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# Forest soil carbon changes from measurements and models

## Site-specific comparisons and implications for UNFCCC reporting

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**TITTEL/TITLE**

Forest soil carbon changes from measurements and models - Site-specific comparisons and implications for UNFCCC reporting

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# Forord

I rapporteringen til FNs klimakonvensjon og under Kyotoprotokollen (UNFCCC) er estimater for karbon i skogsjord i Norge basert på beregninger med Yasso07 modellen ved bruk av inngangsvariabler fra Landsskogtakseringen. Der er i Norge ikke nasjonalt dekkende data som gjør det mulig å verifisere denne metodikk. Denne rapport viser resultater fra prosjektet «Endringer av karbon i skogsjord - referansedata for utvalgte felt og validering av prosessmodeller til bruk for Klimakonvensjonen og Kyotoprotokollen» (2011-2013), finansiert av Landbruks- og matdepartementet og Miljødirektoratet (tidligere Klima- og forurensningsdirektoratet). I prosjektet ble simuleringer av jordkarbonutvikling med to modeller (Yasso07, Romul) sammenliknet med målinger av jordkarbon gjennom 34 år i to unge treslagsforsøk på Østlandet. I tillegg til jordprøvetaking ble en betydelig mengde data innsamlet i de to forsøkene som input til de to modellene. Hovedformålet med rapporten er å presentere en sammenlikning mellom modellert og målt jordkarbonutvikling for de to lokalitetene. I rapporten blir i tillegg simuleringsresultater for hele skogsarealet i Norge, som gjennomført for rapporteringen under FNs klimakonvensjon, diskutert i forhold til data for jordkarbonlagre og endringer målt utenfor Norge.

En rekke personer har vert involvert i prosjektet, både internt ved NIBIO og fra andre institusjoner og vi ønsker å takke alle for deres bidrag. Forfattere er nevnt for de ulike kapitler. Vi ønsker å takke Helge Meissner for bidrag i feltarbeid og forbehandling av prøver, og Jan Erik Jacobsen og Monika Fongen for kjemiske analyser. I tillegg ønsker vi å takke deltakerne i prosjektets referansegruppe, Lars Vesterdal (University of Copenhagen, Denmark), Per-Arild Arrestad (NINA, Norwegian Institute for Nature Research) og Jari Liski (SYKE, Finnish Environment Institute) samt representanter for oppdragsgiver for verdifulle innspill under to seminarer arrangert som en del av prosjektet.

Kvithamar, 18.10.17

Gunnhild Søgaard, prosjektleder

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# Sammendrag

For å verifisere beregningsmetoder og modeller for endringer av karbonlagre i skogsjord brukt i UNFCCC rapporteringen er det behov for data fra jordprøver med gjentak over tid og der prøvetakingsmetoder er konsistente. I Norge finnes ikke denne typen data på nasjonalt / landsdekkende nivå. For å møte behovet for verifisering av beregningsmetodikken brukt i UNFCCC rapporteringen innenfor rammene av eksisterende data med metodisk konsistens over tid, er det i denne undersøkelsen gjennomført ny prøvetaking av jord og vegetasjon i to etablerte forsøksfelt i skog i sør-øst Norge der vi fra før av både har data fra tidligere jordprøveanalyser og tilvekstdata for trær i skogsbestand.

De to forsøksfeltene ligger på Nordmoen i Akershus (etablert 1973 og tilplantet 1974) og i Skiptvet i Østfold (etablert 1976 i eksisterende foryngelse med supplerplanting i 1977). Med nye jordprøver, biomassemålinger og vegetasjonsanalyser i 2011 gir dette to tidsserier på hhv. 38 og 34 år med hensyn på endringer i jordkarbon og inngangsverdier i beregningsmodellene. Den eksperimentelle behandlingen i Skiptvet omfatter ulik grad av treslagsblanding av bjørk og gran på de enkelte forsøksrutene, mens på Nordmoen sammenliknes rene bestand av hhv. bjørk, gran og furu. De klimatiske forhold er tilnærmet like, mens jordsmonntypen er ulik med næringsfattig sandjord på Nordmoen og næringsrik leirjord i Skiptvet. Resultatene fra forsøkene er begrenset til å representere klimatiske og vegetasjonsmessige forhold på Østlandet (og forhold tilsvarende de to lokalitetene), og forsøksfeltene er dermed ikke representative eksempelvis for kystnære og kontinentale strøk.

De to beregningsmodeller som benyttes er Yasso07 og Romul. Yasso07 benyttes nå i beregning av estimater til UNFCCC rapporteringen. Den beregner endringer i karbon basert på årlige inngangsverdier av strøproduksjon og på nedbrytning avhengig av årsmiddel for klima. Beregninger fra Romul er basert på månedlige inngangsverdier av strøproduksjon og klima, og en noe mer detaljert representasjon av jordas hydrologi og næringsdynamikk enn i Yasso07.

Dette sammendraget beskriver de overordnede resultater, dvs. de målte og modellberegnede endringene i jordkarbon på forsøksflatene over tid. Det gis også en kort gjennomgang av jordkarbonlagre og endringer beregnet på nasjonalt nivå. Data fra feltstudiene vil muliggjøre detaljerte økosystemanalyser med relasjon til karbondynamikk i trær og jord, fordeling og sammensetting av bunnvegetasjon og utvikling i skogen. Denne typen analyser er ikke ferdigstilt og er derfor ikke inkludert i sammendraget. Tidsserier inkludert målinger av jordkarbon over samme tidsrom er meget sjeldne og har et stort potensiale for anvendelse i fremtidige studier for å avdekke endringer over tid under kontrollerte forsøksbetingelser. Forsøksfeltene bør derfor vedlikeholdes og innsamling av data bør videreføres med nye gjentak.

På Nordmoen ble den overjordiske og underjordiske biomassen i trær estimert ut fra alle tilgjengelige inventeringer mellom 1978 og 2011. Ved den siste inventeringen i 2011 var den levende biomassen 49, 37 og 24 kg/m$^2$ for hhv. bjørk, furu og gran, hvilket reflekterer bestandsutviklingen for de ulike treslagene på Nordmoen. I Skiptvet var den levende biomasse i 2011 mellom 34 og 38 kg/m$^2$.

Biomasse i bunnvegetasjonen ble kun målt en gang, ved en inventering i 2012. Den var ubetydelig i Skiptvet (0-5 g karbon/m$^2$) pga den tette skogen, mens på Nordmoen varierte den mellom 38 (gran) og 85 (furu) g karbon/m$^2$. I bjørkeskog var biomassen av bunnvegetasjonen mellom disse to verdiene. En regresjonsanalyse mellom biomasse og dekningsgrad for bunnvegetasjon på Nordmoen var statistisk signifikant ($p < 0.005$). Dette viser at metoden forventes å kunne videreutvikles til å gir gode estimater for biomasse i bunnvegetasjon. For å kunne beskrive biomassen i bunnvegetasjon i skog i Norge må det etableres en sammenheng mellom biomasse og dekningsgrad siden vi har mye mer data for dekningsgrad enn direkte biomassedata. Regresjonene er artsspesifikke. Presisjonen forventes å kunne forbedres ved å inkludere andre datasett med samhørende observasjoner av biomasse og dekningsgrad. I den nåværende form er regresjonene ikke brukbare for estimering av bunnvegetasjonsbiomasse for eksempel på landsskogflater.

På Nordmoen var både det totale jordkarbonlageret og karbonlagret i det organiske sjikt nær konstant over hele forsøksperioden, men med en tendens til karbontap i bjørkeskog. I Skiptvet var det pga. forsøksdesign ikke mulig å gjøre statistiske sammenlikninger av forsøksbehandlinger. Resultater for Skiptvet indikerte likevel at behandlingen der gran dominerte hadde tendens til en økning i jordkarbonlagre mens andre treslagsblandinger hadde tendenser til et tap eller ingen endring i lagrene over tid. Den gjentatte jordprøvetakingen var tidligere begrenset til en jorddybde ned til omtrent 30 cm ved etableringen av begge forsøkene, og på Nordmoen var det ikke full kontinuitet i dybden. Ytterligere prøvetaking ble gjort i 2012, som omfattet en kontinuerlig prøvetaking til en totaldybde av 40 cm i begge forsøkene. For Nordmoen var data for karbonlagre i dypere jordsjikt tilgjengelig fra et nærliggende feltforsøk, som gav mulighet til å estimerer jordkarbonlagre helt ned til 1 m dybde. Et estimert lager til 1 m dybde er direkte sammenliknbart med modellestimert karbonlagre fra Yasso07.

Med utgangspunkt i data fra Nordmoen viste begge modeller en generell økning i jordkarbonlagre over tid unntatt for gran i Yasso07 som viste et lite tap. De observerte karbonlagre viste ingen endring eller en svak nedgang. Den generelle økning i lagre iflg modellene var en respons på en økt estimert strøtilførsel gjennom forsøksperioden, men dette var ikke reflektert i de observerte lagrene. I Skiptvet viste begge modellene et generelt tap (Romul et resultat av et stort tap etterfulgt av en markant økning), mens målingene antydet ingen endring, en svak økning eller et lite tap avhengig av behandling. Den estimerte dynamikken over tid var mindre ekstrem for Yasso07 enn for Romul og dermed nærmere den målte dynamikken. Begge forsøkene kan vurderes som utfordrende å modellere pga. endringer i flatenes historikk og arealbruk over tid, hvilket er vanskelig å inkluderer i modell-simuleringer (feltet i Skiptvet var tidligere jordbruksland, mens på Nordmoen har det i perioder vært kullmiler og sannsynligvis et intenst biomasseuttak til en nærliggende glassindustri). Forandringer i arealbruk gjennom tidene må likevel forventes å være karakteristisk for mange steder i Norge. Basert på denne forholdsvis begrensede modellverifiseringen, ser det ut til at Yasso07 reflekterer virkeligheten bedre på flater med liten eller ingen endringer. Vi kan likevel ikke trekke en slutning om at dette gjelder på nasjonal skala i Norge. Den sterkere følsomheten i dynamikk som Romul har kan antagelig knyttes til en mer sofistikert parameterisering som inngår i modellen. I Romul kan detaljerte data om flatene (for eksempel hydrologi) legges inn, men dette er generelt ikke allment tilgjengelige data i Norge. Dvs. en tilpasning av Romul på stor skala i Norge med mange flater er derfor utfordrende. Resultater fra de to forsøkene indikerte at Yasso07 er en robust og forholdsvis konservativ modell mht. dynamikk. Yasso07 estimerte jordkarbonlagrene relativt bra på Nordmoen med målt 6.6-7.1 vs. modellestimert ca. 7 kg C/m$^2$ ved starten av tidsserien, mens det ved slutten var modellestimert omtrent 6, 8 og 9.5 kg C/m$^2$ for hhv. gran, furu og bjørk. I Skiptvet gav Yasso07 imidlertid en generell underestimering av karbonlagrene. Endringsestimater fra Yasso07 samsvarte med de observerte målingene med kun moderate eller ingen endringer i jordkarbonlagrene i blandingsbestand av bjørk og gran i Skiptvet og i granbestand på Nordmoen.

På nasjonalt nivå ser vi tydelig at Yasso07 underestimerer jordkarbonlagre. Dette er sannsynligvis fordi det i Norge er mye hydromorfe jordsmonn og generelt fuktige forhold der jordsmonndannelsen er kraftig påvirket av hydrologien. Slike forhold er ikke tilstrekkelig inkludert i modellens parametre og/eller struktur. Endringer i nasjonale jordkarbonlagre i Norge estimert med den nåværende Yasso07 metoden ligger på nivå med estimater for andre nordiske land, men endringene kan ikke verifiseres med Norske nasjonale data.

Resultatene fra forsøksflatene på Nordmoen og Skiptvet samsvarte med resultatene i en meta-analyse fra tempererte skogøkosystem mht. endringer i jordkarbon etter hogst. De fleste observasjoner viste stabile eller minkende jordkarbonlagre. Forventet skulle det vært et større tap i første del av tidsperioden etterfulgt av en akkumulering drevet frem av en økt strøproduksjon når kronedekket sluttes og selvtynningen øker sterkt. Det var også forventet en større forskjell mellom de ulike bestandstypene og treslagene. Uoverenstemmelser mellom observert (målt) og modellert resultater danner grunnlag for fremtidig videreutvikling og analyser.

# Summary

To verify the methodology and models used for estimating forest soil C changes for UNFCCC reporting, data from repeated and methodologically consistent soil sampling are needed. There are currently no data on changes in forest soil C pools available on a national level in Norway. To meet the need for model validation and with the limitations of sampling consistency for old data, the current project comprises a re-sampling of soil from two old forest experiments in south east Norway. The two experiments (Nordmoen in Akershus county established 1973 and planted 1974, Skiptvet in Østfold county, established 1976 in established regeneration with some planting in 1977) provide, with the necessary gap filling, a total time series for soil C stocks and model input data over a 34-year and 38-year period, respectively. The experimental sites provide variation in tree species composition where Skiptvet covers situations (treatments) with varying portions of downy birch (*Betula pubescens*) and Norway spruce (*Picea abies*) and Nordmoen covers situations of pure stands with planted Norway spruce, Scots pine (*Pinus sylvestris*) and European white birch (*Betula pendula*). The climate is similar at the two sites, but the soil types differ, from a nutrient poor sandy soil at Nordmoen to a nutrient rich clay soil at Skiptvet. These two sites can only represent the geographical region where they are found i.e. regions with a more coastal or a more continental climate are not represented in these time series.

The two models used are Yasso07 (annual litter production and climate data) and Romul (monthly litter production and climate and in addition more detailed model of soil climate and nutrient dynamics).

This summary focus on the overall results i.e. the simulated and measured soil C dynamics on the field sites and a very short account of the estimation of soil C stocks and changes on the national level. The field site studies will provide data for in-depth ecosystem analyses relating to forest tree and soil carbon dynamics, ground vegetation distribution and mixed forest development. These integrated analyses are not completed and therefore not presented in this summary. Soil C time series of this length are rare and will potentially be used in several future studies and should be extended in due time when possible.

In Nordmoen the aboveground and belowground tree biomass was estimated at each inventory between 1978 and 2011. At the last inventory, living tree biomass (kg biomass/m$^2$) was 49 (birch), 37 (pine) and 24 (spruce) reflecting differences in stand development for the tree species on this site. In Skiptvet the living tree biomass, at the last inventory in 2011 ranged from 34 to 38 kg biomass/m$^2$.

Ground vegetation biomass (or coverage) was only measured at the last inventory in 2012. It was almost absent in Skiptvet (0-5 g C/m$^2$) and ranged from 38 – 85 g C/m$^2$ in Nordmoen for spruce and pine respectively (birch intermediate). For Nordmoen, the results of the linear regression between biomass and percentage cover show highly significant ($p < 0.005$) correlations. This demonstrates that the method may be further developed to give reasonable estimates of ground vegetation biomass, based on vegetation cover data. Vegetation cover data is available to a much larger extent than biomass data across the Norwegian forest area. The regression parameters are species-dependent. Using the same coefficients at other sites where coordinated observations of biomass and vegetation cover are available is a feasible way to further test and improve the methodology At this point, the regression method is not suitable to be used routinely for the estimation of ground vegetation C pools at the individual site level, e.g. from the national forest inventory.

In Nordmoen, total soil C stocks as well as forest floor C stocks were close to constant over the time series with birch showing a tendency for decreasing stocks. For Skiptvet the experimental design did not allow for rigid statistical analyses across treatments. Results suggested that the treatment favoring spruce tended more toward an increase in soil C stocks whereas other treatments (mixed spruce and birch) tended toward decreasing or no change in the stocks. The repeated soil sampling was limited to

a soil depth of approximately 30 cm at both sites, however, the soil at Nordmoen was not sampled continuously. Additional sampling in 2012 was carried out for a total depth of 40 cm. For Nordmoen, existing data on C stocks from deeper soil layers from nearby sites enabled estimates of stocks to 1 m soil depth. A soil C stock to 1 m depth can be directly compared to stock estimates from the Yasso07 model.

Based on the site-specific studies in Nordmoen, both of the chosen models generally showed an increase in soil C with time (except Yasso07, spruce), whereas measurements showed limited or no changes. Thus, models responded to an increase in litter input which was not reflected in the measured soil C stocks. In Skiptvet, models generally showed a decrease (Romul incl. large loss and following accumulation) where measurements showed no change or a slight decrease. The carbon dynamics of Yasso07 is less pronounced than that of Romul, and thus closer to observations. Both sites may be viewed as challenging case studies due to their management history which is difficult to represent in model simulations (Skiptvet is a former agricultural site and Nordmoen have experienced intense biomass extraction through history related to nearby glass industry). However, such situations are characteristic of many sites in Norway.

Based on this rather limited comparison, it seems that Yasso07 is better adapted to sites with small or almost no changes. To which extent this holds also on a large scale is unknown for Norway. The stronger responsiveness of Romul is accompanied by a more sophisticated parametrization procedure. Thus, detailed information on site-specific conditions (e.g., information on hydrology) is an advantage, but not routinely available at most sites. In practical situations, routine application of Romul on a large scale (or many plots) is a challenging task. Site-specific studies gave support to Yasso07 as a relatively conservative and robust model; it was able to estimate the soil C stocks relatively well in Nordmoen (measured 6.6-7.1 and model ca. 7 kg C/m$^2$ at start, ca. 6 (spruce) and 9 (birch) at end of time series. At Skiptvet, on the other hand, the Yasso 07 model generally underestimated the soil C pool. Like the measurements; Yasso07 showed very modest or no changes in Skiptvets mixed birch and spruce and in Nordmoen spruce.

At the national level we clearly see that Yasso07 underestimates the observed soil C stocks. This is likely to be related to a high frequency of hydromorphic soils and generally wet conditions across Norway producing processes of soil development over time that may not be sufficiently well represented in the model parameters. Changes estimated with the current Yasso07 methodology on the national level were in the range observed for other Nordic countries but cannot be verified with national data.

The field measurements on Nordmoen and Skiptvet were generally in agreement with the results from a meta-analysis of changes in soil C stocks following harvest.

Measurements did, in most cases, show rather stable or decreasing soil C stocks over time. Expected results would have been a larger decrease in soil carbon at the start of the experiment, based on low litter input and increased decomposition, followed by an increase due to canopy closure, increased litter production and tree biomass. Also, tree species/stand types were expected to show larger differences. Discrepancies between measured and modelled results provide a basis for further model developments and studies.

