodologies were applied: 1) Basic systematic sampling (M1), and 2) sampling around large trees (M2). For M1 the center of the site was found initially, and the northern direction located. Every circular site was then measured up and divided systematically into 73 plots (Fig. 1b). The distance between any pair of plots was set to be 5 meters. Firstly, all field layer vegetation was sampled within a 25x25 cm plot using a scissor. Secondly, soil and bryophyte samples were collected using a cylinder (diameter 56 mm). Soil samples were taken to the maximum depth of 15 cm and the depth of each sample was noted. The motivation for a focus on the 15 cm top-soil layer- is that this layer is rich in carbon and that this carbon pool is biologically reactive. In contrast, the carbon pool in the underlying mineral soil, which can be substantial, is more stable and will not respond as fast to climate change and forest management as the top organic soil (Finer et al. 2003). Because of this the deep mineral soil carbon pool is a less important factor with regard to climate change (Liski et al. 1999; Giardina & Ryan 2000), at least in a short-term time perspective. Vegetation, bryophytes, soil were stored in separate pre-marked paper bags. Totally, 870 samples with aboveground vascular plants, bryophytes and organic soil were collected from all study sites.

For M2 the ten pine-trees with the largest diameters were selected at every study site for analysis. Every tree was localized using coordinates and compass, since these had been located earlier in other projects made earlier at Norwegian University of Life Sciences. For every tree sampling was done at distances of 15, 31, 62, 125 and 250 cm in three different directions (0 (north), 120 (s-east), and 240 (s-west) degrees). The (above ground) biomass of bryophytes and field layer vegetation were measured and analyzed. Further, the (below ground) organic mass in soil was also sampled and analyzed. The sampling was made in the same way as for basic systematic sampling. In addition, in one random direction for each tree the soil sample was cut into 2 cm pieces and put into separate paper bags (Fig. 3).

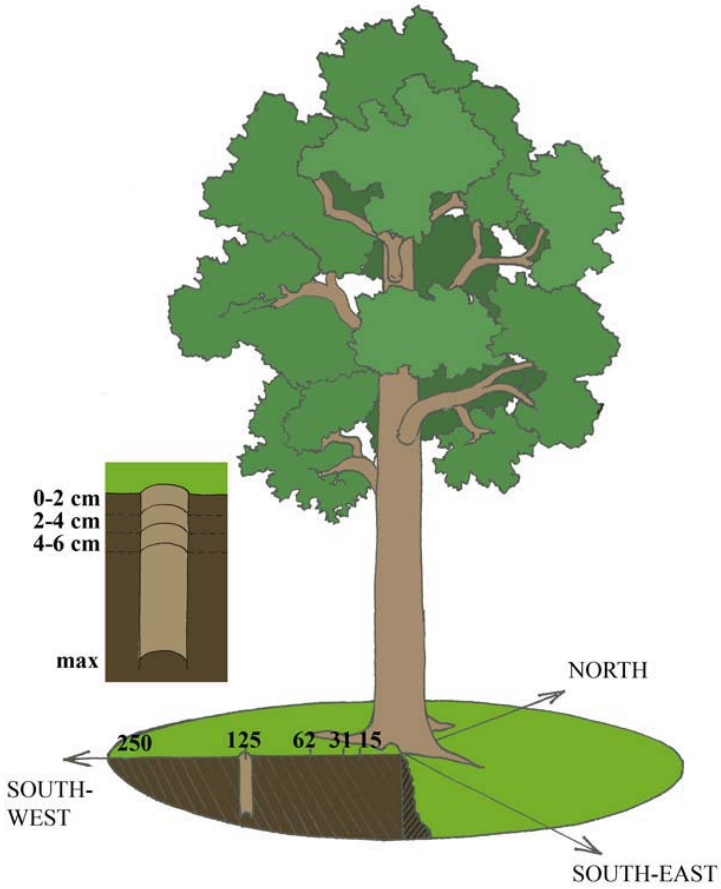


Fig. 3. Sampling schema for Method 2 (M2).

For these samples, the full length of the sample was taken (not only the top 15 cm). For M2 study sites of size 1000 m^2 was used, whereas for M1 (soil/bryophytes/vegetation) a bigger site size of 1962,5 m^2 was used. However, all results are presented as kg per m^2 and are thus comparable despite of the differences in study site sizes. Totally, 600 samples with aboveground vascular plants, bryophytes, and organic soil were collected for this analysis. The samples were then transported to the lab for further analyses.

2.3 Laboratory analyses

First of all, the samples were dried to constant weight in the dryer - room with the temperature 60° C. All soil, field layer vegetation and bryophyte samples were put into a bowl and weighed. For the soil samples divided in smaller sizes (2 cm fractions) the same procedure for weighing was followed.

Basic systematic sampling

Ten soil samples were randomly selected from every study site. These were homogenized in a mill (mesh size 2 mm), weighed, burned in an oven at 450 °C for 24 hours. The mass of the dried soil that was burned did not exceed 5 g. The site-specific amount and percentage of soil organic matter was then calculated.

Tree influence on spatial soil carbon

For carbon analyses 3 trees from every study site (totally 12 trees) were randomly selected. For each of these trees all samples in a random direction was analyzed using the same methods as described for basic systematic sampling. In addition one random tree was selected from all study sites. For this tree the samples in all directions were analyzed.

Trees (depth graduation)

For analyzing the relationship between depth and amount of carbon, all soil samples of trees, for which the sample was cut into 2 cm pieces and put into separate paper bags, were selected and examined with the same method as was applied for basic systematic sampling.

2.4 Calculations

2.4.1 Biomass

The information on tree biomass was taken from previous studies (Terje Gobakken, pers. com.) that were made at the same study sites. SE was not available for trees. The biomass was defined as total mass of living matter within a given unit of environmental area (in my case square meter). Biomass was divided into aboveground and belowground level. The aboveground biomass was calculated as the sum: stem + bark + branches + needles + dead branches + stub. The belowground biomass was defined as the sum of roots+stub and calculated using the formulas as given by Petterson & Ståhl (2006).

The organic mass was defined as total organic soil mass that has come from a once-living organism within a given unit of the environmental area (in our case- square meter). The litterfall and mineral soil were not included in this research. Biomass and organic mass content for soil, bryophytes and vegetation samples were calculated with different formulas. From the field layer vegetation samples that were collected in squares (25x25 cm) and measured in grams, the biomass (kg per square meter) was calculated by: Biomass (kg/m^2) =weight$_{(g)}$*(1002/252)/(1000). For bryophytes and soil samples which were sampled using the cylinder of diameter 5,6 cm (area = 3,14*(5,6/2)^2= 24,62 cm^2) the formula used was: Biomass (kg/m^2) = weight$_{(g)}$*(1002/24,62)/(1000).

2.4.2 Carbon

For all living components such as filed layer vegetation, bryophytes, branches, needles, roots, living trees a carbon percentage of 50% was assumed (Chapin et al. 2002). For all soil samples (systematic sampling and samples around trees) another method was applied. In this case, the C% was calculated from the field data and laboratory analyzes. For soil samples a carbon % for every study site was calculated as the mean % calculated from soil samples burned at the laboratory. This % was applied to the rest of the samples and carbon content was calculated with the following formula C=M*C%/100, where M is the mass of the dried soil sample. Further, the amount of carbon for every compartment (kg/m^2) was calculated with the same formulas that were used for biomass calculation.

2.4.3 Bulk density

Bulk density was calculated with following formula: = p_b M_s/V_t, where p_b is the bulk density, (g/dm^3), M_s is the mass of the oven dried soil and V_t is the total volume of soil.

2.5 Statistical analyses

In the analyses I have studied the carbon pool in the boreal forest in two different ways. Firstly, I have used all samples with the actual carbon measured as data, regardless of whether any biomass and organic mass was found. Many samples contained no organic soil, for instance if the sampling spot was a rock outcrop or root at the soil surface etc. The amount of carbon was thus zero, and a value of zero was also used for these samples. In the following I refer to this as a quantitative analysis of carbon amount. Secondly, for soil I have also studied the carbon content for the samples were soil was actually found. Since I was interested in studying the actual soil carbon property, all zero values were removed from the data before the analysis. This approach I refer to as qualitative analysis of carbon content in soil. This analysis was not performed for bryophytes and field layer vegetation since the same carbon content of 0,5% was assumed for both these compartments.

2.5.1 Summary statistics and plots

Simple summary statistics like mean, median, standard deviations, standard errors of the mean and range of the observations were calculated for the raw data and are presented in tables and graphs in the results section and in the appendices. In cases where mean values are presented in the text, the precision of the mean is indicated by ± 1 SE of the mean, whereas in barplots approximate 95% uncertainty intervals for the means are marked with ± 2 SE limits.

2.5.2 Kruskal-Wallis (KW) and Mann-Whitney U (MW) tests

The data collected on carbon amount were highly non-normally distributed with a long tail towards larger values. Further, there were many instances of zero-measurements. Skewed data may often be normalized by a transformation (e.g. logarithm, square root), but a large numbers of zeros in the data cannot be corrected by such a transformation. I therefore applied the Kruskal-Wallis test (Kruskal & Wallis 1952), which does not require normality, to test for differences. The KW test was used for: 1) testing differences between sites with regard to the amount of carbon in soil, bryophytes and vegetation (for both M1 and M2), 2) testing the effects of distance and direction from tree on carbon amount in soil, bryophytes and vegetation (for M2), and 3) testing the effect of depth on soil carbon amount (for M2).

The amount of carbon in the soil, bryophytes and field layer vegetation compartments as measured with M1 and M2 was compared using a Mann-Whitney U test (Mann & Whitney 1947).

2.5.3 ANOVA methods

After removing zero values and transforming the data (logarithm or square root) the data were closer to normal. For the qualitative analyses of carbon content the analysis of variance (ANOVA) (e.g Montgomery et al. 2006) could therefore be used. The ANOVA models were fitted to the data by using the R software (R Development Core Team 2008). ANOVA analyses were used for the following purposes: 1) Testing the differences in soil carbon content between sites (for M1). In order to adjust for differing volumes of the collected samples, the thickness of the samples was also included in this analysis. 2) Testing the effect of distance and direction from tree on carbon content (for M2). Also here the soil sample volume was included in the model as well as study site (levels 1,2,3 and 4). 3) An ANOVA model was also used for the analysis of the effects of depths on carbon content. In this analysis I have adjusted for other known systematic factors. The full list of factors included in the model was: study site (1,2,3,4), direction from tree (1,2,3), distance from tree (15, 31, 62, 125 and 250 cm), depth (1 (0-2 mm), 2 (2-4 mm), 3 (4-6 mm), 4 (6-8 mm), 5 (8-10 mm)) and tree (1,2,3,...,39,40).

3.RESULTS

The raw data for both sampling methods can be found in APPENDIX 1 and 2. The main results are presented below.