# 1 Introduction

## 1.1 Background

As a part of the national greenhouse gas (GHG) inventory, Norway reports changes in carbon (C) for forest soils. This follows from the commitments under the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol (KP). The reported estimates have been based on model predictions (Anonymous 2005, 2013, 2014). The mean (2000-2012) estimated annual forest soil C change on mineral soils is 1900 Gg C; for comparison, the mean estimate for net C changes in the living biomass is 6700 Gg C (Anonymous 2014). According to the Good Practice Guidance (IPCC, 2003) and Annex in Decision 19/CMP.1, paragraph 7 (UNFCCC 2005) it is necessary that countries validate the models used in the GHG inventory. While there are field based measurements of forest soil C stock in Norway on a national scale (Esser and Nyborg 1992, DeWitt and Kvindesland 1999, Strand et al. 2016), there have been no attempts to measure countrywide forest soil C stock changes. The work presented in this report builds on the project "*Endringer av karbon i skogsjord - referansedata for utvalgte felt og validering av prosessmodeller til bruk for Klimakonvensjonen og Kyotoprotokollen*"; 2011-2013 (*"Forest soil C changes on selected field sites and validation of process models for use in GHG reporting*"). This project was funded by The Norwegian Environment Agency and The Norwegian Ministry of Agriculture and Food and represents an alternative approach to the need for validation of forest soil C changes. On a few sites we i) use and update the best available soil C and vegetation measurements in Norway repeated over time, ii) establish estimates based on two contrasting soil C models; one being the model currently used in the GHG inventory, the second a process based model, and iii) use the results in an evaluation of the methodology currently used in the GHG inventory. Existing data on forest soil C change in Norway are generally sporadic and differ in quality and applicability specifically for this purpose (see below). We stress the fact that this report will not be able to conclude on a national scale concerning model validation for forest soil C changes.

## 1.2 Project aim

The project had the overall aim to i) contribute to the establishment of reference data for forest soil C changes and ii) compare and validate models for forest soil C changes using these reference data. Results from the project were expected to i) support the choice of model used on a national level, ii) contribute to the validation of national level estimates for soil C changes and iii) contribute to the knowledge on soil C changes on two sites differing in soil type and tree species.

## 1.3 The structure of this report

First, the background for the selection of the study sites is given in chapter 2. Then follows a description of the methodology and results from field studies (chapter 3) and the model simulations (chapter 4). These studies are referred to as "site specific studies/simulations". Chapter 5 describes the methodology used for the estimation of forest soil C changes in the annual GHG inventory. This includes some model output and a first comparison of simulated and measured forest soil C stocks on a national scale and for selected counties (fylke). In chapter 6 we discuss the findings (site specific results and national scale C stocks) and conclude.

During the project, two seminars were held with participation from the funding agencies and a group of specifically contracted external researchers (reference group) in addition to project researchers. The establishment of the reference group was a prerequisite for project funding. Discussions and recommendations from these two seminars are documented in Appendix 4 and Appendix 5 of this report. The reference group members were Lars Vesterdal (University of Copenhagen, Denmark), Per-Arild Arrestad (NINA, Norwegian Institute for Nature Research) and Jari Liski (SYKE, Finnish

Environment Institute) as well as representatives from the funding agency. The seminars and the results from the field and simulation studies are considered an important contribution to the Quality Assurance activities for the GHG inventory on forest.

# 2 National Level Data Availability and Background for the Selection of Study Sites

O. Janne Kjønaas and Gro Hylen

The GHG inventory for forests includes changes in living biomass, dead organic matter, including the humus layer, and mineral soil.

The main focus of the Norwegian GHG inventory for forests has been to quantify the uptake of C in trees. Estimates of uptake (growth) and loss (harvest, mortality) of C in trees are based on validated biomass functions, combined with tree and stand data from the Norwegian National Forest Inventory (NFI). This approach is an excellent foundation for estimating C changes in living tree biomass with time. The Norwegian NFI consists of data collected from approx. 11 000 permanent sample plots in forest, re-measured every 5 years, and located in a systematic grid (3x3 km, 3x9 km or 9x9 km, depending on strata; see NIR 2014 for details; Anonymous 2014). Approx. 8700 plots are in productive forest (volume increment > 1 $m^3$ / (ha * year)). The grid includes lowland as well as mountain forests throughout Norway. Lowland plots were generally established between1986 and 1993, whereas plots in Finnmark County and in mountain forest were established between 2005 and 2011 (Tomter et al. 2010).

The accumulation or loss of C from the soil has received considerably less attention than the C uptake in trees. During the time period 1988 to 1992, soil samples were collected from soil profiles in ca. 1000 ICP level I (NFI) plots located 5-30 degrees East, 58-70 degrees North and 2-1190 m above sea level (Strand et al. 2016; chapter 5.3). In contrast to the living biomass, the soil in these plots has never been resampled. Thus, currently, the availability of long-term, nation-wide data on changes in the soil carbon stocks is limited.

In addition to the above mentioned plots, soil samples were collected from 18 plots within the Norwegian monitoring program for forest damage (ICP level II plots) during the time period 1986 – 1989 (OPS 1988a, 1988b). This soil was resampled after 5 years (Jensen 1993, Jensen and Frogner 1994), and an additional repeated soil sampling took place at selected plots in 2011 (5 plots) and in 2013 (6 plots). At all sampling occasions, four replicate bulked samples were collected from each diagnostic horizon or designated soil depth, consisting of approx. 30 sampling points in each bulked sample. The repeated soil sampling in 2011 and 2013 showed, however, limitations regarding the reliability of the data for estimations on changes in the soil C pool[1]. This was mainly due to the sampling method.

During the first sampling periods, the soil was sampled by use of a single gouge auger, whereas during the two latter sampling occasions, the soil was collected by use of a cylinder auger (see chap. 3.2.5) to reduce sampling errors related to C stock estimates. The single gouge auger may, depending on soil

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[1] Data on soil chemistry have not yet been subject to numerical/statistical analyses.

type and soil moisture content, cause a compression of the sampled soil. In addition, an accidental mixing of the top soil layers during the sampling may frequently occur. At the first sampling occasions, sample parts that consisted of soil that was accidentally mixed during the sampling process were excluded from the bulked soil samples. This may have resulted in an exclusion of transitional layers that may contain high concentrations of C (e.g. Ah below Ae, Bh on top of Bf). As both C concentration and soil depth are key factors for calculation of the soil C pool, the earlier sampling approach may underestimate the C pool of the soil. A comparison of C pools obtained by the two different methods may thus potentially result in an overestimation of the soil C accumulation rate over the given time period. With a small population (11 plots), a high level of uncertainty rendered the data less suitable for model validation purposes.

Repeated soil sampling was also part of the program initiated by the Norwegian Pollution Authorities (SFT): “Monitoring of long range pollution in air and precipitation” (Anonym 1984). Soil samples were collected from 8 areas consisting of small catchments as part of the soil chemistry monitoring program. The sampling was repeated two or three times (1981-1988, 1989-1997, and 1998-2001). The research focus was on acidification, and the purpose of the study was to determine changes in soil chemistry and water quality over time in small catchments with different atmospheric inputs. The 8 areas spanned a gradient from Birkenes (Aust Agder County, southern Norway) to Dalelva, Finnmark. Each area consisted of four small catchments (sub plots) with or without forests. Four replicate bulked samples were collected by use of a cylinder auger per sub plot, and each bulked sample consisted of soil from 50 sampling points. The soil was originally sampled by combination of fixed depths and horizons. This entailed sampling of only the upper part of the organic horizon. As total humus thickness was not recorded, data on changes in the thickness of the humus layer with time was not available. Thus, a re-sampling of these plots could not provide C stock estimates for model validation purposes.

According to IPCC "good practice guidance", data from repeated soil samplings are needed in order to provide data on changes in soil C pools for model validation, and the samplings have to be comparable. There are currently no data on changes in soil C pools available on a national level in Norway. To meet the need for model validation, the current project thus comprises a re-sampling of soil from two old experiments in south east Norway. The data include experiments involving different tree species or mixes of tree species: a) an experiment on regrowth in stands with varying portions of downy birch (*Betula pubescens*) and Norway spruce (*Picea abies*) in mixtures at Skiptvet, Østfold County and b) an old acidification experiment in small plots with planted Norway spruce, Scots pine (*Pinus sylvestris*) and European white birch (*Betula pendula*) at Nordmoen, Akershus County. Whereas the climate is relatively similar at the two sites, the soil type differs, from a nutrient poor sandy soil at Nordmoen to a nutrient rich clay soil at Skiptvet. The soil C and the tree diameter have been measured repeatedly over the period since the experiments were established, which provides data to calculate temporal changes in the C pools of the soil and tree biomass. The two experiments provide a total time series over a 34-year and 38-year period, respectively. As data on forest floor thickness was note recorded at some of the sampling occasions, the time series on soil C pools comprise 34 years at both sites. The long-term data series that include C pools in both soil and trees sampled at three to five sampling occasions make these experiments valuable as reference data for model validation purposes.

# 3 Repeated Sampling of two Tree Species Experiments in S.E. Norway

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## 3.1 Background

The main purpose of the field study was two-fold: To quantify changes in the soil C pools with time in order to produce reference data for model validation, and to estimate standing living biomass and input of dead organic matter from trees and ground vegetation as input parameters to model simulations. The work was carried out in order to extend the stand C measurement time series to 34 and 38 years, respectively, at two sites with contrasting soil properties. The experimental sites had either 3 or 5 stand types.

On the current sampling occasion, and in contrast to the earlier sample collections and registrations, also the ground vegetation biomass and species abundance was recorded. Data on ground vegetation biomass in forests are generally sparsely available due to its time-consuming laboratory work. The understory vegetation in boreal forests contribute relatively little to the total standing biomass, but the total annual nutrient uptake by dwarf shrubs, herbs, graminoides and bryophytes is substantial, and their combined net primary productivity (NPP) may be substantial (Nilsson and Wardle 2005). Due to the much higher turnover rates of the understory species compared to trees, the understory plants produce a substantial proportion of the annual litter fall that is returned to the soil. The species composition is likely to affect nutrient flow and decomposition, thereby influencing soil carbon accumulation (Song et al., 2010). Thus, also the litter input from ground vegetation may be an important input variable when changes in soil C are modeled.

Specific goals of the study were:

- Quantify changes in the soil C pools with time in different stand types (tree species/ mixtures).
- Quantify effects of stand type on the total soil C pool down to approx. 40 cm soil depth.
- Quantify the standing living and dead tree biomass and their C pools.
- Quantify effects of different stand types on the standing biomass and the C pool of the trees.
- Investigate the relationship between the cover of ground vegetation species and their biomass as well as analyze and describe the ground vegetation species composition and diversity and their relationship to biomass, stand type and environmental conditions.

Quantify the total C pool (trees, soil and ground vegetation combined) in different stand types, with a focus on the most recent and extensive observations in 2011-2012.

Together, the data from the soil, ground vegetation and trees provide a budget for the total C pool of the forested systems down to approx. 40 cm soil depth.

## 3.2 Materials and methods

### 3.2.1 Site description

The site at Nordmoen was situated in Akershus county approx. 45 km north of Oslo (60°16'N, 11°06'E) at an elevation of 200 m, and the site at Skiptvet was situated in Østfold county approx. 60 km south-east of Oslo (59°32'N, 11°08'E) at an elevation of 140 m.

The mean annual temperature (MAT) and precipitation (MAP) were 4.65 °C and 853 mm, respectively at Nordmoen (Gardermoen meterological station mean for the period 1978 - 2012), and the MAT and MAP at Skiptvet were 6.30 °C and 959 mm, respectively (Fløter meterological station (precipitation) and Rygge meterological station (temperature) for the period 1976 - 2012).

The experiment at Nordmoen was set on a well-drained, glaciofluvial plain with deep sandy deposits overlaying Precambrian and Permian crystalline bedrock. The mean inclination at the experimental area is 3.2°. The soil is sandy (90-98% sand) with a groundwater level between 1-4 m depth (Stuanes et al. 1994a). The soil is classified as Typic Udipsamment (U.S. Soil Taxonomy, Soil Survey Staff 1999) and Cambic Arenosol (FAO-Unesco 1990) (Stuanes et al. 1994a). Historically, the site has been used for forestry, with regular harvesting as well as charcoal production due to the forest being easily accessible and in relatively close vicinity to industry. The site index (H40, defined as top height (H) in meters at reference age 40 years at breast height) was 17-19 for the spruce, 21-23 for the birch and 19 for the pine stands.

The experiment at Skiptvet is set on a close to flat plain of marine sediments, with a mean inclination of 4.8°. The soil type is silt loam consisting of 26 % clay. The soil is a nutrient rich Brunisoil classified as an Umbric Endoaqualfs (U.S. Soil Taxonomy, Soil Survey Staff 1999), and a Humic Gleysol (FAO-Unesco 1990) (Hanedalen 2004). The site index was 23 - 28 for spruce and 24 - 27 for birch (Hanedalen 2004). Historically, the site has been trenched and used for agriculture purposes before being planted with forest. The first generation spruce forest was harvested in 1965-1968. Spruce seedlings were planted about 1970. Birch was naturally regenerated after the harvest from surrounding birch and shoots from cut birch.

### 3.2.2 Experimental design and sampling

The experiment at Nordmoen was part of a large scale field experiment to study the effects of acid rain on soil and trees (Stuanes et al. 1994b). This location has been home to several experimental studies; in the current study the A3 experimental site was used (Appendix 1). In 1973, the experimental area was clear cut and all branches and other harvest residues were carefully removed by hand from the site. Planting took place in 1974 in a randomized block setup with four replicates (blocks) and each block divided into three parts (split plot). Each part consisted of 20 macro plots (4 m x 4 m) planted either with birch, spruce or pine (referred to as stand types). Each macro plot (16 m$^2$) was planted with 36 seedlings.

The treatment with various levels of acid irrigation took place between July 1974 and September 1978. In addition to the acid rain treatments, a single dose of crushed limestone ($CaCO_3$) was added at four levels at the start of the experiment: 0) no lime; 1) 1500 kg $CaCO_3$ ha$^{-1}$; 2) 3000 kg $CaCO_3$ ha$^{-1}$; 3) 6000 kg $CaCO_3$ ha$^{-1}$. Un-watered plots (UW) served as controls for the effects of irrigation (IR) (Stuanes et al. 1994b). In 1996, the site was thinned and some of the felled trees were removed from the site. Soil samples and needle / leaf samples were collected from all plots in 1974, 1978, 1981, 1984, and 1988, and the height of the trees were measured. In 1996, the 72 macro plots which were not artificially acidified, the UW and IR plots, were sampled (see Appendix 1 experimental design Nordmoen). The soil sampled from these UW and IR plots were bulked into one sample per soil layer for each of the 3 lower levels of initial limestone addition, giving bulked soil data from a total of 36 combined UW+IR plots. This same approach was used on the current sampling occasion.

Althogehter, the soil was sampled from all plots in 1974, 1978, 1981, 1984, 1988, 1996, and 2012, whereas the height of the trees were measured in 1978, 1985, 1988 and 2011. In 2011, diameter was measured on all trees and the height was measured on sample trees (Table 3.1)

No needle / leaf samples were collected in 2011.

The experiment at Skiptvet was established in August 1976 in a mixed regeneration of Norway spruce and birch (Braathe 1992). The site was included in a country-wide study with a total of 14 sites in Southern Norway and Trøndelag, however, the site at Skiptvet was the only site with repeated soil sampling. The background for the country-wide study was an increased growth of broadleaf trees which was caused by a combination of decreased grazing, intensified use of clear cut as the major harvesting method, and an increased planting distance. As open clear cut areas to a large extent favor the regrowth of broadleaf trees, the aim was to investigate how and to what extent the broadleaf trees may be used in an optimal way.

The study at Skiptvet used randomized blocks with two replicates, and five treatments (referred to as stand types):

- T0: control (undisturbed);
- T1: systematically favoring birch trees;
- T2: spruce and birch in balanced stands (birch planted in gaps);
- T3: spruce and birch, supplementary plots (as (2) but supplemented with birch);
- T4: systematically favoring spruce trees.

The size of five of the treatment plots were 20 x 30 m, with inner plot of 10 x 20 m and the remaining five plots were 25 x 25 m, with an inner plot of 15 x 15 m (see Appendix 2, experimental design Skiptvet).

At the start of the experiment there was an abundance of both spruce and birch in the plots, with no need for supplementary planting; however, in 1977, T3 received some supplementary planting of birch. As the regrowth of different broadleaf species proceeded, two plots were treated with herbicide (glyphosate) to remove some of the unwanted regrowth (one plot in each of T2 and T4), whereas in 1979, the unwanted regrowth was removed by hand in one plot in each of T1 and T4. Natural thinning by mortality was frequently recorded. A limited thinning took place in 1988, however, the stands are still relatively dense.

Soil samples and needle / leaf samples were collected from all plots in 1978, 1988, 1993, and 2012, and the diameter and height of the trees were measured in 1976, 1980, 1985, and 1990. In 1996 and 2012, diameter was measured on all trees whereas the height was measured on sample trees (Table 3.1 and Figure 3.1, Figure 3.2).

**Table 3.1 Background information on the experiments at Nordmoen and Skiptvet. SE Norway**

| Location | Nordmoen | Skiptvet |
|---|---|---|
| **County** | Akershus | Østfold |
| **Established (year)** | 1973 | 1976 |
| **Tree species / stand types** | Spruce, pine and birch | Spruce dominated, birch dominated, and mix of spruce and birch |
| **Measurements of trees**[e] | 1978, 1985, 1988, 2011 | 1976, 1980, 1985, 1990, 1996, 2012 |
| **Collection of soil samples (year)**[ae] | 1974[bc], 1978, 1981[d], 1984, 1988, 1996, 2012 | 1978, 1988, 1993[b], 2012 |
| **Length of time series for soil C (including first sampling at Nordmoen)** | 34 (38) years[b] | 34 years |
| **Original soil sampling Regime** | O/Ah, E, B3-8 cm, B18-23cm | O, O-10 cm, 10-15 cm, 15-20 cm, 20 - 30 cm |
| **Additional soil sampling in 2012** | B0-3 cm, B8-18 cm, B23 - approx. B33 cm. (Total depth approx. 40 cm) | 30 - approx. 40 cm total soil depth (below the soil surface) |
| **Soil quality** | Sandy soil, nutrient poor | Clay soil, nutrient rich |
| **Background** | Established as an acid rain experiment with different tree species (spruce, pine, birch) planted in 4x4 m plots | Established to investigate re-growth in stands with different compositions of spruce and birch |
| **References** | Abrahamsen, G., Stuanes, A.O. & Tveite, B. (Eds.) 1994 | Braathe, P. 1992 |
| **Number of macro plots originally sampled (2011/2012 in parenthesis)** | 240 (72) | 10 (10) |

a. Soil C was analyzed as Loss on Ignition (LOI) between 1974 and 1988 and as total C in 1996; in 2012 the soil was analyzed for both LOI and total C
b. The thickness of horizons, including the forest floor (organic) horizon, were not registered in 1974 at Nordmoen and 1993 at Skiptvet.
c. The layer B8-23 cm was not sampled. In addition, mineral soil from $CaCO_3$ $ha^{-1}$ plots (1500 kg $CaCO_3$ $ha^{-1}$) was not sampled.
d. Un-watered plots (UW) were not sampled
e. In the current study, only the treatments UW (un-watered) and IR (irrigated) were used (chapter 3.2.2).

### 3.2.3 Field methods: tree biomass

The most recent inventory of tree data was done in October 2011 at Nordmoen and in October 2012 at Skiptvet. The diameter was measured on all standing trees, whereas the height was measured on selected trees: At Skiptvet, every 4th tree was selected as a sample tree, whereas at Nordmoen approx. 3 trees were subjectively selected from each macro plot, one in each of the higher, middle and lower height classes. The volume of the trees was estimated by models of Braastad (1966), Brantseg (1967) and Vestjordet (1967). Tree heights were calculated by interpolation of heights from sample trees or heights from diameter classes. We calculated volume, basal area and stems per ha for each tree species separately.

Trees that were visually determined as being dead were separated into two categories: standing dead trees and dead trees that had fallen down. Most of the latter dead trees at Nordmoen were from the thinning in 1996. All dead trees were measured in the same way as the living trees and the standing dead trees were included as part of the estimated total above- and belowground standing tree biomass (living biomass + dead wood) at the inventory in 2011. A corresponding year of death was estimated for each tree as a best guess between the two embracing inventories.

To determine the site index (=site productivity class = tree height at age 40 years) at the two sites, the tree age at breast height (1.3 m) was calculated. The site index was estimated according to Tveite and Braastad (1981), for both spruce and for birch when both tree species were present in the plot.

For spruce and pine, the biomass was estimated by models of Marklund (1988) (aboveground) and Petterson & Ståhl (2006) (belowground). For birch, the biomass was estimated by models of Marklund (1988) (aboveground) and Repola (2008) (aboveground and belowground compartments). The biomass for each fraction of the tree was calculated separately, e.g. stem, bark, branches, foliage (needles and leaves) etc.

The C pool in trees was estimated by models of Nurmi (1993) and Nurmi (1997), which is based on measured reference C concentrations in the different tree compartments for different tree species. This gives slightly different C pools as compared to the method based on the general assumption of 50% C in trees. The latter is nevertheless used for the model simulations (chapter 4).

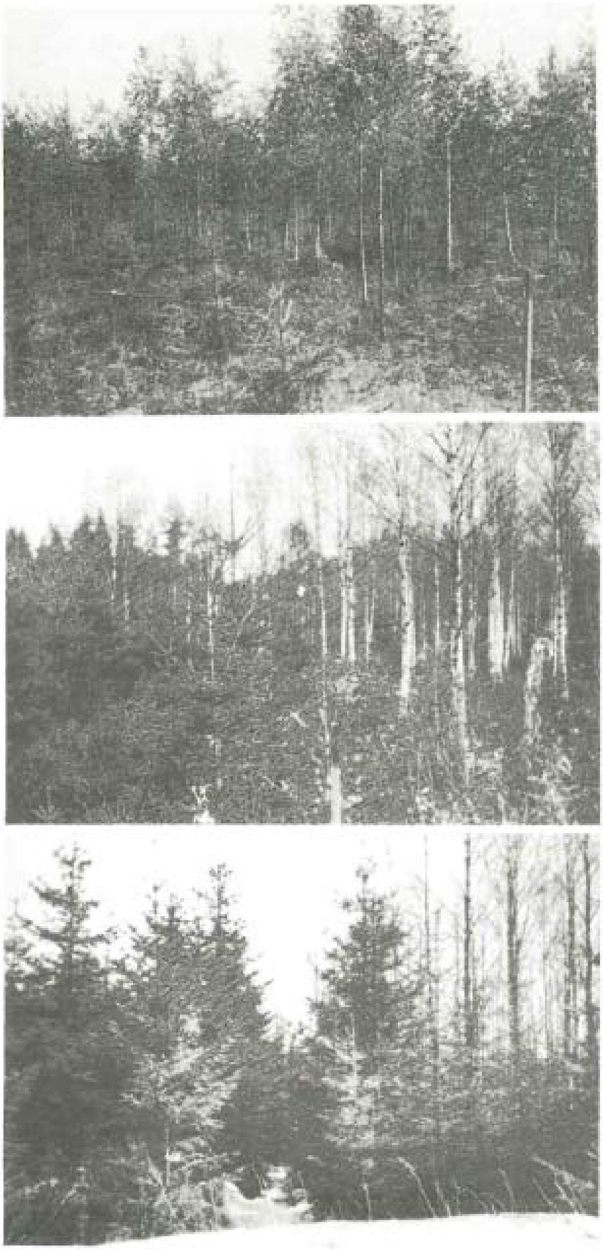


Figure 3.1 Photos of site Skiptvet in 1977 (upper), 1981 and 1987 (lower).

**Figure 3.2 Photos of sites Nordmoen (top-down: spruce, pine, birch) and Skiptvet in 2012**

## 3.2.4 Field methods: Ground vegetation - species abundance and biomass

### 3.2.4.1 Plot placement at Nordmoen and Skiptvet

The fieldwork at Nordmoen was performed in 2011 and 2012. Inside each of the 72 macro plots (Table 3.1), one 1m x 1 m vegetation plot was established and permanently marked. As far as possible the vegetation plot was situated at the same relative position within the macro plots. Biomass plots (50 cm x 50 cm) were placed ca. 50 cm to the right of the vegetation plots, preferably in areas with similar species composition.

The fieldwork at Skiptvet was performed in 2012. Within each macro plot, four 1 m x 1 m vegetation plots were randomly positioned and permanently marked, giving a total of 40 sample plots. Plots for biomass were positioned and sampled as for Nordmoen.

For both sites the vegetation plots were divided into 16 subplots.

#### 3.2.4.2 Vegetation analyses and biomass harvesting

In each 1x1m vegetation plot, the abundance of all ground vegetation species were recorded using two different measures: (1) percentage cover of each species and (2) subplot frequency (presence/absence of each species in 16 subplots). For each vegetation plot we recorded several explanatory variables describing local environmental conditions (inclination, heat index, soil depth, surface roughness) and properties of the humus layer, determined as part of the general soil sampling procedure (thickness, density, loss on ignition, soil pH, total C, total N, exchangeable Ca, Mg, K, Na, Al, Fe, Mn, Zn, P, S). Stand density and tree influence on the vegetation was quantified by measuring the basal area at breast height using a relascope (Økland 1996, Liu et al. 2008). We also recorded the cover of the i) field layer (vascular plants < 0.3 m), ii) bottom layer (bryophytes and lichens) and iii) litter.

Cover estimates for dominant species were also recorded in the biomass plots at Nordmoen. In addition, all living biomass as well as litter was harvested and preliminary sorted into separate groups in the field. Immediately after fieldwork, all harvested biomass samples were stored in a freezer until further sorting took place.

#### 3.2.4.3 Laboratory work

In the laboratory, the different species harvested at the biomass plots were compiled into the following main groups:

- Wavy hair grass (*Avenella flexuosa*) .
- Wooded species (dwarf shrubs such as bilberry (*Vaccinium myrtillus*) and lingonberry (*Vaccinium vitis idaea*) and small trees (< 80 cm height)).
- Herbs and other graminoides.
- Bryophytes.
- Litter (dead organic material).

At Nordmoen, the component “herbs” included two species of *Lycopodium*, while at Skiptvet this component included *Dryopteris expansa* and *Equisetum sylvaticum*.

After sorting, the biomass samples were dried for at least three days at 70 °C, and then weighed. After weighing, a subsample from each main biomass group was milled before analysis of total C. For Nordmoen the samples from the UW and IR plots were mixed before chemical analyses.

### 3.2.5 Field methods: soil carbon

#### 3.2.5.1 Nordmoen

Twelve subsamples were collected within each macro plot by use of a cylinder auger (Ø 28 mm). The soil was sampled in a grid from each paired UW and IR macro plots and bulked into one sample per horizon for chemical analysis (n=12 samples from each horizon for each stand type). Originally, the soil was sampled from the forest floor (O) or Ah horizon, from the eluvial horizon (E), and from one section of the B horizon. For the collection of the B horizon sample, the upper 3 cm of the horizon was discharged and the subsequent 5 cm sample was collected (Bs3-8cm). From 1978 and onwards, the soil between 8-18 cm was discharged and an additional 5 cm of the B horizon was collected (Bs18-23 cm) (Table 3.1). This sampling procedure is labeled “original mineral soil sampling” in the following text.

The thickness of each forest floor, Ah and E horizon was measured at each sampling point (n=24 for each UW+IR plot). However, no data on thickness was recorded for any horizon in 1974. Additionally, in 1981, only IR plots were sampled, which rendered the data less suitable for comparison. Thus, the data from 1974 and 1981 were excluded from the C pool data analysis.

In order to calculate the total C stock of the soil down to approx. 40 cm, the mineral soil sampling in 2012 included additional soil sampling of the upper 3 cm of the B horizon, the 10 cm layers between 8 and 18 cm, as well as 10 cm of the B horizon below the lower boundary of Bs18-23cm (23 cm to approx. 33 cm depth below the forest floor).

The thickness of both the forest floor and E horizon differed between sampling times. In 2012, the total depth of the sampled soil varied between the tree species: The mean total sampling depth was 37.8 cm, 36.7 cm and 36.9 cm in the birch, pine and spruce plots, respectively, which is referred to as a total depth of approx. 40 cm in the text.

To enable estimates of the total C pool down to 1 m soil depth, we used data on C pool in the mineral soil from an adjacent age chronosequence study (Kjønaas et al. in prep.). The data are based on the mean C pool between approx. 40 cm soil depth down to 1 m soil depth in stands of Norway spruce age 12, 30, 60 and 130 years (n=12). Results from the chronosequence study did not show any significant difference in the C pool of the mineral soil between different stand ages (Kjønaas et al. in prep).Thus, the current estimates are based on the assumtion of no change in the deeper mineral soil C pool over the approx. 40 year time span.

#### 3.2.5.2 Skiptvet

At Skiptvet, 45-48 subsamples were collected within each macro plot by use of a cylinder auger (Ø 28 mm). The locations of the sampling points were randomly selected by throwing an object three times for every 5 meters. The sampling of the soil was continuous with depth, and apart from the forest floor, the soil was sampled by depth. Originally, the following layers were collected: humus (O); below humus -10 cm, 10-15 cm, 15-20 cm and 20-30 cm. In 2012, the sampling regime also included addition 10 cm of the soil, sampled from 30 and approx. 40 cm soil depth.

The soil from each horizon/soil depth of each macro plot was bulked for chemical analysis (n=2 samples from each horizon for each stand type). The thickness of each horizon was measured at each sampling point (n=45 - 48 for each macro plot) in 1978, 1988, and 2012. Thickness of the soil was not recorded when sampled in 1993, thus all the data from this year were excluded from the Skiptvet data analysis.

No measured data were available for estimates of soil C stocks down to 1 m soil depth, and thus the current soil C stocks reported for Skiptvet are limited to approx. 40 cm soil depth.

At both Skiptvet and Nordmoen, the total sampling depth varied to some extent between sampling points due to natural obstacles. For the purpose of comparison of soil C pools, the thickness of the lower mineral horizon was set to 10 cm for the estimates of soil C stocks in all macro plots at both Nordmoen and Skiptvet.

#### 3.2.5.3 Chemical analysis and bulk density

At all sampling occasions, the samples were air dried and then passed through a sieve with 2 mm mesh size. In 2012, the soil from was weighed prior to and after air drying to determine total dry weight of soil as well as gravimetric water content. Dry matter was determined on a subsample.

The calculated soil C pool was based on three factors: the concentration of C, the thickness of a given layer, and the soil bulk density (BD). As the stone content was negligible in both soil types, there was no need for a correction factor for stoniness.

For the years 1978 - 1988, the content of organic matter in the soil was determined as loss on ignition, LOI (%). In 1996, C concentration was determined as total C (%), whereas in 2012 both LOI and total C were determined. The carbon concentration was analyzed according to Ogner et al. (1999).

For the years 1978 - 1988, the conversion of LOI to total organic C (%) was calculated based on a linear regression between C (%) and LOI in 2012. The regression analysis was performed for each horizon separately, but all tree species pooled together.

In 2012, the BD of the soil was calculated for each horizon at each plot based on the following data: diameter of the auger, sum of the thickness of each layer and the total dry weight of the collected soil in each plot.

No data on soil BD was available for any of the plots at Nordmoen or Skiptvet prior to 2012. Differences in bulk density in 2012, along with differences in LOI, were used as indicators to evaluate possible changes in bulk density with time.

At Nordmoen, the LOI in the forest floor in 1974 was relatively similar between the stand types, amounting to 78%, 79% and 86% in the birch, spruce and pine stands, respectively. We also assumed the BD to be relatively similar between the stand types, as the spatial heterogeneity of the soil at the start of the experiments was expected to be independent of the experimental design. In the spruce stands, the BD was not expected to change with time within the given stand development. This assumption was based on data from the adjacent chronosequence of Norway spruce (Kjønaas et al. in prep.) where the BD of the forest floor was 0.20, 0.19 and 0.19 g cm$^{-3}$ in 10, 32 and 55 year old stands, respectively. The assumption of a similar BD between the stand types at the start of the experiment, along with the similar BD of the spruce and pine stands in 2012 (Table 3.2), led to the assumption that the BD of the pine stand did not change with time. Thus, for the spruce and pine stands, the BD for the period 1978 - 1998 was set equal to 2012.

The higher BD in forest floor and the lower BD in the mineral horizons of birch stand in 2012, on the other hand, suggested that a change had taken place in this stand type with time (Table 3.2). To allow for a similar density at the early part of the experiment when the effect of stand type was expected to be minor, the density for the years 1978 – 1988 was set equal to the mean density of the different horizons of the spruce and pine stands in 2012. In 1996, the BD of the different horizons was set equal to the mean BD of each horizon in the birch stand in 2012.

At Skiptvet, there was a relatively large heterogeneity in LOI at the start of the experiment. The initial LOI in the forest floor was lower and had a larger range compared to Nordmoen (43% - 63%). This suggested a variable degree of mixing of mineral soil and forest floor material in the different plots, which affects the BD. With time, the combined forest floor and mineral soil down to 10 cm suggested only minor changes in the LOI (chap. 3.3.4.1). Based on this, the soil density in 1978 and 1993 was set equal to the calculated soil density for each plot in 2012.

The uncertainty of the C pool estimates both at Nordmoen and Skiptvet is affected by the lack of data on soil density in the years prior to 2012. Further, the separation between the forest floor horizon and the underlying mineral horizon may differ between years and between different sampling personnel, which in addition to variable degrees of mixing of forest floor and mineral soil, will also affect the BD estimates and the estimated C pool.

Table 3.2. Calculated bulk density in the different layers of the soil of the birch, spruce and pine stand at Nordmoen in 2012.

| Calculated bulk density (g $cm^{-3}$) in 2012 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Soil horizon** | Birch<br>n=12<br>mean | Std | Spruce<br>n=12<br>mean | Std | Pine<br>n=12<br>mean | Std | Mean spruce and pine<br>n=24<br>mean | Std |
| **O** | 0.20 | 0.07 | 0.16 | 0.02 | 0.17 | 0.02 | 0.16 | 0.02 |
| **E** | 0.81 | 0.25 | 0.87 | 0.08 | 0.88 | 0.11 | 0.88 | 0.11 |
| **Bs 3-8** | 0.88 | 0.27 | 0.95 | 0.05 | 0.96 | 0.05 | 0.96 | 0.05 |
| **Bs 18-23** | 1.03 | 0.31 | 1.12 | 0.06 | 1.12 | 0.06 | 1.12 | 0.06 |

### 3.2.6 Statistical analyses

At Nordmoen, the main focus of the statistical analysis was to test for significant differences in vegetation and soil parameters between the different tree species, as well as test for significant changes with time. At Skiptvet, the limited number of replicates (n=2) excluded testing of statistical differences between stand types, however, changes in the soil parameters were indicated by using a simple one-sample t-test (see below).

#### 3.2.6.1 Trees

To test differences in volume, basal area, and biomass/C pool in living and dead trees between the tree species, we applied the non-parametric Kolmogorov-Smirnov (K-S) test (Corder and Foreman 2014) using SPSS 22 (IBM). This test was only performed on the data from Nordmoen.

#### 3.2.6.2 Ground vegetation

We performed GNMDS-ordination (global non-metric multidimensional scaling; Minchin 1987, Oksanen 2013) on percent cover data for all species in the vegetation plots at Nordmoen using R (R Development Core Team 2011). We calculated the Kendall's correlation coefficient ($\tau$) between ordination axes and the environmental variables and some variables derived from species data, using SPSS. Statistical analyses were not performed on the Skiptvet data due to very sparse vegetation cover and thus insufficient vegetation data.

We applied multiple Kruskal-Wallis tests (Kruskal and Wallis 1952) in SPSS for comparing differences between stand types regarding position along ordination axes, cover of field layer, bottom layer and litter. Due to the simultaneous consideration of multiple significance tests we adjusted the $p$ values according to the Dunn–Sidak procedure (Quinn and Keough 2002). Using the conventional $p < 0.05$ for individual tests, we adjusted to $p < 0.017$ for three combinations.