3.1 Systematic sampling (Method 1)

3.1.1 Biomass and organic mass

Across all study sites the average total organic mass (including all living vegetation and organic soil) was 20,4 kg/m^2. Study sites 1, 2 and 4 had a bit lower level compared to study site 2. Site 3 had the highest value (Table 2).

Table 2. Average organic mass for all study sites (kg/m^2)

Site 1	Site 2	Site 3	Site 4
18,5	19,5	24,0	19,4

Above ground biomass

The average aboveground biomass across all study sites was 7,6 kg/m^2. The highest biomass value of 9,0 was found in site 1. Study site 2 had the lowest biomass aboveground with 6,0 kg/m^2 on average. Across all study sites, the trees made up the most of the biomass, 7,4 kg/m^2, with following contribution from max to min: stem (5,1 kg/m^2), crown (1,6 kg/m^2), bark (0,5 kg/m^2) and dead branches (0,2 kg/m^2). The field layer vegetation average was 0,08 kg/m^2. Regarding the bryophytes the average mass for all study sites was 0,08 (±0,006) kg/m^2 and the range of observations was 0,0 – 0,5. The bryophyte mass differed significantly between sites (chi-squared = 27,3, df=3, $p<0{,}001$).

Below ground biomass and organic mass

Average belowground organic mass (with tree roots and stud included) across all study sites was 12,8 kg/m^2. The lowest mean of 9,6 kg/m^2 was observed at study site 1, while the highest quantity for belowground layer, e.g. 17,4 kg/m^2, was found at study site 3. The mean organic soil mass across all study sites was 10,3 (±0,8) kg/m^2. For the soil mass the extreme mean values were site 1 with value 6,5 (±1,4) kg/m^2 and study site 3 with 15,2 (±2,0) kg/m^2. There was a significant difference between sites (chi-squared = 14,2, df = 3, p = 0,003)

The average organic soil depth across all sites was 3,2 (±0,2) cm. The range of collected depths of the soil samples was 0-15 cm, but the largest observed organic soil depth of 45 cm was obtained at site 3. Across all sites the main part of the organic mass was stored at the belowground level with 51% in organic soil, 12% in tree roots and stub. The aboveground level of biomass ranged from 28% at site number 3 to 48% at site 1, with an average of 37% across all sites. The field layer vegetation and bryophytes accumulated only 1 % of aboveground biomass. There were significant differences between sites for field layer vegetation (chi-squared = 78,9, df=3, p<0,001), as well as for bryophytes (chi-squared = 27,3, df=3, p<0,001), (Fig. 4).

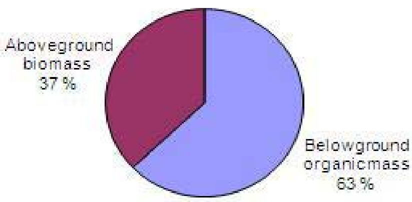


Fig. 4. The distribution of aboveground biomass and belowground and organic mass (tree roots included). For the aboveground layer the trees, field layer vegetation and bryophytes are included. For the belowground layer the tree roots and soil are included.

3.1.2 Quantitative differences - Carbon amount

The average total amount of carbon over all study sites was 7,4 kg/m^2, with the highest carbon content for study site 3 and lowest for study site 2 (Table 3). The average amount for soil carbon across study sites was 2,4 kg/m^2, with minimum and maximum values at study sites 1 and 3, respectively (Table 3, Fig. 6a). There was a significant difference between the sites as regard the amount of soil carbon (chi-squared = 16,5, df=3, p<0,001). The overall range of carbon measurements in soil was 0 to 19,1 kg/m^2. The tree values are given in table 3 and Fig. 6d.

Table 3. Average amount of carbon for all study sites (kg/m^2)

Compartment	Site 1	Site 2	Site 3	Site 4
Total trees	5,9 (*)	3,9 (*)	4,3 (*)	5,7 (*)
Soil	1,2 (0,3)	2 (0,3)	4,1 (0,5)	2,2 (0,5)
Bryophytes	0,03 (0,005)	0,06 (0,006)	0,03 (0,007)	0,03 (0,005)
Field layer vegetation	0,06 (0,003)	0,04 (0,004)	0,04 (0,004)	0,01 (0,002)
Total	7,2 (*)	6,0 (*)	8,5 (*)	7,9 (*)

SE of the mean is given in parenthesis. *SE was not available for the trees and the total.

Generally, the distribution above/below ground carbon across all study sites was similar. However site 3 appears to have higher belowground value for carbon than the others. The minimum carbon concentration in belowground and maximum in aboveground layers was obtained at site 1 (Table 4).

Table 4. Above/Belowground carbon distribution across study sites

Compartment	Site 1	Site 2	Site 3	Site 4	All sites
Above-ground	4,5	3	3,3	4,2	3,8
Below-ground	2,7	3	5,2	3,7	3,7

The organic soil held the major part of the belowground carbon, while trees accumulated most carbon in the aboveground layer. Tree roots and stub accounted for a small part of the total belowground carbon with the value of 1,3 kg/m^2 (Fig. 5). When it comes to the bryophytes and field layer vegetation, they made up only a small proportion of the total aboveground carbon (Fig. 5).

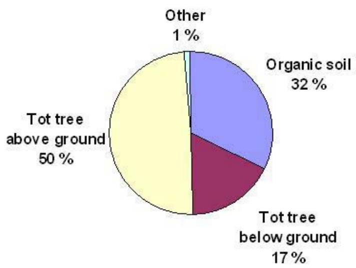


Fig. 5. Carbon distribution in belowground and aboveground layers. The category "Other" includes bryophytes and field layer vegetation. Tot. tree belowground includes tree roots and stub. Tot tree aboveground includes crown, stem, bark, stub and dead branches.

The mean carbon value across study sites for all bryophytes was found to be 0,04 (±0,003 kg/m^2). Site 2 appeared to have more carbon bound in bryophytes than the other sites, with 0,06 (±0,006) kg/m^2, while both site 1 and 4 had the lowest amount of carbon accumulated in bryophytes with 0,03 (±0,005) kg/m^2 for every site (Table3, Fig. 6b). The site differences for bryophytes were found to be significant (chi-squared = 27,3, df=3, $p<0,001$). Finally, for the field layer vegetation the overall mean was 0,04 (±0,002) kg/m^2. Site 1 had the maximum observed mean value whereas site 4 had by far the lowest level (Table 3, Fig. 6c). The mean values for carbon amount in the soil, bryophytes, vegetation and tree compartments are visualized in Fig. 6.

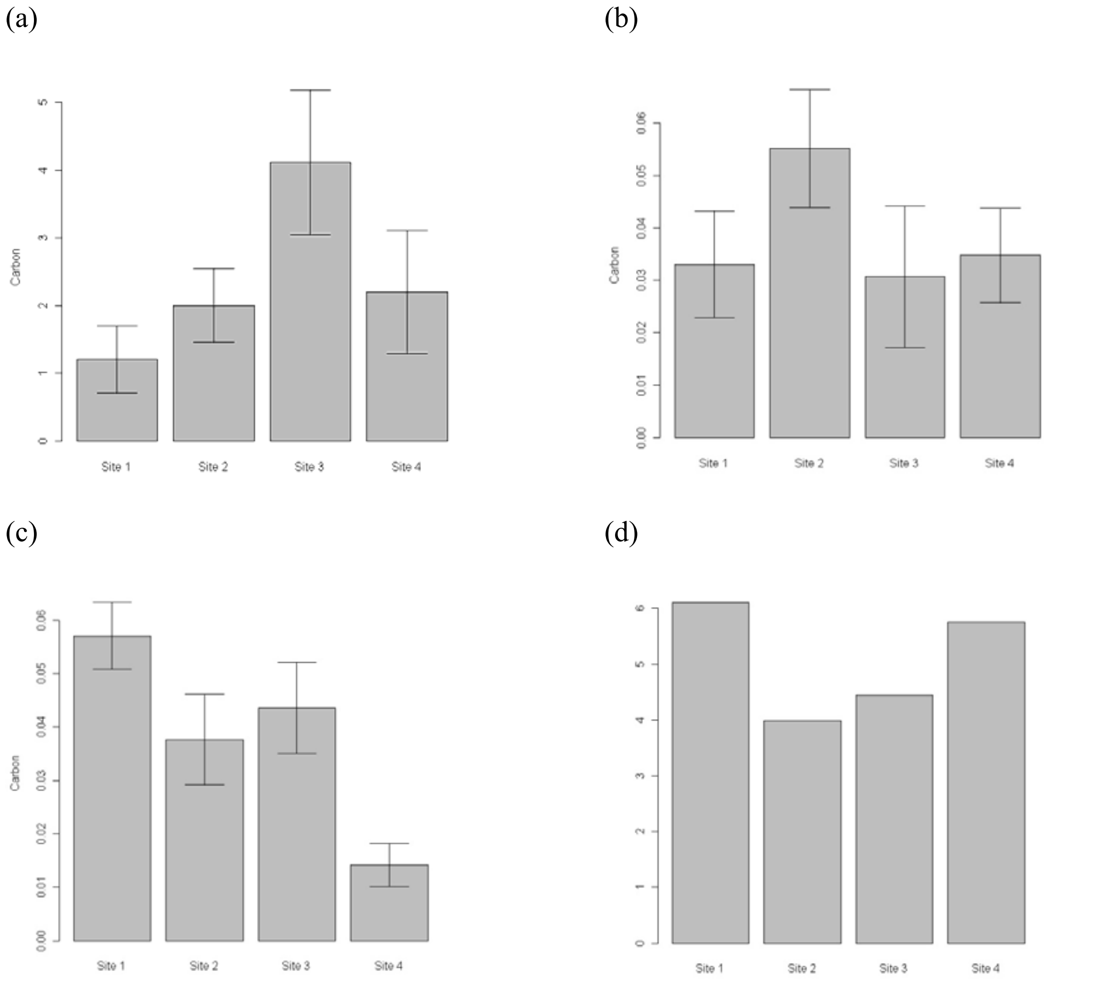


Fig. 6. Mean Carbon amount (kg/m^2) across 73 plots for each site for different compartments (a-soil, b-moss, c-field layer vegetation, d- trees). Approximate 95% confidence intervals for the site means are also given (where available).

3.1.3 Qualitative differences – Carbon content

As described in section 2.5.2 an ANOVA analysis was run to study the carbon content in soil between the sites. The site effect was highly significant (F=55,3, df=3, p-value <0,001), also when adjusting for the varying depths of the samples. So, in addition to the quantitative differences found between sites in section 3.1.2, the carbon content per unit soil also seems to be different at least between two sites. The estimated site effects are shown in Fig. 7.

The site effect is highest for site 3 and lowest for site 1 and 2 (Fig. 7), which means that, given the same depth of a sample, there tends to be more carbon in the sample from site 3 than sites 1 and 2.