We investigated the relationship between biomass and cover percentage by use of a linear regression in order to quantify the strength and significance of the relationships. As the density of plant tissue is expected to vary largely, we worked at the level of individual species. Species which are almost absent have very low biomass and the regression can be expected to be of very limited quality. We therefore excluded all species which had an average percentage cover of less than 1% on the biomass plots. This left eight species for which regression analysis were performed.

#### 3.2.6.3 Changes in soil variables with time

At Nordmoen, we used the Kolmogorov-Smirnov test (Corder and Foreman 2014) using SPSS 22 (IBM) to test for significant differences in forest floor thickness, LOI and soil C pools between years within tree species, as well as between tree species within years.

Assuming prevailing trends are strictly linear, a general linear regression model was used to test the change over time in LOI (O-layer and E-layer) and C pool in soil (O horizon and the original mineral soil sampling (model 1)). A mixed linear model with plot number as random effect was used to estimate changes in the thickness of the O-horizon and the E horizon with time for each stand type (model 2). Furthermore, a mixed linear model with years, tree species, water- and lime treatments specified as fixed effects and plots as random effects was used to test for differences in the thickness of the forest floor, LOI, and C pools according to tree species and between years (model 3) (SAS Institute Inc. 1989, Littell et al. 1996).

Model 1

[1] $$y_{sti} = \beta_s + \gamma_s t + \varepsilon_{sti}$$

where $\beta_s$ is the effect (intercept) of tree species $s, s = 1,2,3$ (for spruce, pine, and birch); $\gamma_s$ is the species-dependent linear temporal slope; $t$ is the number of years since 1978; $\varepsilon_{sti}$ is the error term and $i$ indicates the measurement number.

Model 2

[2] $$y_{sti} = \beta_s + \gamma_s t + \alpha_i + \varepsilon_{sti}$$

where $\beta_s$ is the effect of tree species $S$ =1, 2, 3, $\gamma_s$ is the time trend for species; $t$ is the number of years since 1978, $\alpha_i$ is the random effect of plot and $\varepsilon_{sti}$ is the error term. The standard errors in the mixed linear model were corrected for repeated measurements in the same plots (SAS Institute Inc. 1989, Littell, et al. 1996).

Model 3

[3] $$y_{kwsti} = \theta_k + \eta_w + \beta_s + \gamma_t + \alpha_i + \varepsilon_{kwsti}$$

where $\theta_k$ is the effect of lime treatment, $\eta_w$ is the effect of water treatment, $\beta_s$ is the effect of tree species, $\gamma_t$ is the effect of year, $\alpha_i$ is the random effect of plot and $\varepsilon_{kwsti}$ is the error term (model residual).

At Skiptvet, we calculated the difference in the thickness of forest floor, LOI and C pool for the different stand types between the years 1978 and 1988 (d_1), and 1988 and 2012 (d_2). A one-sample t-test was used to test that the mean calculated difference between years and between different stand types within years was equal to zero (($H_0$: mean = 0;). To investigate if the changes in thickness, LOI and C pool was different between different stand types, we used a regression analysis (two plots (j) and two paired years 1978-1988 and 1988-2012 (t)) according to the following model:

$$\Delta_{ijt} = \beta_{it} + \varepsilon_{ijt}$$

where $\Delta_{ijt}$ is the change in the measured variable (forest floor thickness, LOI, Soil C ) between years, $\beta_{it}$ is the effect of stand types , $\varepsilon_{ijt}$ is the error term; $i$ =treatment 0, 1, 2, 3, 4; $t$ = time 1, 2; $j$ = 1, 2 is the observation within stand types.

#### 3.2.6.4 Total C pools related to stand type

Differences in C-pools between stand types were performed by the two-sample K-S test for soil C pools, C in ground vegetation total living biomass, C in litter sampled in the ground vegetation biomass plots, carbon pools in standing living tree biomass and dead wood, and total ecosystem C pools. This test was only performed on the data from Nordmoen due to lack of replicates (n=2) in Skiptvet.

# 3.3 Results

## 3.3.1 Results: Trees

#### 3.3.1.1 Changes in tree volume and tree biomass with time at Nordmoen in 2011

In 2011, there was a significant difference in the volume and basal area between the different tree species (Figure 3.3). The increases in standing volume in the birch and pine stands were significantly higher relative to Norway spruce since planting ($p<0.0001$) (Table 3.3). The former two tree species also seemed to have the highest growth rate compared to the spruce stand (Figure 3.3), resulting in a lower site-index for the spruce stand at this site (Table 3.3). The number of trees was significantly lower in the pine stand relative to the birch stand ($p=0.012$). Estimated mean ages at breast height in 2011 was 32, 33, and 35 years for the spruce, pine and birch stands, respectively.

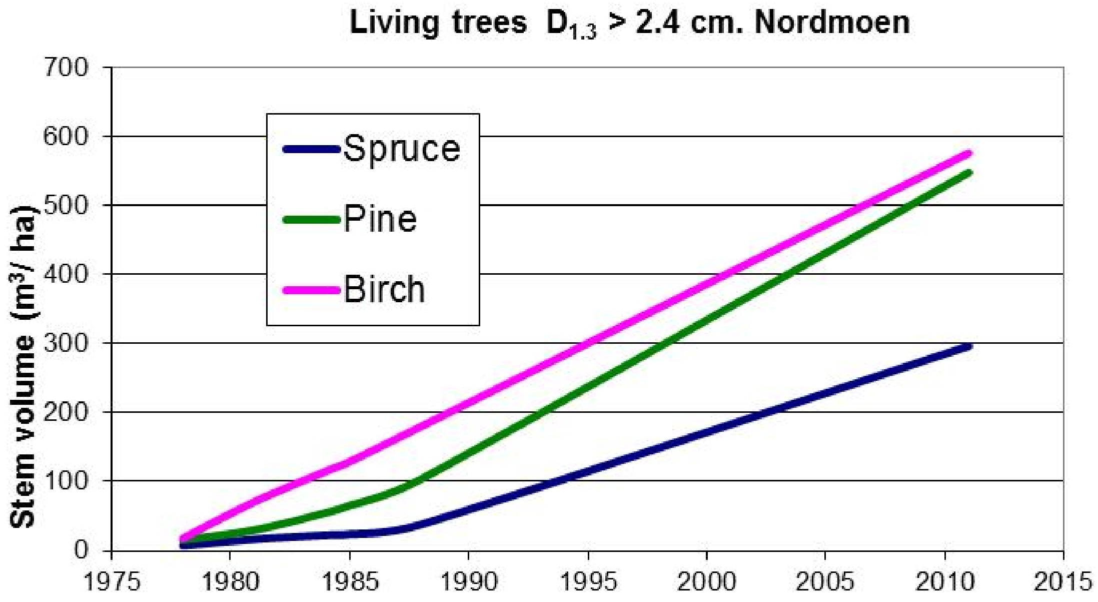


**Figure 3.3** Changes in tree stem volume with time for birch, pine and spruce at Nordmoen, SE Norway. $D_{1.3}$ = diameter at 1.3 m height (breast height).

**Table 3.3** Volume, basal area and number of trees $ha^{-1}$ for standing living biomass and dead biomass in 2011, as well as site index for spruce, pine and birch stands at Nordmoen, SE Norway ($D_{1.3}$ > 2.4 cm)

| | | Living trees in 2011 | | | Observed dead trees | | | Site index |
|---|---|---|---|---|---|---|---|---|
| Species | Block | Volume $m^3ha^{-1}$ | Basal area $m^2ha^{-1}$ | Trees $ha^{-1}$ | Volume $m^3 ha^{-1}$ | Basal area $m^2 ha^{-1}$ | Trees $ha^{-1}$ | H40 m |
| **Spruce** | 1 | 225 | 41 | 10104 | 27 | 7 | 4167 | 16.9 |
| **Pine** | 1 | 523 | 72 | 7813 | 53 | 9 | 3646 | 19.4 |
| **Birch** | 1 | 491 | 68 | 11406 | 44 | 8 | 4375 | 20.8 |
| **Spruce** | 2 | 317 | 50 | 8646 | 32 | 8 | 3854 | 18.0 |
| **Pine** | 2 | 476 | 62 | 4688 | 140 | 20 | 2604 | 18.5 |
| **Birch** | 2 | 598 | 78 | 9167 | 36 | 7 | 3021 | 22.7 |
| **Spruce** | 3 | 284 | 48 | 9375 | 56 | 14 | 6875 | 17.0 |
| **Pine** | 3 | 519 | 67 | 4792 | 141 | 20 | 3125 | 18.9 |
| **Birch** | 3 | 681 | 84 | 7500 | 43 | 7 | 2292 | 22.1 |
| **Spruce** | 4 | 366 | 59 | 10104 | 99 | 18 | 6146 | 18.6 |
| **Pine** | 4 | 676 | 88 | 6771 | 59 | 9 | 2188 | 18.7 |
| **Birch** | 4 | 502 | 65 | 8333 | 16 | 4 | 2188 | 21.3 |
| **Spruce** | | 298 | 50 | 9557 | 53 | 12 | 5260 | 17.7 |
| **Pine** | | 548 | 72 | 6016 | 96 | 15 | 2891 | 18.9 |
| **Birch** | | 575 | 74 | 8892 | 34 | 6 | 2841 | 21.7 |

The aboveground and belowground biomass was estimated at each inventory between 1978 and 2011 (Figure 3.4). As shown, the aboveground biomass of birch increased most rapidly, while the biomass accumulation in Norway spruce was slower. This corresponds with the calculated site index (Table 3.3). In 2011, the living biomass and standing dead wood, as well as the aboveground biomass, differed significantly between the birch, pine and spruce stands ($p \leq 0.04$). The total standing biomass (living + dead wood) was significantly lower in the spruce stand relative to the birch and pine stands ($p<0.0001$, $p=0.002$, respectively). In 2011, the belowground biomass of the spruce stand was also significantly lower than the pine and birch stands ($p \leq 0.013$). The belowground biomass of pine and birch was increasing at about the same rate.

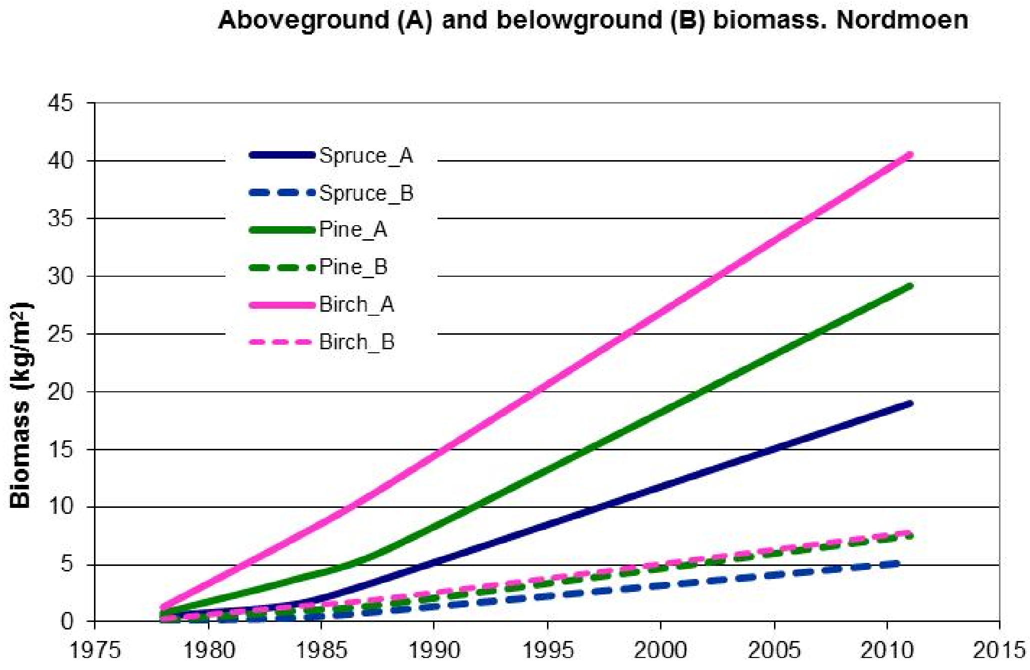


**Figure 3.4** Above- and belowground biomass of living trees at Nordmoen.

Changes in tree volume and tree biomass with time at Skiptvet in 2012

In 1976 the planted spruce trees were approx. 1 m and birch trees were approx. 4 m in height (Figure 3.1).

The total number of trees ha$^{-1}$ varied between 4606 in the control plot T0 to 1887 in the pure spruce stand T4. All the mixed plots T0-T3 had a higher number of spruce trees ha$^{-1}$ than the pure spruce stand (Table 3.4). The high number of dead trees indicates that the level of thinning and self-thinning had been high. The results suggested a possibly higher basal area in the manipulated mixed stands (T1-T3), whereas the standing volume in the pure spruce stand was higher compared to all the mixed stands.

The site index at Skiptvet is very high for Norwegian conditions, with H40 about 24 m (Table 3.4). Estimated age at breast height in 1977 and 2012 were 1 and 37 for spruce versus 7 and 43 years for birch.

**Table 3.4** Volume, basal area and number of trees ha$^{-1}$ for standing living biomass and dead biomass, as well as site index for stands with different mixtures of spruce and birch at Skiptvet, SE Norway.

| | | Living trees 2012 | | | Accumulated dead trees | | | Site index |
|---|---|---|---|---|---|---|---|---|
| **Treatment** | **Species** | **Volume m$^3$ha$^{-1}$** | **BA m$^2$ha$^{-1}$** | **Trees ha$^{-1}$** | **Volume m$^3$ha$^{-1}$** | **BA m$^2$ha$^{-1}$** | **Trees ha$^{-1}$** | **H40 m** |
| **T0** | Birch | 323 | 36.4 | 2058 | 87.7 | 15.4 | 4580 | 23.6 |
| **T0** | Spruce | 84 | 13.5 | 2548 | 5.0 | 0.7 | 2849 | - |
| **T1** | Birch | 300 | 34.6 | 1045 | 29.4 | 6.4 | 1959 | 23.3 |
| **T1** | Spruce | 142 | 19.4 | 2246 | 6.4 | 1.2 | 2294 | - |
| **T2** | Birch | 263 | 27.8 | 645 | 16.5 | 3.1 | 588 | 24.2 |
| **T2** | Spruce | 187 | 22.5 | 1952 | 8.1 | 1.7 | 1869 | 25.0 |
| **T3** | Birch | 258 | 28.7 | 882 | 16.8 | 4.0 | 1167 | 23.3 |
| **T3** | Spruce | 223 | 25.0 | 2287 | 7.9 | 1.4 | 2286 | 25.5 |
| **T4** | Spruce | 513 | 47.5 | 1887 | 38.4 | 6.0 | 2229 | 25.3 |

The biomass accumulation rate was higher for birch than for spruce at the start of the experiment (Figure 3.5). After 10 years, the total biomass of spruce was about 50 % of the birch biomass. At the end of the period (2011), the spruce biomass had increased to approx. 80 % of the birch biomass. The estimated accumulation of aboveground biomass was faster than that of the belowground biomass. Results suggested that the accumulation of the belowground biomass for birch was faster than for spruce at the start of the experiment, however, after 10 years the increase seemed to be similar.

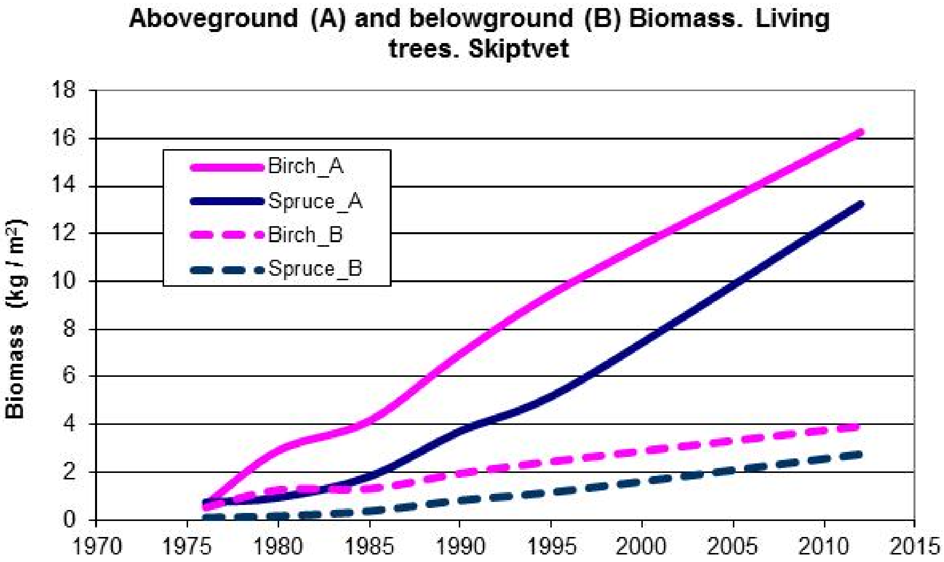


**Figure 3.5** The changes in above- and belowground biomass for birch and spruce trees with time at Skiptvet These curves show averages across the treatments T0-T4 and is therefore not directly comparable to Figure 3.6).

The results indicated that different stand types differed in their biomass accumulation rates over time. The three experimentally manipulated stand types that contained a mixture of spruce and birch T1-T3 showed similar accumulation rates. The pure spruce stand T4 showed the lowest accumulation rate in the beginning, but the rate increased when the trees were 10-15 years old. The control T0 showed the highest biomass accumulation rate the first 30 years. However, around year 2005 the total biomass of stand types T1 and T2 were both higher than T0 (Figure 3.6).