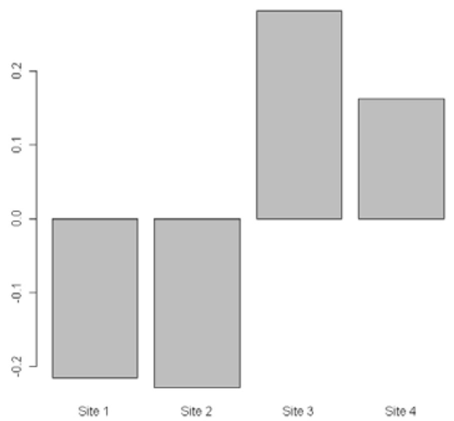


Fig. 7. Estimated ANOVA effects for study sites.

3.2 Sampling around trees (Method 2)

3.2.1 Biomass/organic mass

The mean organic mass (including field layer vegetation and bryophytes) across all sites was 4,4 (kg/m^2). The lowest and highest mean soil values were 2,7 (±0,4) kg/m^2 and 7,0 (±1,1) kg/m^2, which were observed at sites 1 and 2, respectively. The overall range of organic mass measurements for soil was 0 to 69,0 kg/m^2. The field layer vegetation and bryophytes made up the smallest part of the biomass (Table 5).

Table 5. Average biomass and organic mass for all study sites (kg/m^2)

Variable	Mean	SE	Range
Soil	4,3	0,4	0,0 – 69,0
Bryophytes	0,04	0,004	0,0 – 2,2
Field layer vegetation	0,04	0,002	0,0 – 0,4

The average values over study sites were 0,04 (±0,004) kg/m^2 for bryophytes and 0,04 (±0,002) kg/m^2 for field layer vegetation (Table 5). Site 2 appeared to have the highest values for field layer vegetation and bryophytes, site 4 showed the lowest biomass average (Fig. 8).

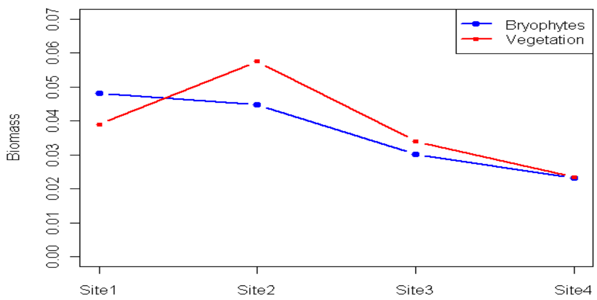


Fig 8. Biomass (kg/m^2) across study sites for bryophytes and field layer vegetation.

3.2.2 Carbon amount (Quantitative differences)

The overall average of soil organic carbon across four study sites was 0,9 (±0,09) kg/m^2. Site 2 showed the highest value of 1,6 (±0,3) kg/m^2, while the lowest value of 0,3 (±0,06) kg/m^2 was found at site 4. The overall range for carbon in organic soil was 0 to 16,2 kg/m^2 (Fig. 9).

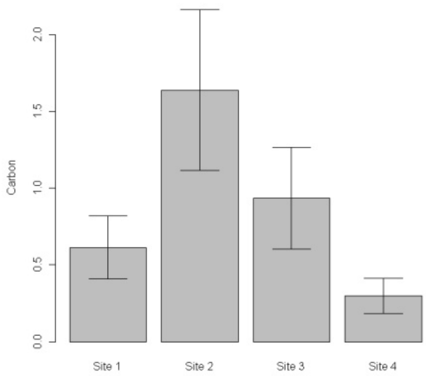


Fig. 9. Carbon amount in soil (kg/m^2) across study sites.

When it comes to field layer vegetation the general mean was 0,02 (±0,001) kg/m^2. Site 4 had the minimum observed average value (0,01 (±0,001) kg/m^2), whereas site 2 accumulated more field layer vegetation than other sites (0,03 (±0,002) kg/m^2). The range of carbon in field layer vegetation across sites was 0,0 – 0,2 kg/m^2. Concerning bryophytes the minimum value 0,01 (±0,002) kg/m^2 was obtained at site 4, while the general mean across all sites had the value 0,02 (±0,002) kg/m$^{2.}$ The range of observed carbon in this compartment was from 0 to 0,4 kg/m^2. The difference between sites turned out to be significant for all components: field layer vegetation (p<0,001) bryophytes (p<0,001) and soil (p<0,001).

(a) (b)

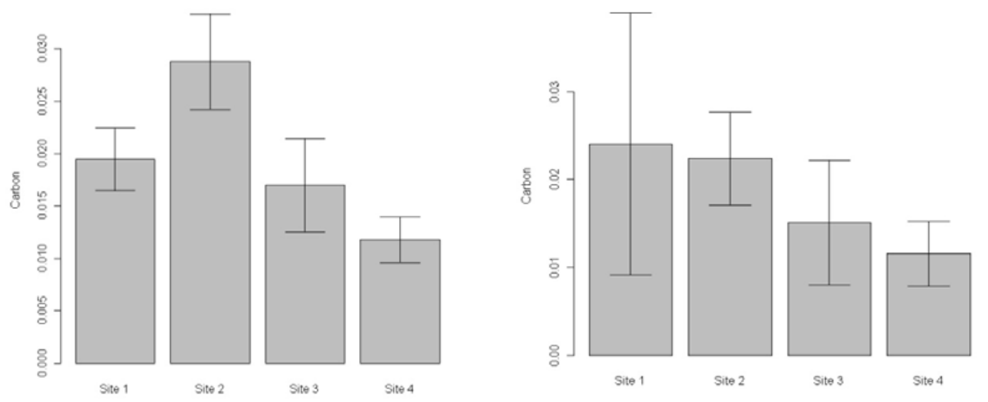


Fig. 10. Carbon amount (kg/m^2) across all sites in a) field layer vegetation, b) bryophytes.

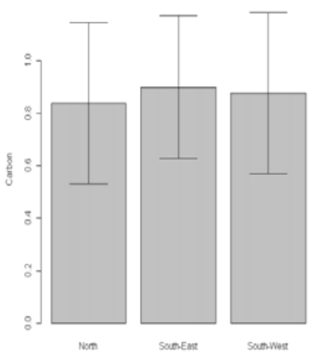
3.2.3 Influence of direction and distance from tree on carbon amount

The amount of carbon in soil did not differ among the three directions studied (Kruskal-Wallis chi-squared = 1,1, df = 2, p-value = 0,6) (Fig. 11a). When it comes to the distance factor, the clear increase in carbon amount in soil was found from distance 15 cm (0,4 (±0,1) kg/m^2) to 250 cm (1,2 (±0,2) kg/m^2) from the trees. The distance effect was significant (chi-squared = 15,8, df = 4, p-value = 0,003) (Fig. 11b).

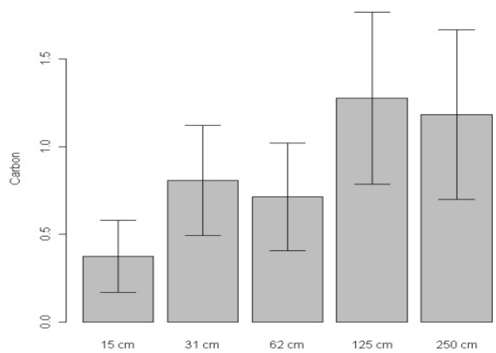
For bryophytes the same increasing trend in carbon amount with increasing distance was observed. At 15 cm we had the smallest amount (0,005 (±0,001) kg/m^2) whereas at 250 cm the average amount was 0,03 (±0,004) kg/m^2. The distance effect was highly significant (chi-squared = 66,9, df = 4, p-value < 0,001) (Fig. 11d). The distribution for bryophytes also seems to vary with the direction from the tree. Most carbon was found in direction 1 (north) with an average amount of 0,03 (±0,006) kg/m^2. The other two directions had smaller but equal levels of 0,01 (±0,002-0,003) kg/m^2. Direction north had significantly more carbon than south-east and south-west according to the non-parametric test (chi-squared = 29,4, df = 2, p-value < 0,001) (Fig. 11c).

Finally, for the field layer vegetation the tests gave significance (chi-squared = 8,6, df = 2, p-value = 0,01) for the direction effect with maximum value (0,022 (±0,0019) kg/m^2) in direction 2 (south-east) and minimum (0,017 (±0,0017) kg/m^2) in direction 3 (south- west) (Fig. 11e). However, there was no apparent trend in carbon amount with changing distance from the trees (Fig. 11f). The distance effect was non-significant (chi-squared = 2,2, df = 4, p-value = 0,7).

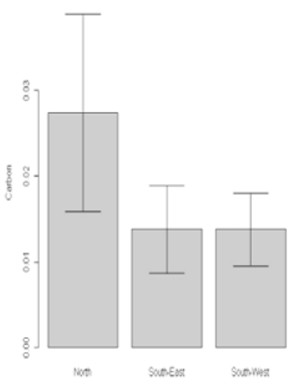
(a)



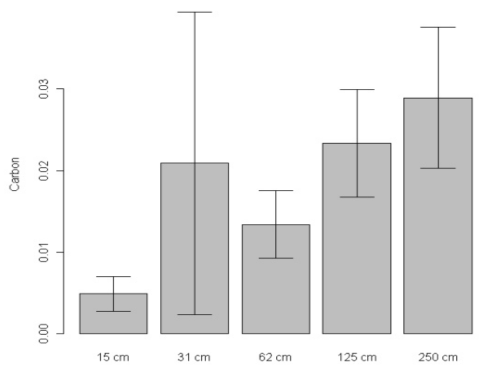
(b)



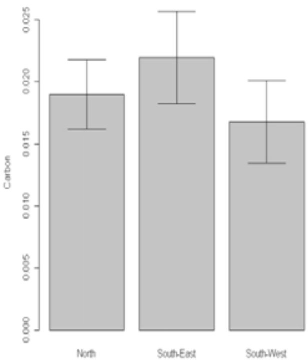
(c)



(d)



(e)



(f)

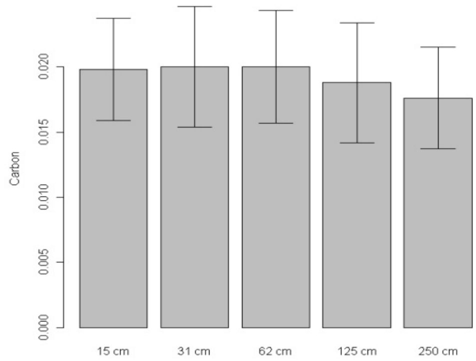


Fig. 11. Direction and distance effect on carbon concentration in 3 compartments across all study sites. Bars represent relationship between soil&direction (a), soil&distance (b), bryophytes&direction (c), bryophytes&distance (d), field layer vegetation&direction (e), field layer vegetation&distance (f).

3.2.4 Influence of direction and distance from tree on carbon content in soil

The ANOVA analysis gave no significant effect of direction nor distance on carbon content when controlling for both site and sample volume. So it was no change in carbon content in soil with direction or distance. Thus, the effect of distance on carbon found by the Kruskal-Wallis test was due to the fact that the soil-samples were increasing (in mass volume) as the distance from the tree was increasing.

3.2.5 Tree influence on soil carbon depth distribution

Figure 12 illustrates the mean carbon amount for various depths between 0 and 10 cm. From the figure it appears as if the smallest amount of carbon is found at level 0-2 cm.

(a) (b)

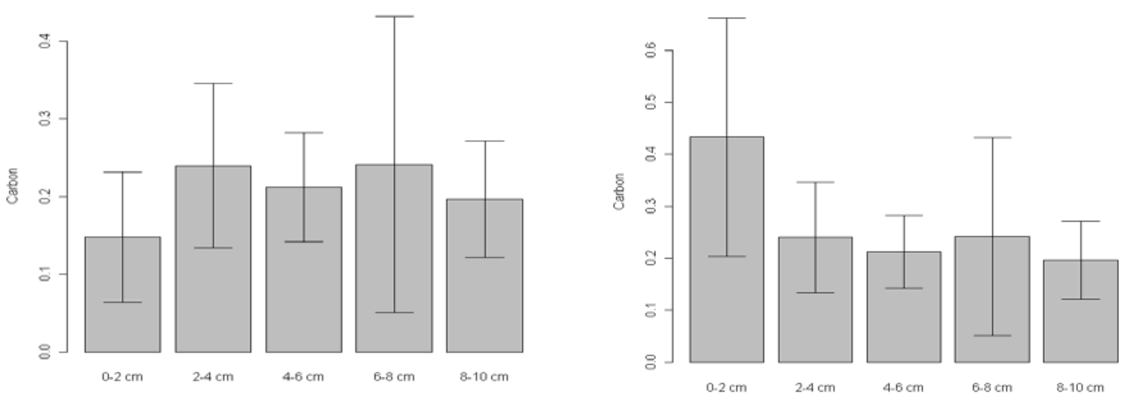


Fig. 12. Depth means (kg/m^2) of deep soil samples. a) All samples (carbon amount), b) All zeros excluded (carbon content).

However, this is due to the fact that cases of "no soil" is registered with a zero value at this depth only. If zeros are excluded the average carbon content in the top 2 cm of the soil increases three-fold to 0,4 (±0,1) kg/m^2 as shown in Fig. 12b. We observe a decreasing trend in carbon values with increasing depth. However, due to the large variation in the observations the Kruskal-Wallis test does not give a significant effect of depth (p = 0,10).

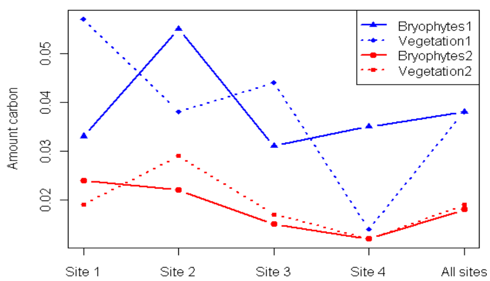
The ANOVA model was used to do further testing of the effect of depth to carbon content while adjusting for potential effects of site, tree, direction and distance from tree. The depth effect turned out to be non-significant (p-value=0,4). An alternative model with depth as continuous variable gave a reduced p-value and a negative coefficient estimate indicating a likely reduction in carbon content with increasing depth, but this was still not significant (p=0,2).

3.3 Difference between two methodological approaches

The results from the systematic sampling (Method 1) and sampling around trees (Method 2) showed differences in the estimated carbon amount for all components across all study sites. The mean soil values were considerable higher for method 1 than for method 2. Across all study sites the mean carbon values were 2,5 kg/m^2 for Method 1 and 1,0 kg/m^2 for Method 2 (soil, field layer vegetation, bryophytes included, trees excluded). Site 3 showed maximum difference with the amount of soil carbon equal to 4,1 kg/m^2 for the 1st method and 0,9 kg/m^2 for the 2nd method (Fig. 13 a,b).

The average value for soil carbon across all sites was 2,4 kg/m^2 and 0,9 kg/m^2 for M1 and M2, respectively. The difference between M1 and M2 across all study sites with regard to soil amount was highly significant (U=120800, p<0,0001). Regarding bryophytes and field layer vegetation the systematic sampling showed overall higher values across all compartments, but the discrepancy between amount of carbon for M1 and M2 method was not as high as for soil carbon. However, the biggest discrepancy in the results for the field layer vegetation was observed at site 1 with values 0,06 and 0,02 for M1 and M2 method, respectively (Fig. 13a).

(a)



(b)

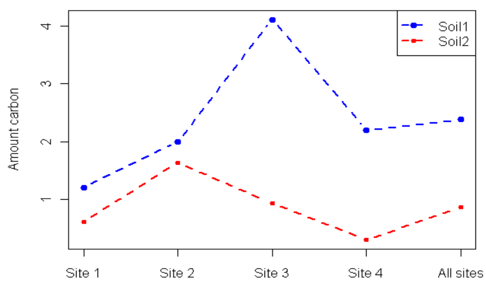


Fig. 13. The amount of carbon measured for the two methodological approaches: a) Amount of carbon in for vegetation and bryophytes across study sites, b) Amount of carbon in soil across study sites. Blue line - Method 1, red line – Method 2.

Different trends for the two methods across the study sites were observed. The average value in carbon across all sites from the M1 method was significantly higher than for M2. For both bryophytes (U=116226,5, p<0,0001) and field layer vegetation (U =119248, p<0,0001).

For M2 we can for all three compartments see a similar trend across all sites. For instance, site 2 appeared to have highest values for bryophytes, field layer vegetation and soil, while site 4 had lowest amount of carbon in general. M1 did not show comparable trends for the 3 compartments across the sites. In particular, study site 3 had the maximum value for soil and the minimum value for bryophytes (Fig. 11a,b).

3.4 Bulk density

The highest average bulk density was found at Site 2 with 263,8 g/dm^3 whereas the lowest level was at study site 4 with 186,3 g/dm^3. The mean value across all sites was 224,8 g/dm^3. For each site a regression analysis was performed to check the dependence between carbon content and bulk density (zeros removed). Since both variables had skewed densities a log-transformation was used for normalization. Plots with estimated regression curves for each site are shown in Figure 14. As we can see from Table 6 there were significant positive relationships between amount of carbon and bulk density for all sites. The R^2 values were, however, not very large.

Table 6. Estimated regression coefficients for the effect of carbon on bulk density for each site

Site	Coefficient estimate	p-value	R^2
1	0,29	<0,001	0,28
2	0,28	<0,001	0,22
3	0,34	<0,001	0,34
4	0,26	<0,001	0,38

With regard to the influence of depth of sample on bulk density (log transformed and zeros removed) there was no significant effect (p=0,3).

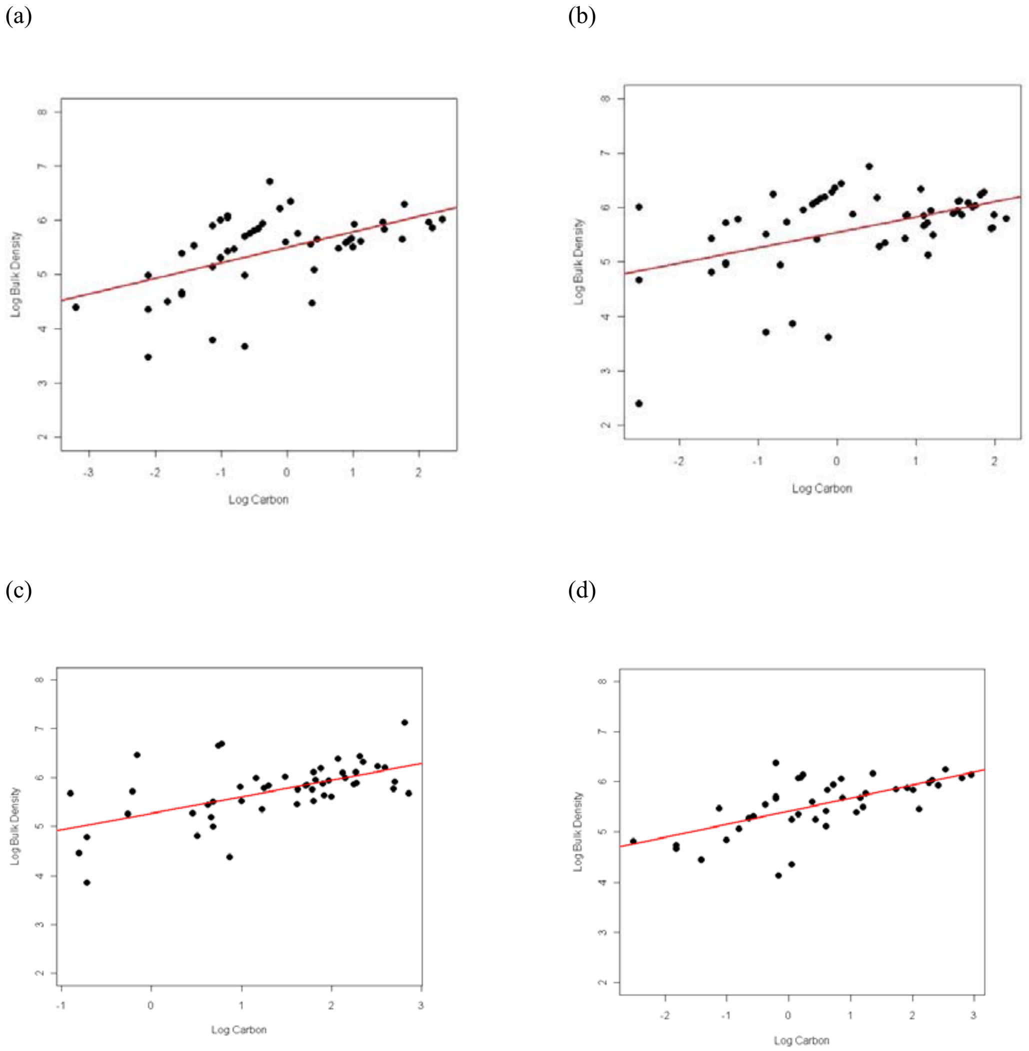


Fig. 14. Log-carbon plotted versus log bulk density with estimated linear models for sites 1-4. Study site 1(a), study site 2 (b), study site 3 (c), study site 4(d).

4. DISCUSSION

In the discussion I will focus on the following main conclusions that I draw from my results:

Method 1

-The average amount of carbon across all study sites was relatively low as compared to some previous studies.

- The results showed different trends and variation in the amount of carbon both between and within study sites. This variability is difficult to relate to concrete explanatory factors due to the complexity of the forest ecosystem. However, I will make some suggestions.
- Significant differences in carbon were found between study sites both for the quantitative (carbon amount) and qualitative analyzes (carbon content).
- Carbon values were higher for belowground level than for aboveground.
- In the organic top-soil there was a significant positive relationship between bulk density and the amount of carbon, but no significant relationship between bulk density and soil depth.