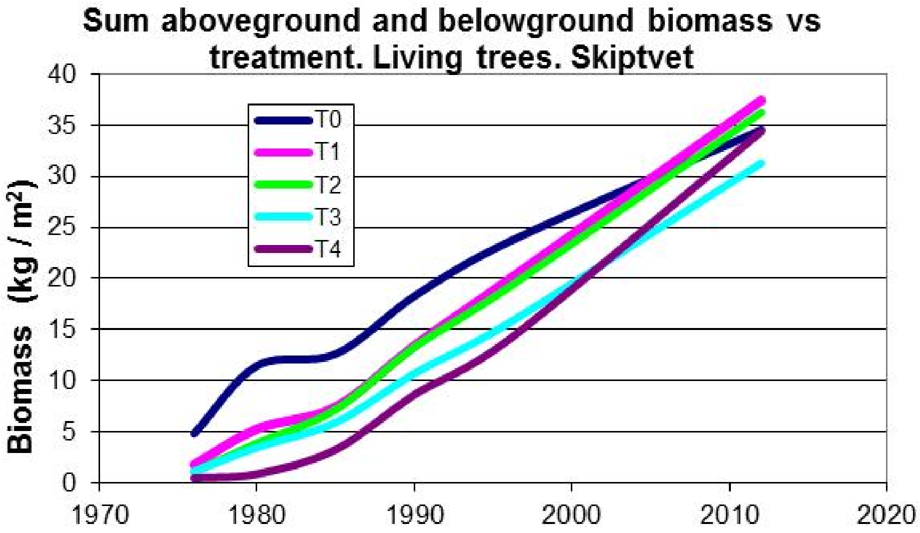


**Figure 3.6** Sum aboveground and belowground biomass of living trees at Skiptvet.

### 3.3.1.2 C-pools in living and dead trees from different stand types at Nordmoen and Skiptvet

We estimated the aboveground and belowground biomass and the carbon storage in both dead and living trees at Nordmoen (Table 3.5) and Skiptvet (Table 3.6). At Nordmoen, the estimated content of carbon was about 52.5 % of the biomass for Norway spruce and birch, and 53.4 % for Scots pine.

As observed for the standing biomass, the C pool (living + dead wood) was significantly lower in the spruce stands relative to the birch and pine stands at Nordmoen, as expected ($p \leq 0.01$; Table 3.5), whereas for the estimated belowground living biomass no significant difference was found between the pine and the birch stands.

**Table 3.5** Above- and belowground biomass and carbon in living and dead trees at Nordmoen (kg $m^{-2}$)

| | | Biomass | | | C pool | | |
|---|---|---|---|---|---|---|---|
| **Trees** | **Species** | **Sum** | **Above** | **Below** | **Sum** | **Above** | **Below** |
| **Living** | Birch | 48.8 | 40.8 | 7.9 | 25.6 | 21.4 | 4.2 |
| | Pine | 36.6 | 29.2 | 7.5 | 19.6 | 15.5 | 4.0 |
| | Spruce | 24.3 | 19.0 | 5.2 | 12.7 | 9.9 | 2.8 |
| **Dead** | Birch | 3.1 | 2.4 | 0.7 | 1.6 | 1.3 | 0.4 |
| | Pine | 6.1 | 5.0 | 1.1 | 3.2 | 2.7 | 0.6 |
| | Spruce | 5.4 | 4.2 | 1.2 | 2.8 | 2.2 | 0.6 |

At Skiptvet, the C pool in the living tree biomass was relatively similar between the treatments, however the distribution of the C pool in different tree species and compartments (living above ground, living below ground and standing dead wood) varied considerably between the stand types (n=2, Figure 3.6). This difference will affect the quality of the litter, the decomposition rates, and subsequently the C pool in the soil.

**Table 3.6** **Above- and belowground biomass and carbon in living and dead trees at Skiptvet (kg/m$^2$)**

| | | Biomass | | | C pool | | |
|---|---|---|---|---|---|---|---|
| **Trees** | **Treatment** | **Sum** | **Above** | **Below** | **Sum** | **Above** | **Below** |
| **Living** | T0 | 34.53 | 28.12 | 6.41 | 18.03 | 14.64 | 3.39 |
| | T1 | 37.41 | 30.22 | 7.2 | 19.54 | 15.72 | 3.82 |
| | T2 | 36.24 | 29.42 | 6.82 | 18.93 | 15.3 | 3.62 |
| | T3 | 38.37 | 31.28 | 7.1 | 20.04 | 16.26 | 3.78 |
| | T4 | 34.36 | 28.54 | 5.83 | 17.94 | 14.79 | 3.15 |
| **Dead** | T0 | 5.96 | 4.63 | 1.33 | 3.11 | 2.41 | 0.7 |
| | T1 | 1.19 | 0.97 | 0.21 | 0.62 | 0.5 | 0.12 |
| | T2 | 1.25 | 1.02 | 0.23 | 0.65 | 0.54 | 0.12 |
| | T3 | 0.74 | 0.6 | 0.14 | 0.38 | 0.31 | 0.07 |
| | T4 | 2.76 | 2.3 | 0.46 | 1.44 | 1.19 | 0.25 |

## 3.3.2 Results: Ground vegetation; species abundance, biomass and C pools

### 3.3.2.1 Species abundance and environmental factors

**Field layer, bottom layer and litter**

At Nordmoen, the percentage cover of the field layer (vascular plants < 0.3 m height), bottom layer (bryophytes and lichens) and litter in the vegetation plots differed significantly between the three stand types ($p < 0.002$). The average cover of the field layer was about 12% in the spruce stands 24% in the birch stands, and 39% in the pine stands (Table 3.7). For a full overview of percentage cover at species level, see **Feil! Fant ikke referansekilden.**. The low cover of the field layer in spruce stands was probably due to shading, as densely growing spruce allowed less light to reach the ground than in pine and birch stands. The bottom layer had a mean cover of nearly 55% in the spruce stands, approx. 19% in the pine stands, and less than 10% in the birch stands. Most likely this can be explained by the negative effect that litter fall has on bottom layer vegetation (cf. Økland 1988), and the differences in litter properties between stand types. Consequently, litter covered 44%, 78% and approx. 90% in the spruce, pine and birch stands, respectively. The mean litter depth decreased from pine stands (3.3 cm), via birch (2.2 cm) to spruce (1.6 cm). Roots and bare soil on average covered 0.2% or less in the plots of all three stand types.

At Skiptvet, the mean field layer cover was less than 1% in four out of five stand types. The exception was in the stand type favoring spruce, where the mean field layer cover was about 16%. The same pattern applies for the bottom layer, with a mean cover of 1.6% or less in four of five stand types, and a mean cover of 10% in stands favoring spruce. The mean cover of litter was more than 80% in all stand types, whereas the mean cover of roots ranged from 1.4 to 4.8%, and the mean cover of bare soil ranged from 0.5 to 8.8%. The mean litter depth varied from 0.8 to 2.1 cm.

As an expression of tree density, we measured the basal area of trees at breast height ($m^2 \, ha^{-1}$), as seen from the lower left corner of each $1m^{-2}$ vegetation plot using relascope factor 2 (i.e. using the narrowest slit on the relascope when counting the number of trees; the higher the number of tree counts the higher the basal area). The total number of trees (the sum of coniferous and broadleaved trees) varied between 20 and 28 at Skiptvet and 18 and 22 at Nordmoen. The combination of little light reaching the ground and a high litter cover negatively affects the growth and survival of species in the bottom- and field layer.

**Table 3.7** Mean percentage cover of field layer, bottom layer, litter and twigs and branches in vegetation plots at Nordmoen (n=72) and Skiptvet (n=40). For Nordmoen the Kruskall-Wallis test revealed significant differences between all three stand types in % cover of field layer, bottom layer and litter ($p \le 0.001$). Twigs and branches were not tested.

| Site and stand type | | | | |
|---|---|---|---|---|
| **Nordmoen** | **Field layer** | **Bottom layer** | **Litter** | **Twigs and branches** |
| **Spruce** | 12.4 | 54.5 | 43.5 | 3.8 |
| **Pine** | 38.9 | 18.5 | 77.8 | 6.8 |
| **Birch** | 23.8 | 7.1 | 89.4 | 4.5 |
| **Skiptvet** | | | | |
| **T0** | 0.3 | 1.4 | 84.3 | 49.6 |
| **T1** | 1.0 | 1.1 | 94.0 | 37.4 |
| **T2** | 0.3 | 1.6 | 92.1 | 29.1 |
| **T3** | 0.4 | 1.1 | 93.8 | 35.6 |
| **T4** | 15.9 | 10.1 | 82.6 | 25.1 |

### Species number and frequency

Summing all stands, a total of 44 species were recorded in the 72 vegetation plots at Nordmoen, while 40 species were recorded in the 40 vegetation plots at Skiptvet (Table 3.8). At both sites combined, a total of 66 species were found, of these 18 species were recorded on both sites, 26 species only at Nordmoen, and 22 species only at Skiptvet. Thus, similar number of species was found at the two sites in spite of the Skiptvet stands being very dense. This may be related to the more nutrient-rich soil at Skiptvet.

At Nordmoen there were no significant differences between the three stand types regarding total species number, which ranged from 30 to 37 (Table 3.8). Mosses were the largest species group (17 species). When comparing pine and birch stands, no species group differed significantly in species number, but both pine and birch stands had more species of herbs and hepatics than the spruce stands ($p < 0.003$). The number of moss species was significantly higher in spruce and pine stands compared to birch stands ($p = 0.008$ and $p = 0.035$, respectively).

The mean sum of subplot frequencies for dwarf shrubs, herbs and graminoides was higher in pine stands than in spruce stands at Nordmoen, while the mean sum for dwarf shrubs and hepatics was higher in birch stands than in spruce stands. The mean sum of mosses, on the other hand, was significantly higher in spruce stands than in both pine and birch stands, while there were no significant differences between pine and birch stands. The mean sum for graminoides was higher in pine stands than in both birch and spruce stands.

At Skiptvet, the number of species per stand varied from 13 to 21 (Table 3.8). Mosses were the species group with most species, with 9-13 species per stand, and 23 species in all stands combined. With the exception of stands favoring spruce at Skiptvet, the mean species number per plot was lower at Skiptvet than at Nordmoen.

**Table 3.8** Number of species within stand types (treatments) at Nordmoen and Skiptvet. For each species group: n - is the number of species per stand type; Σsfr – in parenthesis, the mean sum of subplot frequencies in species groups per vegetation plot.

| Site and stand type | Juvenile trees | | Erica-ceous | | Herbs | | Gramin-oides | | Mosses | | Hepatics | | Lichens | | Species Tot n | Species Mean n |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Nordmoen** | n | Σsfr | n | Σsfr | n | Σsfr | n | Σsfr | n | Σsfr | n | Σsfr | n | Σsfr | | pr plot |
| **Spruce** | 1 | (0.1) | 2 | (16.0) | 4 | (4.0) | 2 | (13.2) | 16 | (53.4) | 1 | (0.5) | 4 | (0.2) | 30 | 10.3 |
| **Pine** | 2 | (1.3) | 3 | (25.1) | 8 | (11.9) | 4 | (18.3) | 13 | (29.3) | 5 | (1.3) | 2 | (0.1) | 37 | 11.5 |
| **Birch** | 2 | (2.2) | 3 | (21.8) | 6 | (5.9) | 3 | (17.7) | 15 | (20.3) | 4 | (2.3) | - | - | 33 | 11.0 |
| **Total species number** | 2 | | 3 | | 9 | | 4 | | 17 | | 6 | | 3 | | 44 | |
| **Skiptvet** | | - | | | | | | | | | | | | | | |
| **T0** | - | - | - | (0.0) | 1 | (0.3) | 1 | (0.1) | 11 | (9.1) | 3 | (2.3) | - | - | 16 | 4.0 |
| **T1** | 2 | (0.4) | 1 | (0.5) | 5 | (2.4) | 3 | (1.6) | 10 | (6.8) | 2 | (2.3) | - | - | 21 | 5.6 |
| **T2** | - | - | - | - | 2 | (0.5) | - | - | 10 | (5.9) | 1 | (2.0) | - | - | 13 | 3.3 |
| **T3** | 2 | (1.0) | 1 | (0.9) | 3 | (0.8) | 1 | (1.4) | 9 | (7.0) | 1 | (1.0) | - | - | 17 | 4.4 |
| **T4** | 1 | (0.6) | - | - | 3 | (12.9) | 1 | (0.9) | 13 | (31.8) | 3 | (6.1) | - | - | 21 | 12.0 |
| **Total species number** | 4 | | 1 | | 7 | | 1 | | 23 | | 4 | | - | - | 40 | |

### Differences in species composition at Nordmoen - ordination analyses

By correlating the position of vegetation plots along ordination axes with explanatory variables, the most important patterns in vegetation-environment relationships are found. Since decomposition rates are related to species composition (Jonsson and Wardle 2008, Song et al. 2010) and environmental gradients, this environmental interpretation of ordination axes may be useful also for interpreting patterns of soil carbon accumulation.

The three different stand types occupied significantly different positions along axis1 (horizontal GNMDS 1 ordination axis; $p < 0.0001$, Figure 3.7). While pine stands showed significantly higher scores along axis2 (vertical GNMDS 2) than spruce and birch stands ($p < 0.002$), there were no statistical differences between spruce and birch stands.

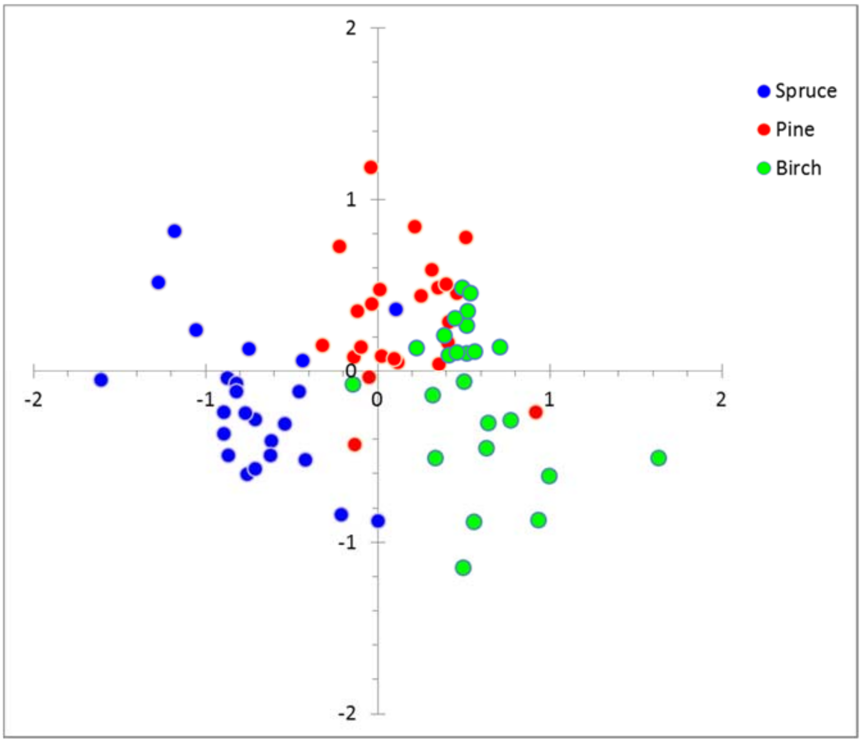


**Figure 3.7** **Results from GNMDS ordination of 72 vegetation plots from Nordmoen, axis 1 (horizontal) and 2 (vertical). Both axes represent gradients in species composition, and are scaled in half change units, meaning that plots separated by one unit on average have half of their species in common.**

None of the environmental or humus related variables (see chap. 3.2.4.2) associated with the vegetation plots at Nordmoen were strongly correlated with the order of vegetation plots along the two ordination axes (Figure 3.7). However, the bulk density of the humus layer showed a weak, but significant increase from left to right along the horizontal ordination axis ($\tau = 0.392$, $p < 0.001$), which represent the main gradient in species composition. This may be an effect of differences in properties of the litter produced in spruce and pine stands relative to birch stands. The percent cover of litter in the vegetation plots also increased from left to right along the horizontal ordination axis ($\tau = 0.695$, $p < 0.001$), as last year's birch leaves covered larger parts of the plots than did spruce and pine needles. Different ecological effects of spruce, pine and birch on the ground vegetation therefore seems to be the most important factor causing the main gradient in species composition.

Environmental parameters such as weight of forest floor and mineral soil ($\tau = 0.167$, $p = 0.039$) increased slightly along the (horizontal) ordination axis, while humus thickness ($\tau = -0.283$, $p = 0.002$), mean C concentration in different layers ($\tau = -0.215$, $p = 0.008$), C pool in soil layers ($\tau = -0.179$, $p = 0.027$) decreased slightly.

From the bottom to the top of the vertical ordination axis, the % cover of mosses ($\tau = -0.776$, $p < 0.001$) and bottom layer ($\tau = -0.719$, $p < 0.001$) decreased strongly. This reflects a dominance of spruce stands in the lower part, and a dominance of birch and pine stands in the upper part of this axis, as well as the higher % cover (and mean sum of subplot frequencies; Table 3.8) of mosses in the lower part of the vertical axis. The % cover and number of hepatics ($\tau = 0.423$, $p < 0.001$), on the other hand, increased towards the upper part of the vertical axis, which is partly a result of more hepatics growing on birch litter and in pine stands than in spruce stands.

Several environmental explanatory parameters such as: thickness and weight of forest floor and mineral soil, bulk density, mean C concentration in different layers, C pool in soil layers, were tested and not found significant relative to the ordination axis.

No environmental variable was strongly positively correlated with axis 2, but the amount of Fe and Ni decreased ($\tau$ = -0.326 and $\tau$ = -0.319, respectively). The cover of the field layer increased along this axis ($\tau$ = 0.378, $p < 0.001$).

As the plots at Nordmoen were confined within an area of about 100 m x 100 m, the environmental gradients were thus mainly restricted to variation caused by influence of the dominating tree species.

### 3.3.2.2 Ground vegetation C pools and biomass

**Ground vegetation living and dead biomass**

At Nordmoen, the C-pools in living ground vegetation biomass were significantly larger in the pine stands (mean 85.3 g $m^{-2}$) relative to the birch stands (mean 37.6 g $m^{-2}$), while there were no statistical differences between pools of total dead biomass (Table 3.9). For both total living and total dead biomass, the C-pool was significantly larger in the pine stands relative to the spruce stands, while the C-pools in total dead biomass was significantly larger in the birch stands relative to the spruce stands.

In the dense stands at Skiptvet, the average C pool in living vegetation was < 1.0 g C $m^{-2}$ in four of five stand types (Table 3.9), the exception being stands favoring spruce (4.6 g C $m^{-2}$). The highest C pool in dead biomass was found in the stands with balanced birch and spruce (mean 621.2 g C $m^{-2}$), while the smallest C pool was found in stands favoring spruce (mean 399.9 g C $m^{-2}$).