Method 2

- The amount of carbon in soil and bryophytes increased significantly with increasing distance from the dominating trees. For field layer vegetation, the distance from the trees did not have any significant effect on the amount of carbon.
- The direction effect was significant for bryophytes and vegetation, but not significant for organic soil.
- The depth effect turned out to be non-significant on carbon content. However, a decreasing carbon trend was observed.

-Method 2 showed a lower average in the amount of carbon than Method 1 for all compartments with highly significance between methods.

4.1 Method 1 (systematic sampling)

4.1.1 Amount of carbon

The average total amount of carbon in the studied compartments across all study sites was 7,4 kg/m^2. This is considerably lower than results found in earlier studies. For instance, Finer

(2003) who studied an old growth mixed coniferous forest in eastern Finland dominated by Norway spruce, had an average of 14,4 kg/m^2. The average forest age for trees was 140 year old. A mini-review by Pregitzer et al. (2004), based on 5 age classes of boreal forests, showed an average of 14,3 kg/m^2 for total ecosystem carbon. However in this latter study the mineral soil was included which can accumulate a great amount of C in the ecosystem. According to the study by Liski & Westman (1995) 28% of C was accumulated in the organic top-soil layer, whereas 68% was found in mineral soil down to a depth of 1m and 4% below 1 m.

4.1.2 Soil organic carbon (SOC)

The average value for SOC across all study sites was 2,4 kg/m^2 with a range from 1,2 to 4,1 kg/m^2. In general, C values from sites 1, 2 and 4 were very close to some of the findings in earlier studies. For example, a study from different aged Scots pine forests in Southern Finland reported average values between 1,2 and 1,8 kg/m^2 (Kolari 2004). My results are also close to the mean soil carbon found by Liski et al. (1997) in a coniferous forest in southern Finland (mean value 1,2 kg/m^2) and studies by Finer (2003) from old growth Norway spruce mixed forest in Finland gave 2,1 (±0,4) kg/m^2 on average. Similar results for SOC was found in different aged Norway Spruce stand in southern Norway. A study by Clarke et al. (2007) showed mean values for SOC from 2,3 kg/m^2 (30-year stand) to 5,2 kg/m^2 (120-year stand).

According to some studies there are different factors that can control C variation and accumulation in forest ecosystems. For instance, the study of Kleja (2007) showed that the main factors that influence the amount soil organic carbon in the first 100 cm is soil texture and climate. The wet, cold and fine texture soil gives the highest amount of SOC. Callesen et al. (2003) showed positive relationship between precipitation, temperature and carbon pools. Liski & Westman (1995) suggested that C density is responding to aspect, topography, parent material, soil age, vegetation and climate.

The study sites at Aurskog-Høyland were situated quite close to each other and are characterized by similar regional climate conditions and similar soil types.

So it can be suggested that more local factors are involved in creating SOC variation. It is thus difficult to say what factors that have caused the variation across sites and the high C level in the soil at site 3 in particular. When it comes to explaining site differences in the relative amounts of carbon in different compartments at fine spatial scales, the topography and forest structure of the study sites can give a good explanation for the local variation in soil organic carbon. Litter production and litter fall plays an important role in soil carbon accumulation, but the amount of litter fall depends on tree species. Some studies prove that canopy litter production appeared to be smaller for Scots pine than for Norway spruce (Saarsalmi et al. 2007; Ukonmaanaho et al. 2008). In my study the crown biomass across sites was very similar and varied from minimum 1,4 kg/m^2 at study site 2 to maximum 1,9 kg/m^2 at study site 1. In the same time tree composition appear to be different. For example, study sites 1 and 4 were dominated by Scots pine, while sites 3 and 2 were mixed forests with Scots pine and Norway spruce. As a consequence of this mixed structure, the bigger amount for litter fall should be expected from site 2 and 3 and thereby also increasing amount of soil carbon. This mixed composition can give an explanation to the higher soil organic value for study site 3. In addition site hydrology and topography can be a very important factor for soil carbon accumulation. The study sites 3 and 2 in my study had the highest altitudes with 306 and 279 m above sea level, respectively and the higher SOC levels found at these sites are in accordance with Walle et al. (2001) who showed that carbon pools in the soil has positive association with altitude. Sites 1 and 4 had in comparison lower altitudes of 185 and 230 m. Study site 1 had the lowest altitude and the lowest soil C pools.

When it comes to forest age as a variation factor some authors found that the amount of soil carbon has a positive correlation with forest stand age (Illvesniemi et al. 2002; Pregitzer 2004). Usually, concentration increases until an equilibrium age. The equilibrium concentration is depending on soil layer and can vary from 756 years to 1200-1300 years for upper and deeper layers, respectively (Illvesniemi et al. 2002). For the study sites in Aurskog-Høland it was no positive age of tree related trend found in SOC. On the contrary, site 1 with oldest stand age (113 years old) showed the lowest SOC accumulation, while site 3 with the youngest stand showed the highest value. Sites 2 and 4 were intermediate in both stand age and SOC values.

Some studies suggested the latitude factor as a reason for the differences in soil carbon pools between sites. Despite some latitude trends found in my study I mean that this explanation can-not be applied in Aurskog-Høland due to quite close site locations, and I believe that the effect of latitude, as found by Reed & Nagel (2003), is only effective at larger geographical scales. The more important factors for my study, giving rise to site differences can be combination of altitude, topography, forest structure and moisture. These are factors that may show considerable small-scale variation.

4.1.3 Field layer vegetation and bryophytes

Generally, the field layer vegetation and bryophytes did not contribute more than 2% of the total ecosystem carbon. Such low figures are corroborated by Finer (2003) who found that field layer vegetation (0,04± 0,01 kg/m^2) and bryophytes (0,08± 0,01 kg/m^2) contributed less than 2% of the ecosystem C pools. Also Reed and Nagel (2003) found that the field layer vegetation and bryophytes make up a small part of the total C pool, i.e. only 1%, or even less. Thus, it seems that the field layer vegetation together with the bryophytes make up only a minor part of the total C pool in boreal forest ecosystems.

For my study sites, the averages for field layer vegetation varied from minimum at site 4 with a value of 0,01 (±0,002) kg/m^2 to the maximum of 0,06 (±0,003) kg/m^2 at site 1. Both these sites are located in the south of my study area. During the fieldwork, it was noticed that study site 1 had much higher vegetation abundance than the other sites. Better moisture could be the cause of this.

In relation to latitude Reed & Nagel (2003) reported a positive relationship between vegetation and latitude and C content, but no such trend was found in my study. So, the effect of latitude may not be very clear for these compartments.

I found no support for the idea that field layer vegetation biomass will be higher at the northern sites due to the better light availability caused by lower stand density and narrower tree crowns in the north (Kleja 2007). It can be suggested that due to very small amounts of vegetation and bryophytes, close geographical location of the study sites and similar biological conditions it may be difficult to find clear trends.

4.1.4 Trees

The average amount of C in trees was 4,9 kg/m^2. This stands as a low value in comparison to results from Finer (2003) with an old-growth, mixed forest in eastern Finland, who found an average carbon value for trees to be 10,7 kg/$m^{2.}$ Different study scales may perhaps explain this difference in the results. The study by (Finer 2003) represented a large-scale research of boreal forest with different stands, ages and locations, while my research is based on detailed measurements on fine spatial scales within fairly small geographical area.

Another result from a study by (Kleja 2008) made in three 40-year old Norway spruce stands along a north-south climatic gradient in Sweden seems to be relatively close to my findings. In this study, the carbon pools in trees varied from 4,6 (±0,9) kg/m^2 in the north to 8,0 (±0,6) kg/m^2 in the south. The stand age in the study by Kleja was about 40 years old, which was close to site 3 (55 years old) and site 2 (65 years old) with values 4,3 and 3,9 kg/m^2, respectively.

A positive trend between the amount of carbon in the trees and forest stand age was observed. For example, in site 1 (stand 113 years old) the trees compartment counted for nearly 70% of all the C found at the site, while site 3 (stand 55 years old) counted just 35% C. The same trend was observed by Kolari (2003) with the highest whole tree biomass for the oldest stand. The study of Pregitzer (2004) also noted increasing living biomass with increasing age in boreal forests.

4.1.5 Carbon distribution

When it comes to above/below ground carbon distribution, generally, across all study sites 49% of C was accumulated in belowground layer with majority (32%) in soil and 17% in roots and stub. Aboveground layer kept 51% of C with the majority stored in the living components of the trees.

In my study the organic-soil layer held from17% to 48% of the total C that I estimated. These results are fairly similar to those presented by Reed & Nagel (2003) from Scots pine forest where from 24% to 58% of the carbon was kept in the organic soil.

4.1.6 Bulk density

The soil characteristics usually depend on soil texture and soil organic matter content. According to Chapin et al. (2002) a negative relationship between bulk density and carbon concentration (% of dry mass) often occurs. Here is it, however, important to bear in mind that Chapin et al. (2002) refers to soil in a broad context, meaning that bulk density increase as mineral content increase, which in turn will explain a general negative relationship between soil bulk density and carbon concentration. As regard entirely organic soils, such as e.g. peat and raw-humus, the relationship between carbon quantities (grams per cubic centimeters) and bulk density is typically positive. With regard to my study, it was not found any significant effect between depth of sample and bulk density (p=0,4). However, significant positive relationships between the amount of carbon and bulk density was found for all sites, which was expected as I examined the organic top-soil. The mean value for bulk density across sites was 224,8 g/dm^3.

4.1.7 Variation across study sites

It is very important to get precise estimates of C pools for using them in climate change analyzes. However, at the same time this task is challenging mainly due to the high natural variability in the forest floor (Shaw 2008). Forest's ecosystems represent a «complex organism» where all components are connected to each other. Organic and mineral soil, vegetation, trees and forest floor have high interactions between each other and at the same time, such factors as moisture, soil texture and temperature have influence on the different components. So, interaction between all factors can give significant variation at the local level that is difficult to explain (Banfield 2002). An interesting study from the Canadian boreal forest showed that large-scale C estimates can not indicate the local variation. In this latter study, the author compared 3 different estimates of total C soil: The Carbon budget model for the Canadian forest sector (method 1), Canadian organic soil database (method 2) and results from fieldwork (method 3). The findings showed large variation in site productivity (measured as C sequestered per area) with values: 15,6 kg/m^2, 14,8 kg/m^2 and 8,3 kg/m^2 for the 1st, 2nd and 3rd method, respectively.

Further, a substantial part of the spatial variation in C pools within an ecosystem can be explained by factors varying between sites. Local variations in nutrients, moisture and local climate may all influence the local C pool and fluxes (Banfield 2002).

4.2 Method 2 (Sampling around trees)

4.2.1 Distance effect

The distance from tree effect was significant on carbon amount for bryophytes and soil, with a positive relationship. In relation to bryophytes, the result was in accordance with a study by Økland et al. (1999) from a Norwegian boreal spruce stand, where bryophytes abundance appeared to increase with increasing distance from the trees due to increased hydration. The lack of relationship between field layer vegetation and distance from the trees was not expected. Influence of distance from tree on field layer vegetation was found by Økland et al. (1999). It was suggested that key factors controlling plant growth are radiation and soil moisture. The big trees limit these factors due to the big root system and crown shadow. Consequently, the abundance of field layer vegetation appeared to increase farther from the trees. According to this latter study trees have a negative effect on the field layer vegetation abundance as far out as 4-5 crowns radius unites from the stem. Therefore the max distance from the tree 2,5 meter, that was measured in my fieldwork, may not be enough to reveal a significant distance effect on field layer vegetation.

The amount of carbon in soil increased with increasing distance from the tree. This must be due to increasing biomass and not a change in soil carbon content, since the ANOVA analysis did find the same distance effect for soil carbon. Soil masses were much smaller near the trees due to high abundance of root systems. In addition cases with "no soil" were more frequent near the trees.

4.2.2 Direction effect

The direction from tree effect was significant for bryophytes and field layer vegetation, but not significant for organic soil. The most of the bryophytes were found in the northern direction. This result is absolutely as expected from knowledge about bryophytes physiology. Bryophytes are known as species usually found in areas with low light and high moisture. Due to small size and thin tissues these two characteristics of the ecosystem are very important in order for them to get enough water and survive. Due to these characteristics, bryophytes usually show higher abundance on rocks, at northern latitudes and in particular the north side of trees (Goffinet 2009). Most of the vegetation appeared in the southeast. This result may be explained by the habitat preference and physiology of *Vaccinium myrtillus*, which has higher light demand than bryophytes and is growing better with good sun conditions and medium humidity. The southeast direction can provide these optimal conditions for the growth of *Vaccinium myrtillus* (Timoshok 2000).

The direction from the tree does not seem to have effect on the carbon content in the soil according to my results. I can suggest that in this case the young age of the forest stands in combination with logging- and management history can explain absence of a direction effect. A direction from tree effect may take time and stable conditions in order to be established.

4.2.3 Depth effect

The depth effect turned out to be non-significant for carbon content, although a decreasing carbon trend was observed. However, some previous studies found significant depth effects. These have, however, studied deeper soil profiles representing both the carbon rich organic top-soil and the less carbon rich underlying mineral soil. The global data set by Jobaggy & Jackson (2000) with depths up to 3 meters and 20 cm intervals showed constant diminishing organic carbon distribution in soil for the 20 cm intervals from 0-1 meter with following distribution: 50%, 25%, 13%, 7% and 5%. Pregitzer (2004) also noted in his study that C concentration was decreasing with the depth. The study by Veire et al. (2003) on Danish forests soil (down to 100 cm depth) confirmed a decreasing trend in soil C concentration with increasing depth as well. Another analysis of well dried forest soil (up to 100 cm depth) from four Nordic countries showed decreasing SOC trend as well (Callesen et al. 2003).

The fact that I did not find a significant effect may be due to the narrow range of depths studied, only 0-16 cm and with 2 cm intervals and the fact that just organic top-soil was examine. I would suggest that decreasing trend with increasing depth would appear if some of the mineral soil located under the organic top-soil was included in the study.

4.3 Difference in carbon distribution between M1 and M2 with regard to the amount of carbon

The main goal for the two methodological approaches was to see how the big trees influence on the amount of carbon, and to see if I could find any trends in carbon distribution between and within M1 and M2. Several interesting results were obtained which will be discussed further.

- The difference between M1 and M2 across all study sites with regard to the amount of carbon in vegetation, bryophytes was highly significant. First of all, it should be noticed that M1 should yield more precise results regarding the average amount of carbon in soil for each study site as compared to M2. This is because M1 is based on a larger set of samples across the entire study site, whereas M2 is more aimed at local soil conditions around trees. M1 provided samples both close to trees and far from trees due to the systematic sampling scheme and the randomness of the distribution of trees across the study sites. However, some more explanation to the observed differences between the methods could be done.
- Across all study sites the biomass from vegetation and bryophytes was found to be lowest near trees (M2). This can be explained with more frequent cases with “no soil” near the trees (due to the root system) and with less sun access. From Figure 13 we observe that the only departure from this general picture is for study site 4 where the biomass measured from vegetation is about the same low level for both sampling methods.
- For soil carbon the two methods did not show similar trends across the sites (Fig. 13b). From this I can only conclude that soil carbon amounts seem to vary considerably within small areas.

- If all three compartments are considered together (soil, bryophytes and field layer vegetation), M2 showed similar trends across all study sites. In particular site 2 appeared to have highest values for all 3 compartments, while site 4 had the lowest amount of carbon. As was mentioned above the vegetation plays a very important role in carbon distribution in the first 20 cm (Jobbagy & Jackson, 2000), hence a correspondence between vegetation abundance and soil carbon should be expected according to this. For M2 samples the case of “no soil” was much more frequent than was the case for M1. All zeros (“no soil” cases) were included in the analyzes leading to these results, so it is logically that vegetation abundance was generally lower for M2.

5.REFERENCES

Banfield, G. E., Bhatti, J. S., Jiang, H. & Apps, M. J. (2002). Variability in regional scale estimates of carbon stocks in boreal forest ecosystems: results from West-Central Alberta. *Forest ecology and management*, 169 (1-2 Sp. Iss. SI): 15-27.

Callesen, I., Liski, J., Raulund-Rasmussen, K., Olsson, M. T., Tau-Strand, L., Vesterdal, L. & Westman, C. J. (2003). Soil carbon stores in Nordic well-drained forest soils - relationships with climate and texture class. *Global Change Biology*, 9 (3): 358-370.

Chapin, F. S., Matson, P. A. & Mooney, H. A. (2002). *Principles of terrestrial ecosystem ecology*. New York: Springer. 436 pp.

Clarke, N., Wu, Y. J. & Strand, L. T. (2007). Dissolved organic carbon concentrations in four Norway spruce stands of different ages. *Plant and Soil*, 299 (1-2): 275-285.

Cohen, W. B., Harmon, M. E., Wallin, D. O. & Fiorella, M. (1996). Two decades of carbon flux from forests of the Pacific northwest. *Bioscience*, 46 (11): 836-844.

de Wit, H. A., Palosuo, T., Hylen, G. & Liski, J. (2006). A carbon budget of forest biomass and soils in southeast Norway calculated using a widely applicable method. *Forest Ecology and Management*, 225 (1-3): 15-26.

Dixon, R. K., Brown, S., Houghton, R. A., Solomon, A. M., Trexler, M. C. & Wisniewski, J. (1994). Carbon pools and flux of global forest ecosystems. *Science*, 263 (5144): 185-190.

Finer, L., Mannerkoski, H., Piirainen, S. & Starr, M. (2003). Carbon and nitrogen pools in an old-growth, Norway spruce mixed forest in eastern Finland and changes associated with clear-cutting. *Forest Ecology and Management*, 174 (1-3): 51-63.

Giardina, C. P. & Ryan, M. G. (2000). Evidence that decomposition rates of organic carbon in mineral soil do not vary with temperature. *Nature*, 404 (6780): 858-861.

Goffinet, B. & Shaw, A. J. (2009). *Bryophyte biology*. Cambridge: Cambridge University Press. 565 pp.

Grace, J. (2004). Understanding and managing the global carbon cycle. *Journal of Ecology*, 92 (2): 189-202.

Hogberg, P., Nordgren, A., Buchmann, N., Taylor, A. F. S., Ekblad, A., Hogberg, M. N., Nyberg, G., Ottosson-Lofvenius, M. & Read, D. J. (2001). Large-scale forest girdling shows that current photosynthesis drives soil respiration. *Nature*, 411 (6839): 789-792.

Jobbagy, E. G. & Jackson, R. B. (2000). The vertical distribution of soil organic carbon and its relation to climate and vegetation. *Ecological Applications*, 10 (2): 423-436.

IPCC (2007). Climate Change 2007: The physical science basis; summary for policymakers. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA, Cambridge University Press.

Ivesniemi, H., Forsius, M., Finer, L., Holmberg, M., Kareinen, T., Lepistö, A., Piirainen, S., Pumpanen, J., Rankinen, K., Starr, M.,Tamminen, P., Ukonmaanaho, L., Vanhala, P. (2002). Carbon and nitrogen storages and fluxes in Finnish Forest Ecosystems. In: Käyhkö, J. and Talve, L. (eds) *Understanding the Global system, The Finnish Perspective*. Finnish Global Change Research Programme FIGARE.

Karjalainen, T. (1996). The carbon sequestration potential of unmanaged forest stands in Finland under changing climatic conditions. *Biomass & Bioenergy*, 10 (5-6): 313-329.

Kleja, D. B., Svensson, M., Majdi, H., Jansson, P. E., Langvall, O., Bergkvist, B., Johansson, M. B., Weslien, P., Truusb, L., Lindroth, A., et al. (2008). Pools and fluxes of carbon in three Norway spruce ecosystems along a climatic gradient in Sweden. *Biogeochemistry*, 89 (1): 7-25.

Knorr, W., Prentice, I. C., House, J. I. & Holland, E. A. (2005). Long-term sensitivity of soil carbon turnover to warming. *Nature*, 433 (7023): 298-301.

Kolari, P., Pumpanen, J., Rannik, U., Ilvesniemi, H., Hari, P. & Berninger, F. (2004). Carbon balance of different aged Scots pine forests in Southern Finland. *Global Change Biology*, 10 (7): 1106-1119.

Kruskal, W. H.&W. A. Wallis (1952). Use of ranks in one-criterion analysis. *Journal of the American Statistical Association,* 47 (260): 583-621.

Liski, J. & Westman, C. J. (1995). Density of organic-carbon in soil at coniferous forest sites in southern Finland. *Biogeochemistry*, 29 (3): 183-197.

Liski, J. & Westman, C. J. (1997). Carbon storage in forest soil of Finland .1. Effect of thermoclimate. *Biogeochemistry*, 36 (3): 239-260.

Liski, J. & Westman, C. J. (1997). Carbon storage in forest soil of Finland .2. Size and regional patterns. *Biogeochemistry*, 36 (3): 261-274.

Malhi, Y., Baldocchi, D. D. & Jarvis, P. G. (1999). The carbon balance of tropical, temperate and boreal forests. *Plant Cell and Environment*, 22 (6): 715-740.

Mann, H. B., and Whitney, D. R. (1947). On a test of whether one of two random variables is stochastically larger than the other. *Annals of Mathematical Statistics*, 18(1): 50–60.