**Table 3.9** Average C-pool (g $m^{-2}$) in living ground vegetation biomass and in litter in different stand types at Nordmoen and Skiptvet. D and p-values for Kolmogorov-Smirnov D tests of differences ground total living and dead vegetation biomass C-pools between forest stands at Nordmoen.

| ***Nordmoen*** | | | | | |
|---|---|---|---|---|---|
| **Total living biomass** | Spruce | Birch | Pine | | |
| **Average C-pool** | 37.6 | 53.2 | 85.3 | | |
| **Spruce** | * | 1.2 | 2.2 | | |
| **Birch** | 0.1389 | * | 1.59 | | |
| **Pine** | **0.0002** | **0.0129** | * | | |
| **Total dead biomass** | Spruce | Birch | Pine | | |
| **Average C-pool** | 212.4 | 273.2 | 333.9 | | |
| **Spruce** | * | 1.6 | 2.7 | | |
| **Birch** | **0.0129** | * | 1.4 | | |
| **Pine** | **< 0.0001** | 0.0310 | * | | |
| ***Skiptvet*** | T0 | T1 | T2 | T3 | T4 |
| **Total living biomass, average C-pool g $m^{-2}$** | 0.5 | 1 | 0.1 | 0.1 | 4.6 |
| **Total dead biomass, average C-pool g $m^{-2}$** | 540.3 | 474.9 | 621.2 | 454 | 399.9 |

### The distribution of the C pool in living ground vegetation

For Nordmoen, the average C pool in living vegetation was calculated for bryophytes and for 3 groups of vascular plants: Wooded plants, *Avenella flexuosa*, and other graminoides and herbs (Table 3.10). For all three groups of vascular plants the largest C pools were found in the pine stands, and the C pool in the pine stands was significantly larger than in the spruce stands for all three groups of vascular plants. The smallest C pools were found in the relatively dense spruce stands. Consequently, the wooded species had a larger C-pool in the birch stands than in the spruce stands, while *Avenella flexuosa* had a significantly larger C-pool in the pine stands than in the birch stands. The C-pool of bryophytes, on the other hand, was significantly larger in spruce stands than in both pine and birch stands (Figure 3.8). Within the spruce stands, living bryophytes constituted the largest vegetation C pool (26.5 g C m$^2$), while the smallest bryophyte C pool was found in the birch stands.

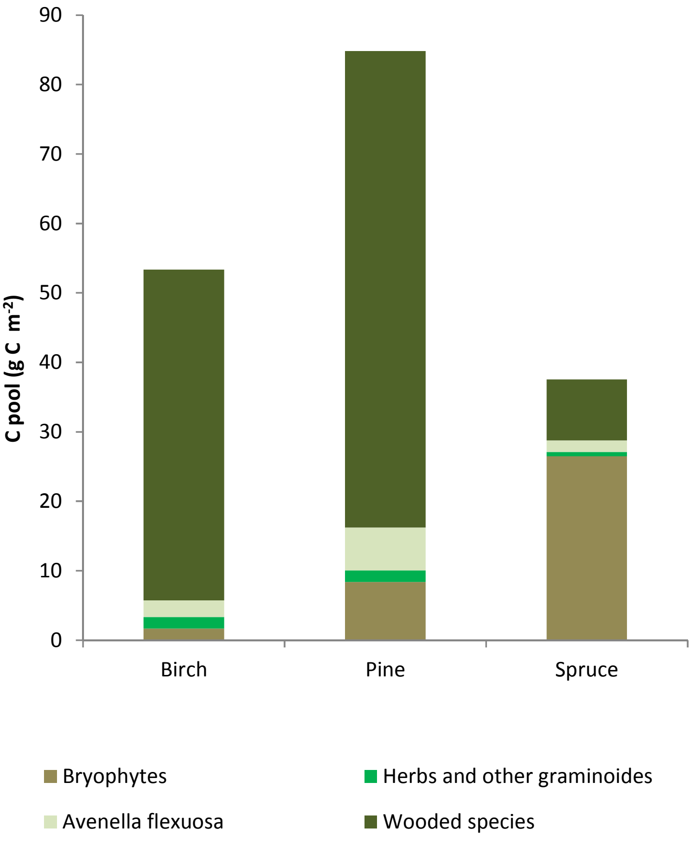


**Figure 3.8** C pool in ground vegetation (living biomass) at Nordmoen in 2012.

At Skiptvet only the two groups "other graminoides" and "herbs and bryophytes" had sufficient biomass for chemical analysis. The average C-pool was considerably higher in the stands favoring spruce (Table 3.10, Figure 3.9). However, the C-pools were very low for all components and stand types.

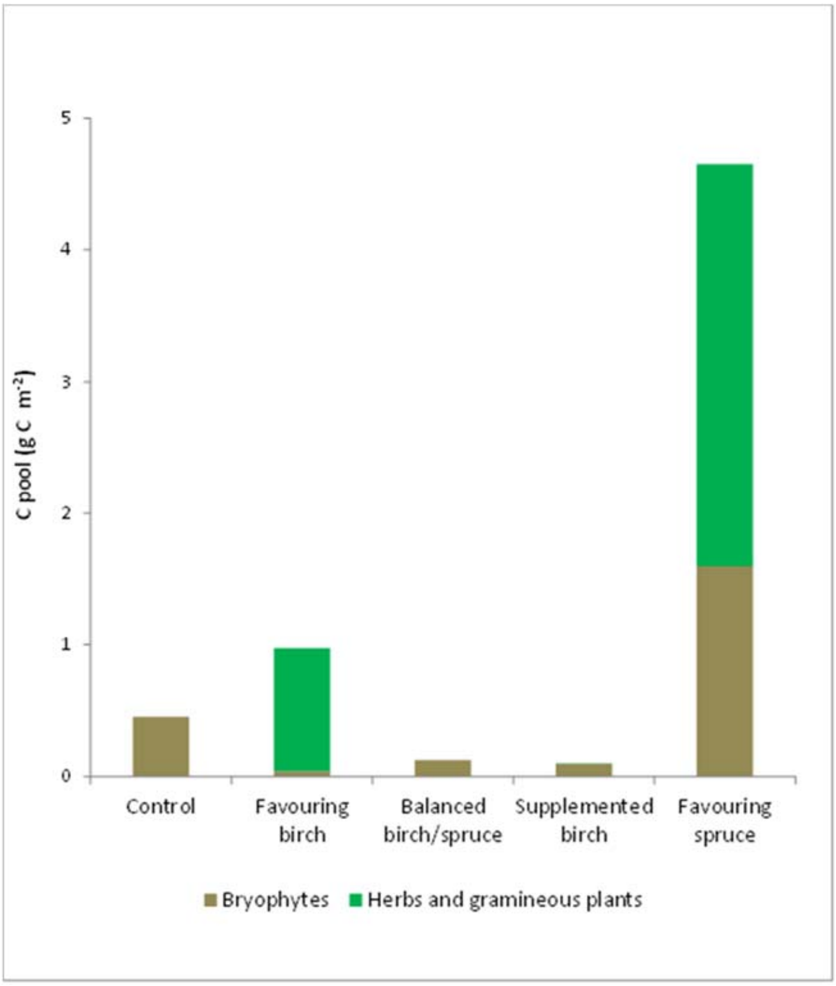


**Figure 3.9** C pool in ground vegetation (above ground living biomass) at Skiptvet in 2012.

**Table 3.10.** Average C-pools (g $m^{-2}$) in groups of above ground living plants from different stand types at Nordmoen and Skiptvet. Within each of the four plant groups, vertical pairs of letters a-a, b-b and c-c, denotes pairs of stand types with significant differences in C-pool size ($p \leq 0.01$ for all pairs).

| Site and stand type | Woody plants | *Avenella flexuosa* | Other graminoides and herbs | Bryophytes |
|---|---|---|---|---|
| **Nordmoen** | | | | |
| **Spruce** | 8.8 *ab* | 1.7 *b* | 0.6 *a* | 26.5 *b* |
| **Pine** | 68.6 *b* | 6.2 *ab* | 2.1 *a* | 8.4 *a c* |
| **Birch** | 47.6 *a* | 2.4 *a* | 1.7 | 1.5 *abc* |
| **Skiptvet** | | | | |
| **T0** | - | - | 0 | 0.4 |
| **T1** | - | - | 0.9 | < 0.1 |
| **T2** | - | - | 0 | 0.1 |
| **T3** | - | - | < 0.1 | 0.1 |
| **T4** | - | - | 3.1 | 1.6 |

### 3.3.3 C pools relative to ground vegetation cover

The differences in C pools of the living biomass components at Nordmoen reflect the % cover of the different species groups in the three different stand types, e.g. with the highest average cover of bryophytes in the spruce stands, and the highest cover of dwarf shrubs (which is included in and the dominating part of the biomass component woody plants) in the pine stands. Shading in the relatively dense spruce stands at Nordmoen excludes most of the vascular plants in the field layer, but mosses were able to overgrow the relatively small needles falling to the ground in the spruce stands, in this case resulting in a small cover of litter and a high cover of mosses compared to the pine and birch stands. In pine and birch stands larger needles and leaves, as well as a more developed field layer, reduced the dominance of the moss layer. The cover of *Vaccinium myrtillus* in the relatively young spruce stands at Nordmoen was lower than in several other (older) spruce forests in Norway (Økland, unpublished data), which also is reflected in the low C-pools in the biomass of dwarf shrubs compared to the pine and birch stands.

As mentioned previously, at Skiptvet, the cover of dwarf shrubs and other woody plants as well as herbs, graminoides and bryophytes were extremely low, due to the high tree density at this site. This is also reflected in the extremely low C-pools in the living vegetation at this site. The C-pools were clearly larger in the stands where spruce had been favored (T4), but still low compared to the corresponding values at the Nordmoen sites.

#### 3.3.3.1 Relationship between vegetation cover and biomass

Estimates of C pools in ground vegetation biomass represent the basis for estimates of litter production and hence total input of litter C to the soil organic matter pool. The data are important both for the C dynamics at a forest ecosystem level, as well as for modelling changes in soil C stocks. At the same time, quantification of the ground vegetation biomass is time consuming and thus costly. Thus, there are much more data on vegetation cover (see Økland 1996, Økland & Eilersen 1993,Økland et al. 2003, Bakkestuen et al. 2010, Økland et al 2016; among others) than on biomass. The purpose of the following study was to investigate our ability to predict ground vegetation biomass based on the vegetation cover with control of the expected error.

At the Nordmoen site, data on vegetation cover were available for all species from both the biomass plots (0.25 $m^2$) as well as for the vegetation plots (1 $m^2$), whereas biomass assessments were available from the biomass plots only. In each macro plot, the biomass and vegetation plots were situated directly adjacent to each other (72 plots of each kind).

The results of the linear regression between biomass and percentage cover in the biomass plots show highly significant ($p < 0.005$) correlations (Table 3.11). The correlation coefficients varied from relatively poor ($r^2 = 0.24$) to very high ($r^2 = 0.93$). The Root Mean Squared Errors (RMSEs) indicated that in many cases, a reliable prediction of biomass from the vegetation cover was possible with acceptable errors.

The variation in the slopes, expressed in g biomass $m^{-2}$ which correspond to an increase of 1% vegetation cover, were largely as expected (Table 3.11). A typical value for many species was less than 1 in these units. An exception was *Vaccinium myrtillus* with a value around 4, indicating that this species can easily dominate the biomass in many plots.

We did not restrict the regression to zero-intercept models which gave an additional degree of freedom and increased the quality check options for the analysis. In half of the cases, the intercept obtained was minor.

The results in figure 3.10 express both the regression between vegetation cover and measured biomass in the same plot (regression from biomass), and a regression between biomass and percentage cover that was measured in different plots situated adjacent to each other (regression from vegetation).

The estimated least-squares fit line and its 95% confidence bounds for the two cases Figure 3.10). The slope for the regression based on the vegetation plots was higher than for that based on the biomass plots; however, the two regressions largely coincide within the respective bounds. This may suggest that the small scale spatial variability was minor within each treatment, alternatively, that an approach to estimate biomass based on % coverage may be a too simplistic approach. A notorious feature of percentage cover datasets were tied values which appeared as vertical lines. These reduced the correlation and also to a certain extent affected the slopes.

The regression parameters were species-dependent. Thus, the results suggests that the model may be promising in respect to giving reasonable estimates of biomass to be used as input variables to models, based on vegetation cover data of vegetation types dominated by certain species.  A future validation of the method, will be based on the coefficients in table 3.11 used at sites where biomass and vegetation cover has been registered in the same subplots. At this point, the regression method is not suitable to be used routinely for the estimation of ground vegetation C pools at the individual site level, e.g. from the national forest inventory.

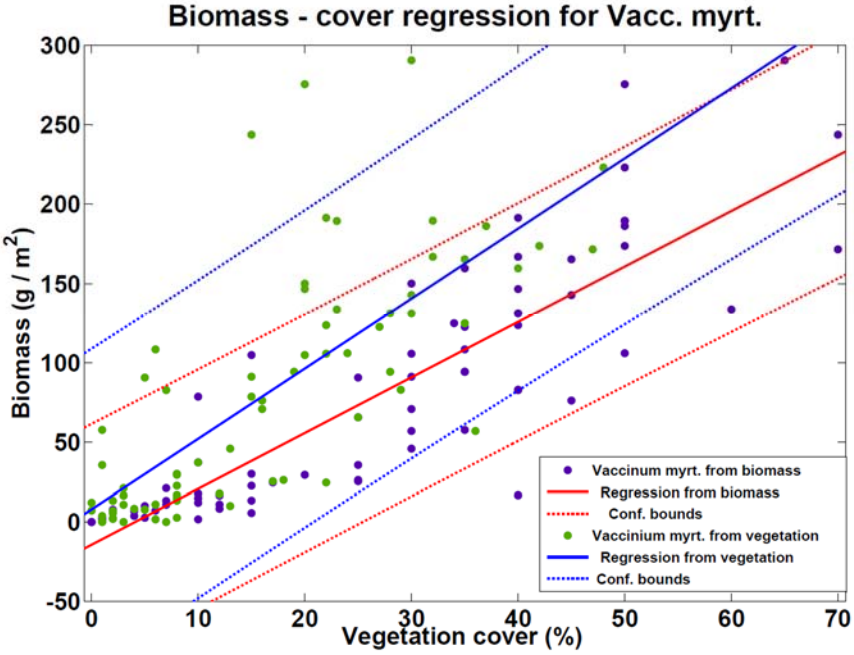


**Figure 3.10** Regression analysis for biomass versus vegetation cover for the case of *Vaccinium myrtillus* at the Nordmoen site. The individual measurements, the regression line calculated from the biomass plots, the regression deduced from the vegetations plots, and their respective 95% confidence bounds are shown.

**Table 3.11 Regression between ground vegetation coverage and biomass measured in the biomass plots.**

| Species | mean cover (%) | slope (g/m$^2$ /%) | intercept (g/m$^2$) | r$^2$ | RMSE (g/m$^2$) |
|---|---|---|---|---|---|
| **Vaccinium myrtillus** | 26.63 | 3.50 | -14.30 | 0.76 | 37.21 |
| **Vaccinium vitis idea** | 1.14 | 1.94 | 1.80 | 0.56 | 4.73 |
| **Maianthemum bifolium** | 3.00 | 0.36 | 0.21 | 0.76 | 1.23 |
| **Avenella flexuosa** | 2.51 | 0.72 | 5.67 | 0.24 | 6.53 |
| **Dicranum spp.** | 4.11 | 0.97 | 0.91 | 0.93 | 3.07 |
| **Hylocomium splendens** | 4.43 | 0.91 | 0.03 | 0.82 | 5.79 |
| **Pleurozium schreberi** | 13.83 | 0.74 | 2.78 | 0.55 | 11.36 |
| **Ptilium crista castrensis** | 7.14 | 0.54 | 0.96 | 0.65 | 6.58 |

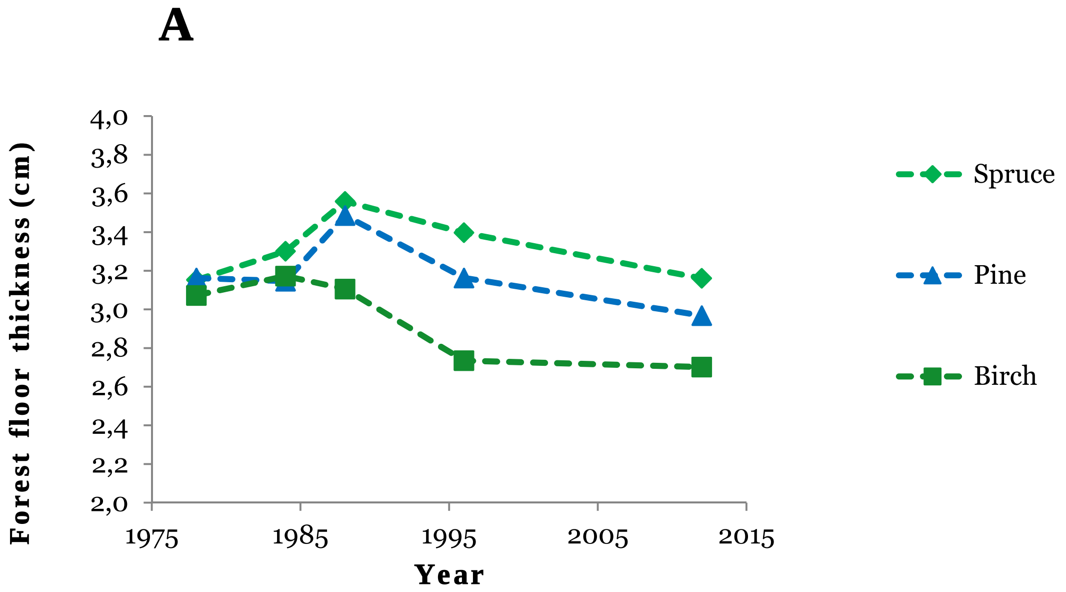
## 3.3.4 Results: Soil carbon

### 3.3.4.1 Differences within years and changes over time at Nordmoen

*Horizon thickness*

At the start of the experiment, there was no significant difference in the thickness of the forest floor between the three stand types, whereas in 2012, the thickness was significantly lower in the birch stand relative to the spruce and pine stands ($p=0.0001$ and $p=0.006$, respectively). The mixed regression analysis showed a significant difference in thickness of the forest floor between tree species and years ($p<0.0001$). The thickness of the forest floor was significantly larger in the spruce stands compared to the pine stands ($p=0,009$), which again was significantly larger than that of the birch stands ($p<0.0001$). There was a significant decrease in the thickness of the forest floor with time in the birch and pine stands ($p<0.0001$ and $p=0.016$, respectively), whereas no significant differences with time were observed for the spruce stand (Figure 3.11A).

The thickness of the forest floor at the start of the experiment was low relative to subsequent years. The data suggest an unexpected increase in thickness between 1978 and 1988 in the spruce and pine stands. As all the slash was removed after the clear felling in 1973, the observed increase may not be explained by a buildup of the forest floor by harvest residues following clear cut. Further, the suggested differences in the forest floor thickness between trees species in 1988 is not expected to be related to differences in input of litter from trees at this stage, as the trees were relatively small during the first 10 year period of the experiment. No data are available on ground vegetation species composition and litter production during these years, however, at this early stage of regeneration the ground vegetation species composition is expected to mainly be affected by the former clear cut rather than by the different tree species. The difference in forest floor thickness between years may potentially be related to differences in the separation between the humus layer and the mineral soil, however, also the E horizon showed a low thickness in 1978 and a significant increase with time for all tree species ($p<0.0001$) (Figure 3.11B). A more plausible explanation for the low thickness at the start of the experiment may be a compression of the forest floor samples. The diameter of the auger which was used on all sampling occasions was small, rendering especially the forest floor samples susceptible to compression. During sample collection, this susceptibility of the forest floor to compression may be affected by the soil moisture content. The sharpness of the augers and the experience of the sampling personnel may also play a role. Additionally, the occurrence of human traffic inside the plots, which was higher during the acid rain experimental period, may also results in a compression of the forest floor. During the sampling in 2012, care was taken to limit compression. Altogether, this imply a possible higher compression of the forest floor samples at the start of the experiment which may have resulted in a low forest floor thickness in the years 1978 and 1984, and possibly also a low thickness of the E horizon in 1978. The compression is not expected to differ between the different stand types at the early stage of the experiment. Thus, a possible compression of the soil at the start of the experiment may lead to an underestimation of the decrease in thickness between 1978 and 2012 for all trees species, which also will affect the estimated changes in C pools with time.



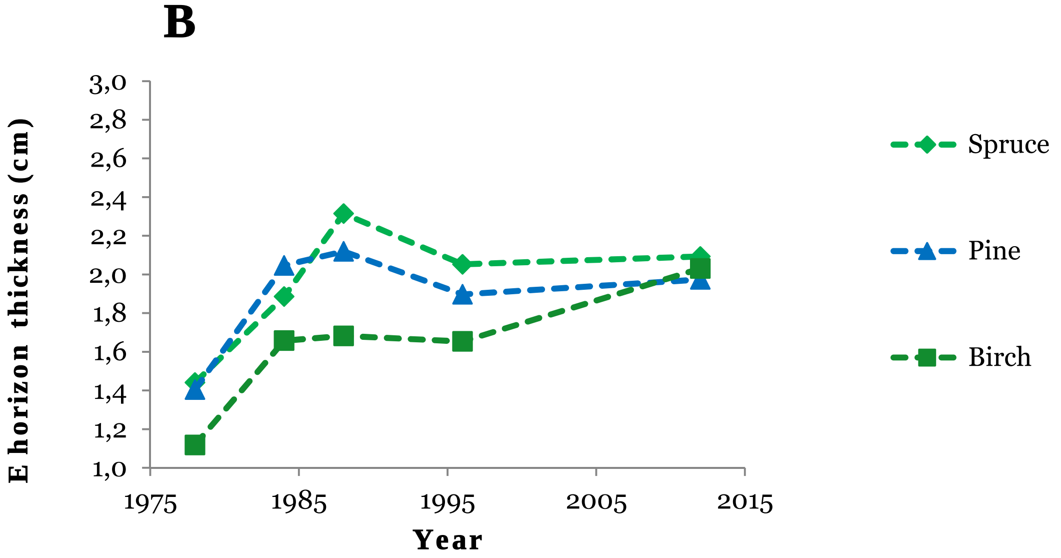


Figure 3.11. Changes in the thickness of the forest floor (A), and the E horizon (B) with different tree species between 1978 and 2012 at Nordmoen, SE Norway. The soil depth was measured at 12 sampling points in each of 24 plots per tree species.

*Loss on ignition*

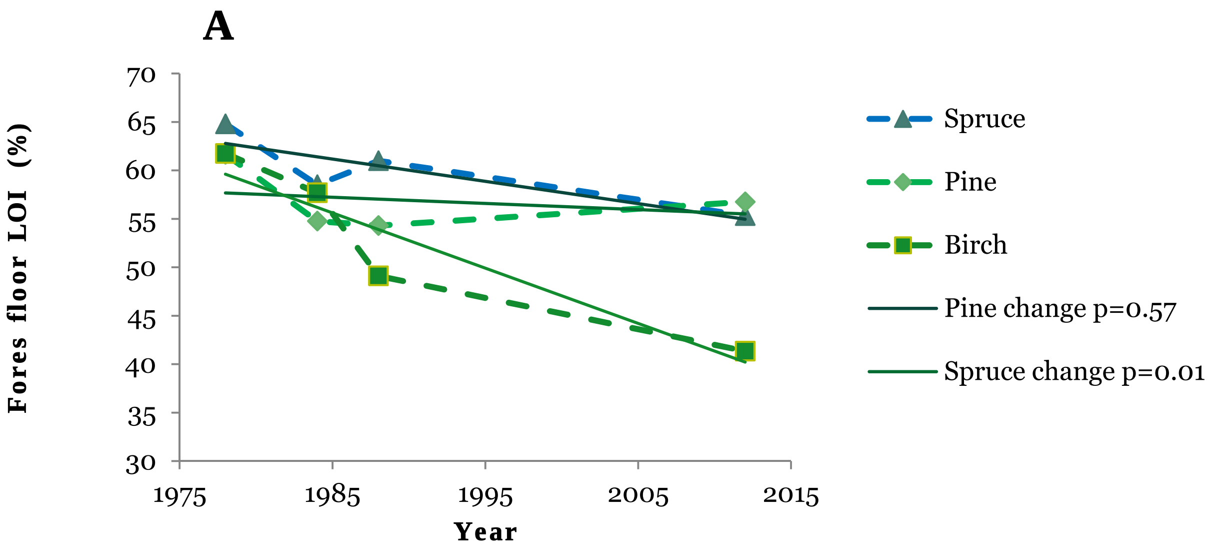
Generally, the loss on ignition (LOI) in the forest floor differed significantly between years and tree species ($p<0.0001$). There was no significant difference in the LOI between tree species at the start of the experiment, whereas a significant difference was found between the birch stands and the pine and spruce stands in 2012 ($p=0.002$, $p=0.01$, respectively). The LOI of the birch stands in 2012 was significantly smaller than in 1978 ($p<0.0001$). This decrease in forest floor LOI was supported by the mixed regression analysis, which showed a significant decrease in LOI with time in the birch and also in the spruce stands (Figure 3.12A). All years and stand types tested together showed no significant difference between LOI in the E horizon of the different stand types, but a significant overall effect of year was found ($p<0.0001$): The LOI of the E horizon increased significantly between 1978 and 2012 in all stand types ($p \leq 0.0002$). For the B-horizons, LOI in the upper B horizon (Bs 3-8 cm) showed a significant effect of both stand type ($p=0.038$) and year ($p<0.0001$), whereas in the deeper B horizon (Bs 18-23) there was only as significant effect of year ($p<0.0001$).

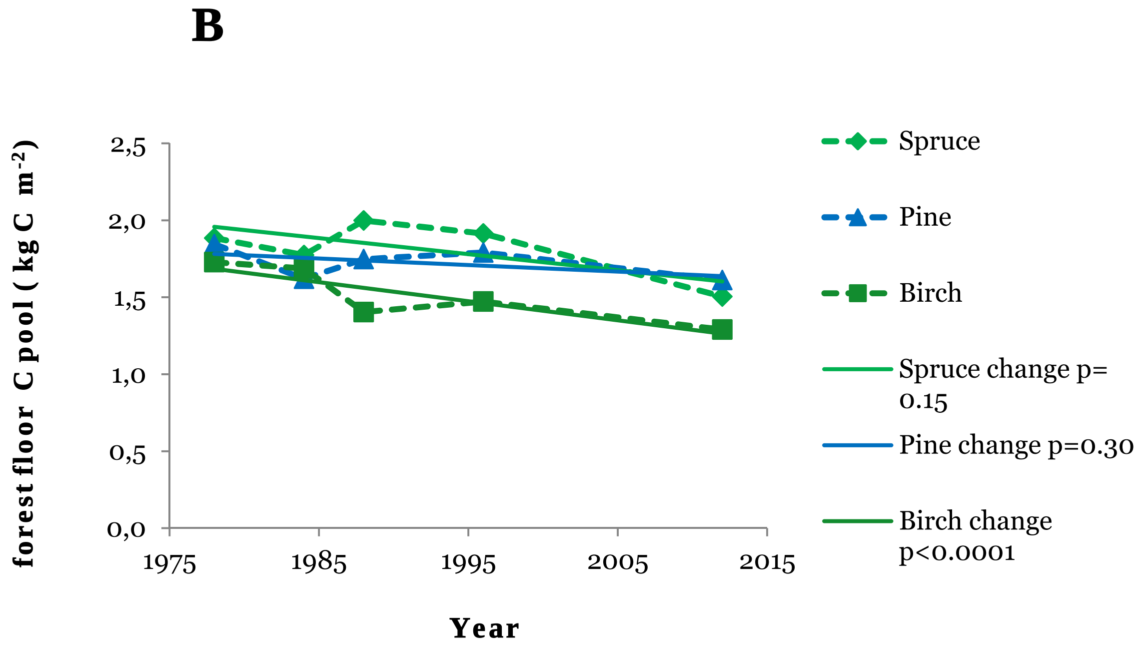
*Soil C pool*

The soil C pool of the forest floor at Nordmoen showed no overall significant difference between stand types for all years tested together. The lack of a tree species effect for all years tested together is not surprising, as three of the five sampling occasions were within the first 10 years following tree planting, when the trees were small and the effect on the soil was expected to be marginal. At the start of the experiment, there was no significant difference in the soil C pool of the forest floor or the total soil C pool. In 2012, the C pool of the forest floor and total C pool was significantly lower in the birch stand ($p=0.03$ and $p=0.01$, respectively), reflecting a possible higher decomposition of soil organic matter and/or a lower input of litter in the birch stands relative to the spruce and pine stands. Additionally, there was a significantly lower C pool in the Bs3-8 cm and Bs18-23 cm of the birch relative to the spruce stand.

The soil C pool of the forest floor differed significantly between years for all species tested together ($p<0.0001$). For the birch stands, the soil C pool of the forest floor was significantly lower in 2012 (and 1996) relative to the years 1978, 1984 and 1988 ($p<0.0001$, $p<0.0001$ and $p=0.01$, respectively). The total soil C pool in the birch stand was significantly lower in 2012 relative to the initial years (1978 and 1984), and showed a slight but significant decrease with time ($p<0.0001$, Figure 3.12B).

In the spruce stands, the C pool of the forest floor was significantly lower in 2012 than in the years 1978, 1988 and 1996 ($p=0.03$, $p=0.03$, $p=0.01$, respectively), however, no significant change with time was found in the regression analysis. Additionally, the total soil C-pool of the spruce and pine stands showed no significant change over the approx. 38-year period following the clear cut (Figure 3.12C). The change in the carbon pool with time follow to a large extent the change in thickness of the forest floor, thus the absence of a significant time trend may partly be related to the previously mentioned potential compression of the forest floor during the early phase of the experiment.


A
Fores floor LOI (%)
70
65
60
55
50
45
40
35
30
1975
1985
1995
2005
2015
Year
Spruce
Pine
Birch
Pine change p=0.57
Spruce change p=0.01


B
forest floor C pool ( kg C m-2)
2,5
2,0
1,5
1,0
0,5
0,0
1975
1985
1995
2005
2015
Year
Spruce
Pine
Birch
Spruce change p= 0.15
Pine change p=0.30
Birch change p<0.0001

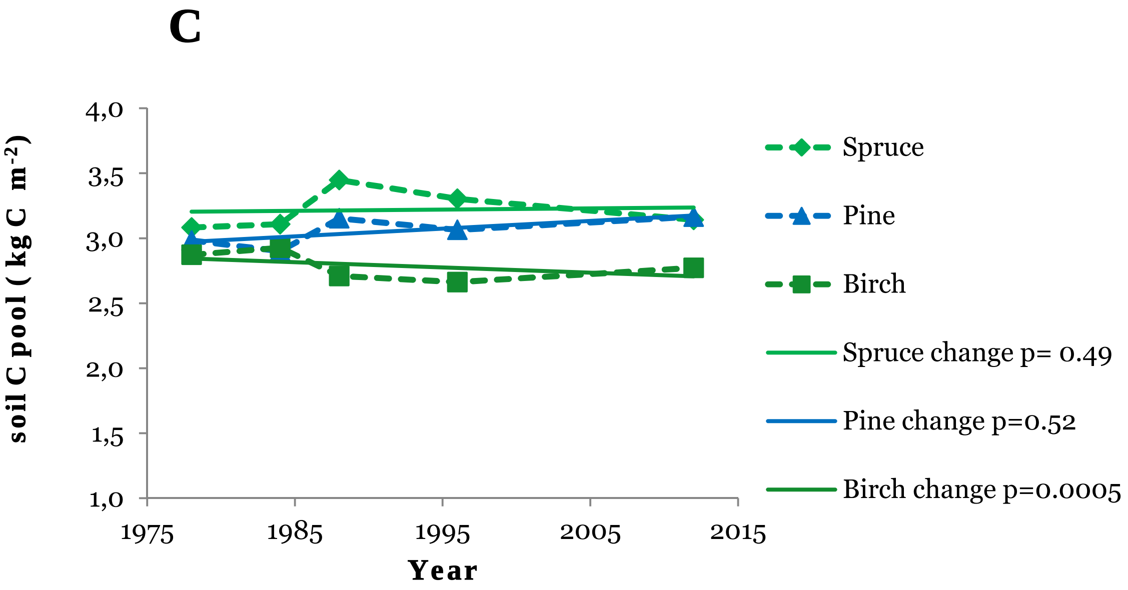


**Figure 3.12** Changes in the LOI in the forest floor (A), C pool of the forest floor (B) and in the sum of the four re-sampled compartments (forest floor, E horizon, B1 horizon and B2 horizon) (C) with different tree species between 1978 and 2012 at Nordmoen, SE Norway (n=12 plots per tree species). (The p values are based on SAS proc reg analysis).

#### 3.3.4.2 Differences within years and changes over time at Skiptvet

*Horizon thickness*

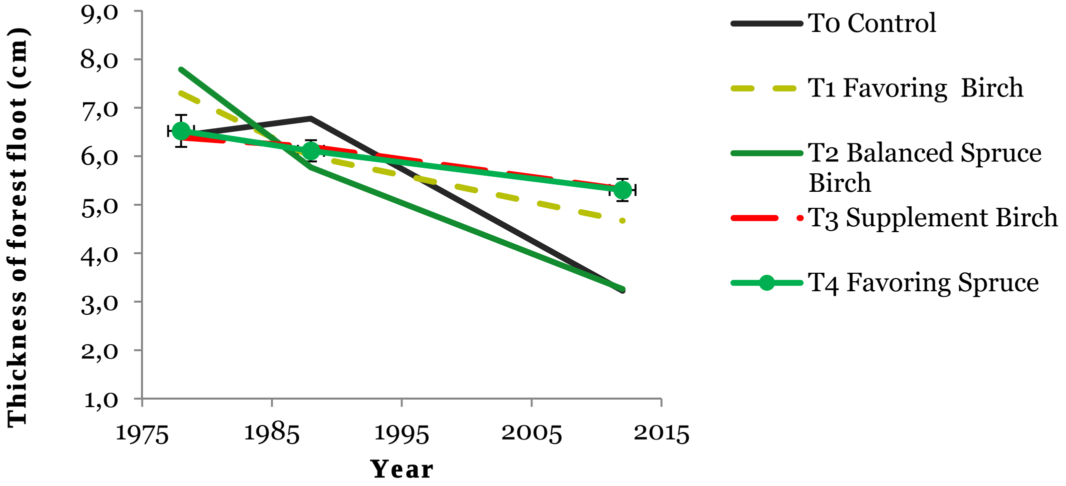
The one-sample t-test indicated a significant decrease in the forest floor thickness with time in the stand type favoring birch (T1), balanced spruce and birch (T2) and the stand type favoring spruce (T4) ($p<0.0001$, $p<0.004$ and $p<0.04$, respectively; Figure 3.13A).

*Loss on Ignition*

The LOI in the forest floor varied considerably between the plots at the start of the experiment, suggesting differences in the degree of mixing of mineral soil and forest floor material during the harvesting operation: The forest floor of the two replicate control plots (T0) both showed high LOI, whereas both replicate plots of the treatments favoring birch (T1) and balanced spruce and birch (T2) were in the lower range of the LOI. For the plots with supplement birch (T3) and favoring spruce (T4), on the other hand, one of the replicates was in the high end of the range and the other in the low end of the range (Figure 3.13B).

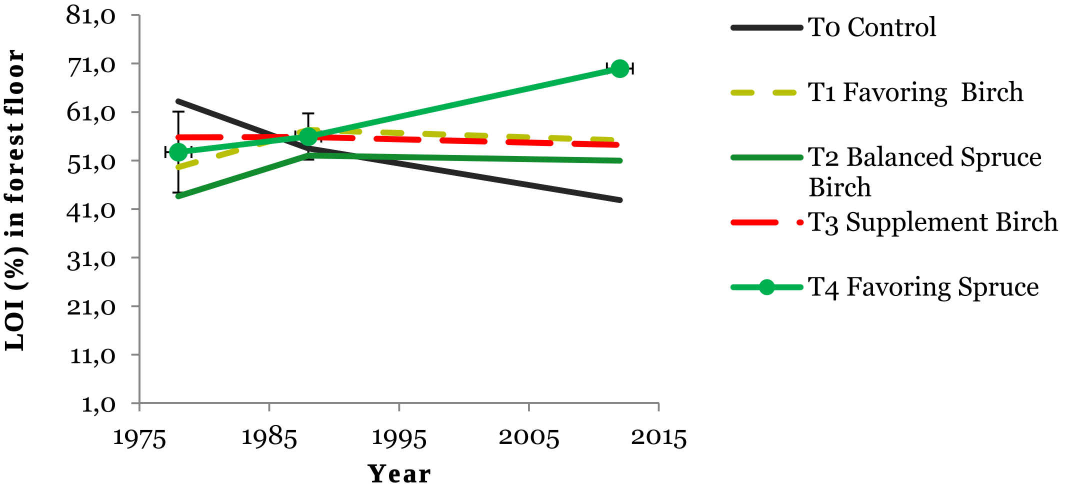
The data indicated different trends in the change in LOI of the forest floor with time between the treatment favoring spruce (T4) and the mixed stands. An increase was suggested in the stand type favoring spruce (T4), although not significant ($p=0.09$) (Figure 3.13). In the control plots (T0), the LOI of the forest floor was found to decrease significantly with time ($p=0.0009$), whereas no significant change with time was found in LOI in the forest floor for any of the remaining treatments. The within treatment variability of LOI decreased with time. There was no significant change in LOI in the upper mineral soil (humus - 10 cm mineral soil) for any of the treatments (Figure 3.13C). The LOI in the total mineral soil showed no significant change with time for any of the treatments (not shown).