Miller, I., Miller, M. & Freund, J. E. (2004). *John E. Freund's mathematical statistics: with applications*. Upper Saddle River, N.J.: Prentice Hall. 614 pp.

Moen, A., Lillethun, A. & Odland, A. (1999). *Vegetation*. Hønefoss: Norwegian Mapping Authority. 200 pp.

Montgomery, D. C. (1997). *Design and analysis of experiments*. New York: Wiley. 704 pp.

Neilson, E. T., MacLean, D. A., Meng, F. R. & Arp, P. A. (2007). Spatial distribution of carbon in natural and managed stands in an industrial forest in New Brunswick, Canada. *Forest Ecology and Management*, 253 (1-3): 148-160.

Okland, R. H., Rydgren, K. & Okland, T. (1999). Single-tree influence on understorey vegetation in a Norwegian boreal spruce forest. *Oikos*, 87 (3): 488-498.

Powlson, D. (2005). Climatology - Will soil amplify climate change? *Nature*, 433 (7023): 204-205.

Pregitzer, K. S. & Euskirchen, E. S. (2004). Carbon cycling and storage in world forests: biome patterns related to forest age. *Global Change Biology*, 10 (12): 2052-2077.

Reed, D. & Nagel, L. (2003). Carbon pools and storage along a temperate to boreal transect in northern Scots pine (Pinus sylvestris) forests. *Polish Journal of Ecology*, 51 (4): 545-552.

Saarsalmi, A., Starr, M., Hokkanen, T., Ukonmaanaho, L., Kukkola, M., Nojd, P. & Sievanen, R. (2007). Predicting annual canopy litterfall production for Norway spruce (Picea abies (L.) Karst.) stands. *Forest Ecology and Management*, 242 (2-3): 578-586.

Schimel, D. S. (1995). Terrestrial ecosystems and carbon cycle. *Global Change Biology*, 1 (1): 77-91.

Shaw, C. H., Boyle, J. R. & Omule, A. Y. (2008). Estimating Forest Soil Carbon and Nitrogen Stocks with Double Sampling for Stratification. *Soil Science Society of America Journal*, 72 (6): 1611-1620.

Timoshok, E. E. (2000). The ecology of bilberry (Vaccinium myrtillus L.) and cowberry (Vaccinium vitis-idaea L.) in western Siberia. *Russian Journal of Ecology*, 31 (1): 8-13.

Ukonmaanaho, L., Merila, P., Nojd, P. & Nieminen, T. M. (2008). Litterfall production and nutrient return to the forest floor in Scots pine and Norway spruce stands in Finland. *Boreal Environment Research*, 13 (Suppl. B): 67-91.

Vande Walle, I., Mussche, S., Samson, R., Lust, N. & Lemeur, R. (2001). The above- and belowground carbon pools of two mixed deciduous forest stands located in East-Flanders (Belgium). *Annals of Forest Science*, 58 (5): 507-517.

Vanderpoorten, A. & Goffinet, B. (2009). *Introduction to bryophytes*. Cambridge: Cambridge University press. 303 pp.

Vejre, H., Callesen, I., Vesterdal, L. & Raulund-Rasmussen, K. (2003). Carbon and nitrogen in Danish forest soils - Contents and distribution determined by soil order. *Soil Science Society of America Journal*, 67 (1): 335-343.

Wigley, T. M. L. & Schimel, D. S. (eds). (2000). *The Carbon cycle*. Office for Interdisciplinary Earth Studies Global Change Institute vol. 6. Cambridge: Cambridge University Press. 292 pp.

Internet sites

R Development Core Team. 2008. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org. 11.05.2009

eKlima. Free access to weather – and climate data from Norwegian Metrological Institute from historical data to real time observation. eklima.no 13.07.2009

WoodWisdom - IRIS: New Technologies to Optimize the Wood Information Basis - Developing an Integrated Resource Information System. http://www.umb.no/lidar-english/article/22 11.11.09

Statens kartverk. http://kart.statkart.no. 13.07.2009

Official website of Aurskog-Holand kommune. www.ahk.no. 10.04.09

APPENDIX 1

Method 1: systematic sampling of 73 plots in 4 sites

Biomass (kg/m^2), carbon (kg/m^2) depth (cm), bulk density (g/dm^3) characteristics for M1

Carbon amount and bulk density across study sites

Variable	Unit	Mean	Median	1 SD	SE.mean	Range
Soil						
Site 1	Kg/m^2	1,2	0,4	2,1	0,3	0,0 -10,5
Site 2	Kg/m^2	2,0	0,9	2,3	0,3	0,0 - 8,5
Site 3	Kg/m^2	4,1	2,4	4,6	0,5	0,0 - 17,4
Site 4	Kg/m^2	2,2	0,8	3,9	0,5	0,0 - 19,1
Total	Kg/m^2	2,4	0,8	3,5	0,2	0,0 - 19,1
Bulk Density						
Site 1	g/dm^3	193,4	203	178,6	20,90	0,0 - 821
Site 2	g/dm^3	263,8	295	200,7	23,49	0,0 - 857
Site 3	g/dm^3	256,2	261	238,0	28,05	0,0 -804
Site 4	g/dm^3	186,3	189	175,9	20,58	0,0 - 585
Total	g/dm^3	224,8	227	201,8	11,83	0,0 - 857
Bryophytes						
Site 1	Kg/m^2	0,03	0,02	0,04	0,005	0,0 – 0,3
Site 2	Kg/m^2	0,06	0,05	0,05	0,006	0,0 - 0,2
Site 3	Kg/m^2	0,03	0,00	0,06	0,007	0,0 - 0,3
Site 4	Kg/m^2	0,03	0,02	0,04	0,005	0,0 - 0,1
Total	Kg/m^2	0,04	0,02	0,05	0,003	0,0 - 0,3
Field layer vegetation						
Site 1	Kg/m^2	0,06	0,06	0,03	0,003	0,0 - 0,1
Site 2	Kg/m^2	0,04	0,03	0,04	0,004	0,0 - 0,2
Site 3	Kg/m^2	0,04	0,04	0,04	0,004	0,0 - 0,2
Site 4	Kg/m^2	0,01	0,007	0,02	0,002	0,0 - 0,07
Total	Kg/m^2	0,04	0,03	0,03	0,002	0,0 - 0,2

Depth information

Variable	Unit	Mean	Median	1 SD	SE, mean	Range
Sites*						
Site 1	cm	2,3	1,0	3,3	0,4	0 - 14
Site 2	cm	3,8	2,0	4,1	0,5	0 - 15
Site 3	cm	4,4	4,0	4,4	0,5	0 - 22
Site 4	cm	2,5	1,0	3,5	0,4	0 - 15
All sites	cm	3,2	1,0	3,9	0,2	0 – 15

Separated soil sampling (zeros included)

Variable	Unit	Mean	Median	1 SD	SE, mean	Range
Sites*						
Site 1	Kg/m^2	0,1	0	0,2	0,02	0,0 - 0,6
Site 2	Kg/m^2	0,2	0,04	0,3	0,03	0,0 - 1,2
Site 3	Kg/m^2	0,2	0	0,2	0,03	0,0 - 1,1
Site 4	Kg/m^2	0,1	0,02	0,1	0,02	0,0 - 0,5
Total	Kg/m^2	0,1	0	0,2	0,01	0,0 -1,2
Depths*						
0-2mm	Kg/m^2	0,1	0,0	0,2	0,01	0,0 - 1,1
2-4mm	Kg/m^2	0,2	0,2	0,2	0,05	0,004 -1,2
4-6mm	Kg/m^2	0,2	0,2	0,1	0,03	0,0 -0,5
6-8mm	Kg/m^2	0,2	0,2	0,2	0,06	0,0 -0,7
8-10mm	Kg/m^2	0,2	0,2	0,04	0,02	0,1 -0,2

* Depths above 10 mm not included due to too small sample sizes

Biomass and soil organic mass

Variable	Unit	Mean	Median	1 SD	SE, mean	Range
Soil						
Site 1	Kg/m^2	6,5	2,0	11,7	1,4	0,0 - 56,9
Site 2	Kg/m^2	11,6	4,9	13,4	1,6	0,0 - 49,1
Site 3	Kg/m^2	15,2	8,9	16,9	2,0	0,0 - 64,2
Site 4	Kg/m^2	8,0	2,8	14,2	1,7	0,0 - 69,4
All sites	Kg/m^2	10,3	3,2	14,5	0,8	0,0 - 69,5
Bryophytes						
Site 1	Kg/m^2	0,07	0,05	0,09	0,01	0,0 - 0,5
Site 2	Kg/m^2	0,1	0,09	0,1	0,01	0,0 - 0,4
Site 3	Kg/m^2	0,06	0,00	0,1	0,01	0,0 - 0,5
Site 4	Kg/m^2	0,07	0,03	0,08	0,009	0,0 - 0,3
All sites	Kg/m^2	0,08	0,05	0,1	0,006	0,0 - 0,5
Field layer vegetation						
Site 1	Kg/m^2	0,1	0,1	0,05	0,006	0,0 - 0,3
Site 2	Kg/m^2	0,08	0,06	0,07	0,008	0,0 - 0,5
Site 3	Kg/m^2	0,09	0,08	0,07	0,009	0,0 - 0,4
Site 4	Kg/m^2	0,03	0,01	0,03	0,004	0,0 - 0,2
All sites	Kg/m^2	0,08	0,07	0,07	0,004	0,0 - 0,5

Trees Biomass kg/m^2

Compartment	Site 1	Site 2	Site 3	Site 4	All sites
Crown	1,9	1,4	1,6	1,7	1,6
Stem	6,2	3,9	4,2	6,0	5,1
Bark	0,5	0,4	0,4	0,5	0,5
Stub	0,8	0,5	0,6	0,8	0,7

Roots	2,2	1,4	1,6	2,1	1,8
Dead branches	0,2	0,2	0,2	0,2	0,2
Tot above ground	8,8	5,8	6,5	8,4	7,4
Tot below ground	3,1	1,9	2,2	2,9	2,5
Total trees	11,9	7,8	8,6	11,3	9,9

Total trees/soil/field layer vegetation/bryophytes biomass (kg/m^2)

	18,5	19,5	24,0	19,4	20,4

Trees Carbon kg/m^2

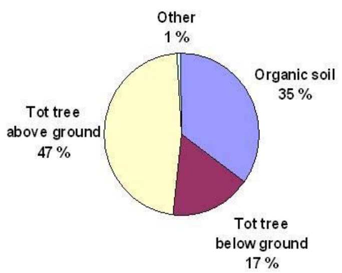
Compartment	Site 1	Site 2	Site 3	Site 4	All sites
Crown	0,9	0,7	0,8	0,9	0,8
Stem	3,1	2,0	2,1	3,0	2,5
Bark	0,3	0,2	0,2	0,2	0,2
Stub	0,4	0,3	0,3	0,4	0,3
Roots	1,1	0,7	0,8	1,0	0,9
Dead branches	0,1	0,08	0,08	0,1	0,09
Tot above ground	4,4	2,9	3,2	4,2	3,7
Tot below ground	1,5	1,0	1,1	1,5	1,3
Total trees	5,9	3,9	4,3	5,7	4,9

Total trees/soil/field layer vegetation/bryophytes carbon (kg/m^2)

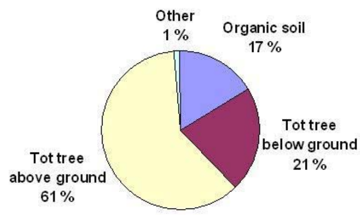
	7,2	6,0	8,5	7,9	7,4

Carbon distribution across study sites for biomass and organic mass (pie)

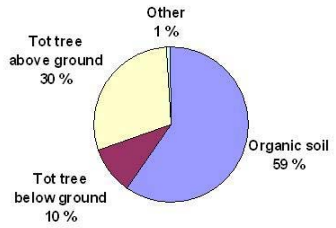
Site 1: Biomass/organic mass



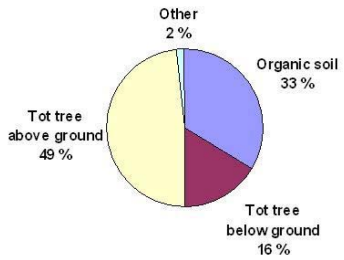
Site 1: Carbon



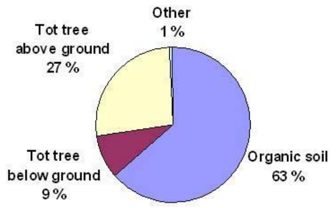
Site 2: Biomass/organic mass



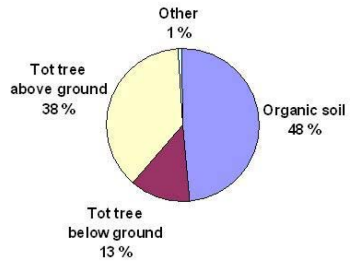
Site 2: Carbon



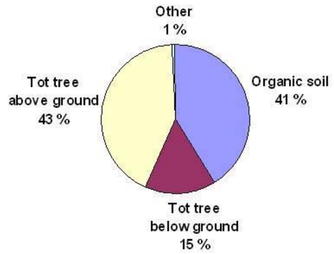
Site 3: Biomass/organic mass



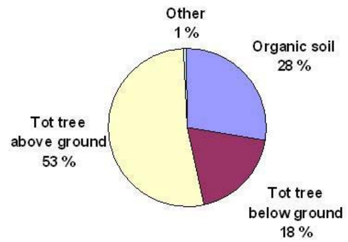
Site 3: Carbon



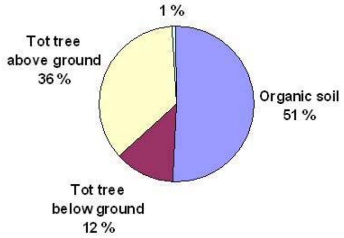
Site 4: Biomass/organic mass



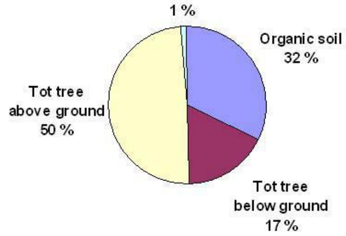
Site 4: Carbon



All sites: Biomass/organic mass



All sites: Carbon



APPENDIX 2

Method 2: sampling around the largest trees

Biomass (kg/m^2), carbon (kg/m^2) depth (cm), bulk density (g/dm^3) characteristics for M2

Carbon amount across study sites

Variable	Unit	Mean	Median	1 SD	SE, mean	Range
Soil						
Site 1	Kg/m^2	0,6	0,0	1,3	0,1	0,0 - 7,6
Site 2	Kg/m^2	1,6	0,0	3,2	0,3	0,0 - 16,2
Site 3	Kg/m^2	0,9	0,0	2,0	0,2	0,0 - 11,7
Site 4	Kg/m^2	0,3	0,0	0,7	0,06	0,0 - 3,6
All sites	Kg/m^2	0,9	0,0	2,1	0,09	0,0 - 16,2
Bryophytes						
Site 1	Kg/m^2	0,02	0,004	0,09	0,007	0,0 - 1,1
Site 2	Kg/m^2	0,02	0,005	0,03	0,003	0,0 - 0,1
Site 3	Kg/m^2	0,02	0	0,04	0,004	0,0 - 0,4
Site 4	Kg/m^2	0,01	0	0,02	0,002	0,0 - 0,1
All sites	Kg/m^2	0,02	0	0,05	0,002	0,0 - 0,4
Field layer vegetation						
Site 1	Kg/m^2	0,02	0,02	0,02	0,002	0,0 - 0,1
Site 2	Kg/m^2	0,03	0,02	0,03	0,002	0,0 - 0,1
Site 3	Kg/m^2	0,02	0,007	0,03	0,002	0,0 - 0,2
Site 4	Kg/m^2	0,01	0,006	0,01	0,001	0,0 - 0,1
All sites	Kg/m^2	0,02	0,01	0,02	0,001	0,0 - 0,2

Carbon amount – Distances

Variable	Unit	Mean	Median	1 SD	SE,mean	Range
Soil						
Distance 1	Kg/m^2	0,4	0,0	1,1	0,1	0,0 - 8,5
Distance 2	Kg/m^2	0,8	0,0	1,7	0,2	0,0 - 11,7
Distance 3	Kg/m^2	0,7	0,0	1,7	0,2	0,0 - 9,5
Distance 4	Kg/m^2	1,3	0,0	2,7	0,2	0,0 - 16,2
Distance 5	Kg/m^2	1,2	0,0	2,6	0,2	0,0 - 15,6
All sites	Kg/m^2	0,9	0,0	2,1	0,09	0,0 - 16,2
Bryophytes						
Distance 1	Kg/m^2	0,005	0	0,01	0,001	0,0 - 0,06
Distance 2	Kg/m^2	0,02	0	0,1	0,009	0,0 - 1,1
Distance 3	Kg/m^2	0,01	0	0,02	0,002	0,0 - 0,09
Distance 4	Kg/m^2	0,02	0,008	0,04	0,003	0,0 - 0,2
Distance 5	Kg/m^2	0,03	0,02	0,05	0,004	0,0 - 0,4
All sites	Kg/m^2	0,02	0	0,05	0,002	0,0 - 1,1
Field layer vegetation						
Distance 1	Kg/m^2	0,02	0,01	0,02	0,002	0,0 - 0,1

Distance 2	Kg/m^2	0,02	0,01	0,03	0,002	0,0 - 0,2
Distance 3	Kg/m^2	0,02	0,01	0,02	0,002	0,0 - 0,1
Distance 4	Kg/m^2	0,02	0,01	0,03	0,002	0,0 - 0,1
Distance 5	Kg/m^2	0,02	0,01	0,02	0,002	0,0 - 0,1
All sites	Kg/m^2	0,02	0,01	0,02	0,001	0,0 - 0,2

Carbon amount – Directions

Variable	Unit	Mean	Median	1 SD	SE, mean	Range
Soil						
Direction 1	Kg/m^2	0,8	0,0	2,2	0,2	0,0 - 15,2
Direction 2	Kg/m^2	0,9	0,0	1,9	0,1	0,0 - 10,8
Direction 3	Kg/m^2	0,9	0,0	2,2	0,2	0,0 - 16,2
All sites	Kg/m^2	0,9	0,0	2,1	0,09	0,0 - 16,2
Bryophytes						
Direction 1	Kg/m^2	0,03	0,01	0,08	0,006	0,0 - 1,1
Direction 2	Kg/m^2	0,01	0,00	0,04	0,003	0,0 - 0,4
Direction 3	Kg/m^2	0,01	0,00	0,03	0,002	0,0 - 0,2
All sites	Kg/m^2	0,02	0,00	0,05	0,002	0,0 - 1,1
Field layer vegetation						
Direction 1	Kg/m^2	0,019	0,013	0,020	0,0014	0,0 - 0,12
Direction 2	Kg/m^2	0,022	0,013	0,026	0,0019	0,0 - 0,14
Direction 3	Kg/m^2	0,017	0,0088	0,024	0,0017	0,0 - 0,18
All sites	Kg/m^2	0,019	0,012	0,023	0,0010	0,0 - 0,18

Carbon amount – Depth

Variable	Unit	Mean	Median	1 SD	SE, mean	Range
Soil depth						
0-2 cm	Kg/m^2	0,1	0,0	0,5	0,04	0,0 – 6,9
2-4 cm	Kg/m^2	0,2	0,2	0,2	0,05	0,004- 1,2
4-6 cm	Kg/m^2	0,2	0,2	0,1	0,04	0,04 – 0,5
6-8 cm	Kg/m^2	0,2	0,2	0,2	0,1	0,04 – 0,7
8-10 cm	Kg/m^2	0,2	0,2	0,1	0,04	0,1 – 0,3
10-12 cm	Kg/m^2	0,3	0,3	0,2	0,1	0,1 – 0,5
12-14 cm	Kg/m^2	0,3	0,3	0,3	0,2	0,2 – 0,5
14-16 cm	Kg/m^2	0,5	0,5	NA	NA	0,5 – 0,5

Biomass and soil organic mass

Variable	Unit	Mean	Median	1 SD	SE,mean	Range
Soil						
Site 1	Kg/m^2	2,7	0,0	5,5	0,4	0,0 - 33,4
Site 2	Kg/m^2	7,0	0,0	13,6	1,1	0,0 – 69,0
Site 3	Kg/m^2	4,2	0,0	9,0	0,7	0,0 – 52,1
Site 4	Kg/m^2	3,3	0,0	7,7	0,6	0,0 - 39,8

All sites	Kg/m^2	4,3	0,0	9,6	0,4	0,0 – 69,0
Bryophytes						
Site 1	Kg/m^2	0,05	0,009	0,2	0,01	0,0 - 2,2
Site 2	Kg/m^2	0,04	0,009	0,06	0,005	0,0 - 0,3
Site 3	Kg/m^2	0,03	0	0,09	0,007	0,0 - 0,8
Site 4	Kg/m^2	0,02	0	0,05	0,004	0,0 - 0,2
All sites	Kg/m^2	0,04	0	0,1	0,004	0,0 - 2,2
Field layer vegetation						
Site 1	Kg/m^2	0,04	0,03	0,04	0,003	0,0 - 0,2
Site 2	Kg/m^2	0,06	0,04	0,06	0,005	0,0 - 0,2
Site 3	Kg/m^2	0,03	0,01	0,05	0,005	0,0 - 0,4
Site 4	Kg/m^2	0,02	0,01	0,03	0,002	0,0 - 0,1
All sites	Kg/m^2	0,04	0,02	0,05	0,002	0,0 - 0,4