**A**



Thickness of forest floot (cm)
9,0
8,0
7,0
6,0
5,0
4,0
3,0
2,0
1,0
1975
1985
1995
2005
2015
Year
T0 Control
T1 Favoring Birch
T2 Balanced Spruce Birch
T3 Supplement Birch
T4 Favoring Spruce

**B**



LOI (%) in forest floor
81,0
71,0
61,0
51,0
41,0
31,0
21,0
11,0
1,0
1975
1985
1995
2005
2015
Year
T0 Control
T1 Favoring Birch
T2 Balanced Spruce Birch
T3 Supplement Birch
T4 Favoring Spruce

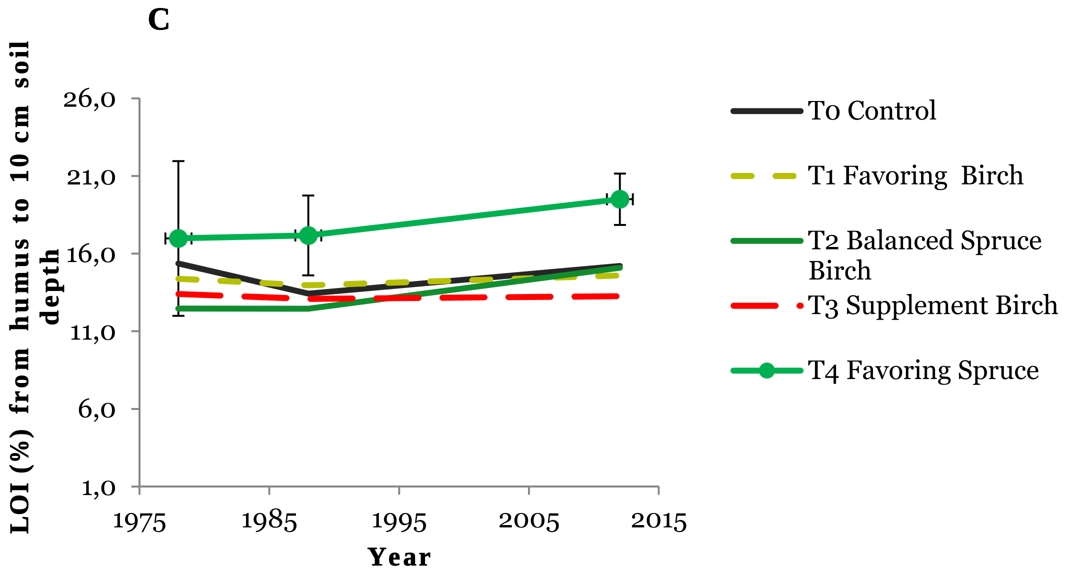


**Figure 3.13** Change in thickness of forest floor (A) (n=45 sampling points in each plot), loss on ignition (LOI) in the forest floor (n=2 plots) (B) and LOI with in the upper mineral soil between the forest floor (O) and 10 cm soil depth (n=2 plots) (C) with different mixtures of birch and spruce between 1978 and 2012 at Skiptvet, SE Norway. Error bars for T4 show ± one standard deviation. The magnitude of the error bars was similar to that of T4. The one sample t-test indicated a significant decrease in the forest floor thickness with time for T1, T2 and T4 ($p<0.0001$, $p=0.004$, $p=0.04$, respectively), and a significant change the LOI of the forest floor for T0 ($p=0.0009$). For T4, $p=0.09$.

### *Soil C pool*

The differences in the LOI, along with the variation in the humus thickness affect the estimated soil C pools. The results suggested a considerably higher C pool in the forest floor of the control plot (T0) compared to the other treatments at the start of the experiment, and a decrease in the forest floor C pool of the control treatment (T0) with time was suggested although not significant ($p<0.07$; Figure 3.14A). Also for the total soil C pool down to 30 soil depth, a significant decrease with time was found for the control plot (T0) ($p=0.01$). For the upper mineral soil (humus-10 cm), a significant increase was found in the plots favoring birch (T1) ($p=0.01$), balanced spruce birch (T2) ($p= 0.02$) and favoring spruce (T4) ($p=0.05$) (not shown). The mixed stand treatments T1-T3 showed no change with time in the total soil C pool down to 30 cm soil depth (Figure 3.14B). Generally, the trends observed for all the mixed stands (T0-T3) were relatively similar, and these trends were suggested to differ slightly from the spruce stand (T4), especially for the C pool of the forest floor (Figure 3.14A).

In 1978 and 1988, the total C pool of the mixed stand types was within the standard deviation of the spruce plots. In 2012, on the other hand, the total C pool down to 30 cm soil depth in the plots favoring spruce (T4) was higher than the mixes of spruce and birch (Figure 3.14B). This support a suggested increase in the soil C pool of the spruce stand compared to the mixed stands (T0-T3) with time. It is, however, important to note that the results have large uncertainties due to the small number of replicates.

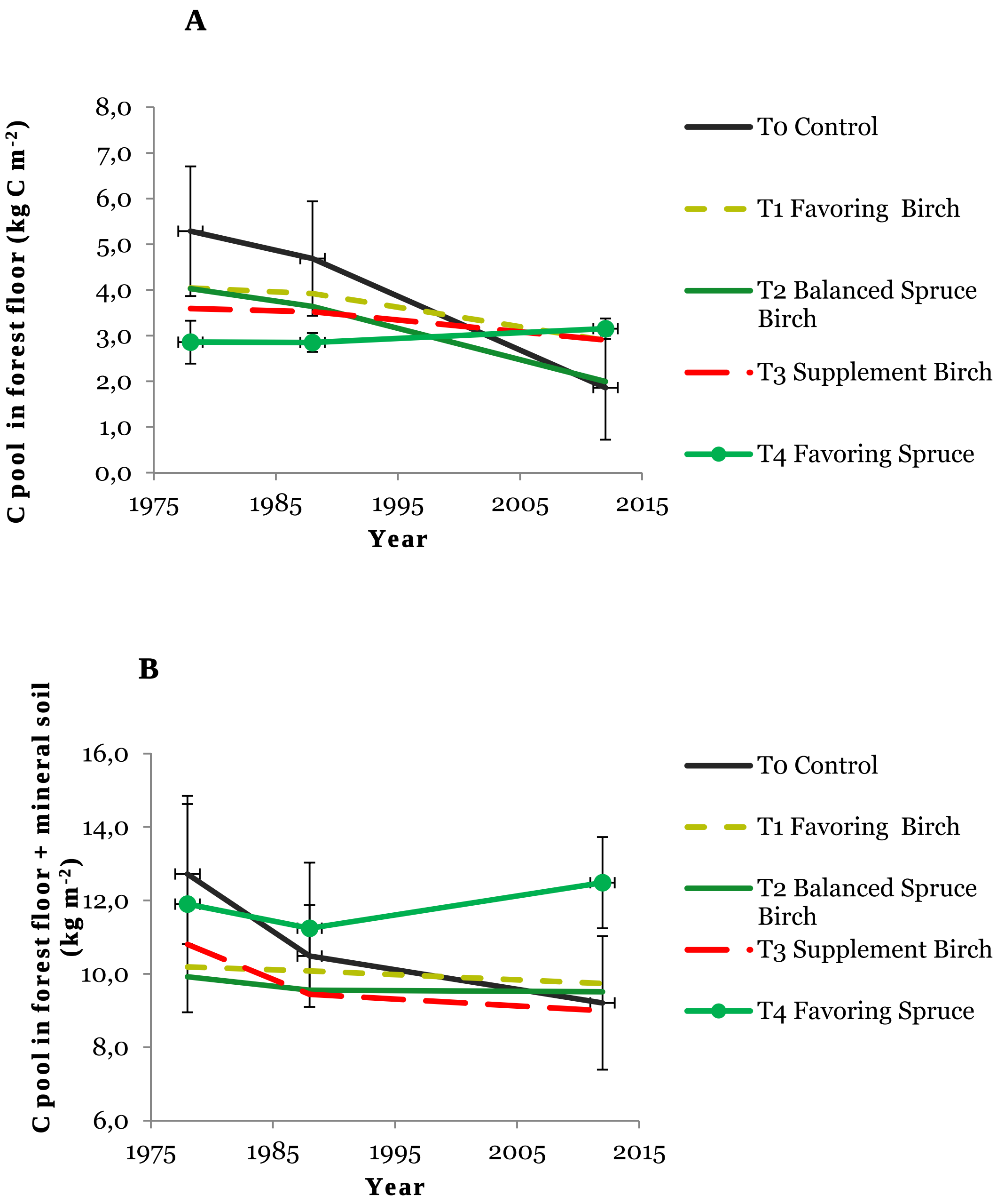


**Figure 3.14.** Change in soil C pool with time in the forest floor (A) and the forest floor + 30 cm mineral soil (B) with different mixtures of birch and spruce between 1978 and 2012 at Skiptvet, SE Norway. (n=2 plots). The error bars for the plots favoring spruce (T4) and the control plots (T0) indicate ± one standard deviation. The other treatments had standard deviations which ranged between those of T0 and T4.

#### 3.3.4.3 Comparison of changes in soil C pools

In the birch stand at Nordmoen, both the statistical analysis of differences between specific years as well as the regression analysis suggested a significant decrease in the soil C pool with time. The difference in the C pools of the forest floor between the years 1978 and 2012 indicated an annual loss of 13 g C $m^{-2}$ $yr^{-1}$, whereas the estimated loss for the forest floor and originally sampled mineral soil combined was 3 g C $m^{-2}$ $yr^{-1}$. The significant difference in the forest floor C pool of the spruce stand between 2012 and 1978 indicated a loss of 11 g $m^{-2}$ $yr^{-1}$, whereas the buildup of C amounting to 5 g $m^{-2}$ $yr^{-1}$ in the forest floor and mineral soil combined was not significant. A possible compression of the forest floor during the earlier sampling occasions suggests that the estimated loss of soil C may be underestimated.

The relative loss from the forest floor of the birch and spruce stands between 1978 and 2012 amounted to 25% and 20%, respectively, of the C pool at the start of the experiment. This estimated loss from the forest floor in the spruce stand is consistent with the 20 % loss from the forest floor of coniferous forests following clear cut reported by Nave et al (2010). Their observed higher losses from the forest floor in hardwood stands (36%) relative to coniferous/mixed stands (20%) is consistent with the significantly higher loss in the birch stand compared to the spruce and pine stands at Nordmoen. In spite of this consistency, the current results are not expected to be representative for single species spruce, pine and birch forests due to the small plot size.

For the Skiptvet site, the calculated relative loss of forest floor C pool between 2012 and 1978 in the mixed stands was 65%, 28%, 51% and 19% in T0, T1, T2 and T3, respectively. In the stands favoring spruce (T4), on the other hand, a 10% accumulation of C was suggested for the forest floor C pool. The changes amount to an annual accumulation of 9 g $m^{-2}$ $yr^{-1}$ in the forest floor, and 17g $m^{-2}$ $yr^{-1}$ in the forest floor+3 mineral horizons, respectively, in the spruce stands, and an annual loss of between 12 and 103 g $m^{-2}$ $yr^{-1}$ from the forest floor+3 mineral horizons in the mixed stands (T0 - T3). The calculated relative change in the mixed stands were within the range found by Nave et al. (2010) following harvesting. The accumulation of soil C in the forest floor of the stands favoring spruce (T4) was less commonly observed in this meta-analysis (ibid.). Due to the low number of replicates, no conclusions can be drawn.

#### 3.3.4.4 Total Soil Pools in 2012

The sampling depths of the mineral soil in the original soil sampling regime differed between Nordmoen and Skiptvet (Table 3.1). In 2012, the soil sampling was augmented to include the layers that had previously been excluded at Nordmoen, as well as the soil layer down to 40 cm at both sites. Additionally, in order to evaluate the modelled changes in the total C pool with time, the total soil C pool down to the depth of 1 m was estimated for Nordmoen.

The sum of all horizons down to approx. 40 cm at Nordmoen showed a significantly larger C pool in the spruce and pine stands relative to the birch stand ($p<0.0001$ and $p=0.03$, respectively) (Figure 3.15). This is in alignment with results reported by Hansson et al (2013), and supports the findings that tree species affects soil C pools (Vesterdal et al. 2013). The results from 2012 reflected the differences in the C pool of the original sampling protocol (Figure 3.12), however, the mineral soil of the original sampling protocol contained less than half (43%) of the total soil C pool down to the approx. 40 cm soil depth (Table 3.13). In all stands, the soil is weakly podzolized, with a downward transport of organic C along with Fe and Al, which is typical for the podzolization process. This process is affected by formation and transport of humic acids, which again is linked to litter quality. When looking at differences in the mineral soil, the soil C pool in the upper 0-3 cm B horizon was significantly higher in the spruce and pine stands relative to the birch stands ($p=0.01$), indicating that the C accumulation processes in the upper B horizon is affected by tree species. This process may possibly also affect subsequent parts of the B horizon as the C pool in the Bs3-8 cm and Bs18-23 cm was significantly higher in the spruce stand relative to the birch stand (see 3.3.4.1). No significant difference was found for the lower B horizon (Bf 23-33 cm).

Table 3.12. Fine litter (Dead organic matter DOM, excluding downed dead trees) sampled in each ground vegetation biomass plot at Nordmoen and Skiptvet, SE Norway

| Site | Treatment | C pool DOM/litter kg C $m^{-2}$ |
|---|---|---|
| **Nordmoen** | Spruce | 0.23 ± 0.03 |
| **Nordmoen** | Pine | 0.31 ± 0.05 |
| **Nordmoen** | Birch | 0.27 ± 0.06 |
| **Skiptvet** | T0 | 0.54 ±0.12 |
| **Skiptvet** | T1 | 0.47 ±0.09 |
| **Skiptvet** | T2 | 0.62 ±0.28 |
| **Skiptvet** | T3 | 0.45 ±0.17 |
| **Skiptvet** | T4 | 0.40 ±0.06 |

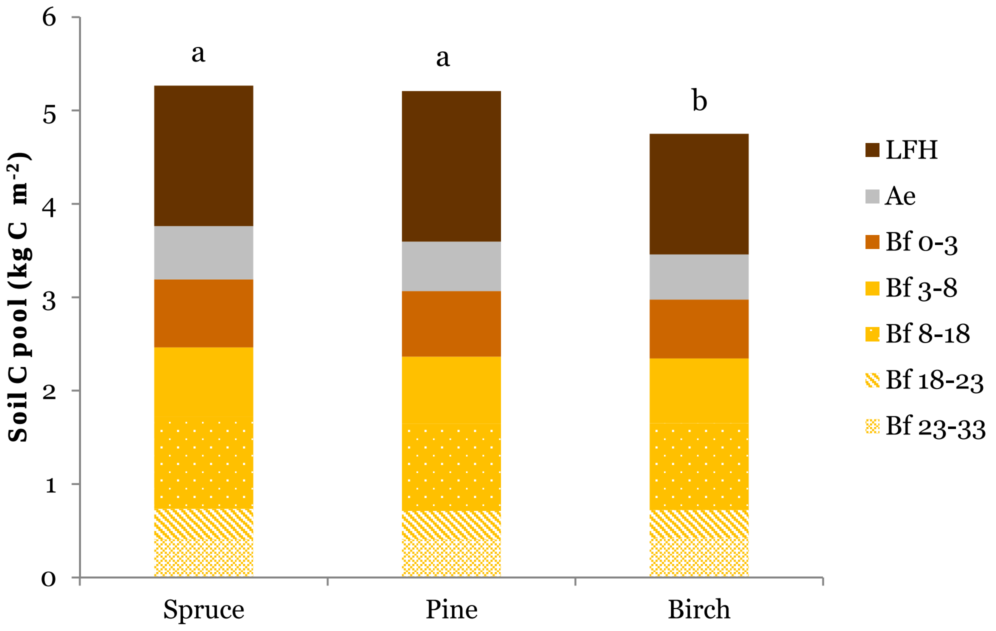


Figure 3.15. Soil C pool in different soil layers of Spruce, Pine and Birch stands at Nordmoen, SE Norway.

In addition to podzolization processes, decomposition processes and litter quality, as well as the total amount of litter input may explain the higher soil C pool in the spruce and pine stands at Normoen relative to the birch stand. The amount of fine litter collected in the ground vegetation biomass plots (dead organic matter, DOM, excluding the fallen dead trees), was significantly higher in the pine relative to the spruce and birch stands ($p=<0.0001$ and $p=0.03$, respectively) (Table 3.12). However, as this litter contains both new and older litter, it is indicative of the relationship between litter input and decomposition combined, rather than the litter flux per se. The total litter input is related to trees and ground vegetation biomass and species distribution: The total tree biomass was significantly lower in the spruce and pine stands relative to the birch stand (Figure 3.3) whereas the ground vegetation biomass was significantly lower in the spruce stand relative to the birch stand (Figure 3.8, Table 3.9). This may suggest higher litter inputs in the birch stand. The pine and birch stands had higher C pools of vascular plants, whereas the spruce stand had the highest cover of bryophytes (Figure 3.8). Some ground vegetation litter types may speed up the decomposition processes whereas others may slow it down: The species composition will affect the litter quality per se as well as the mixture of different litter types, which may affect the decomposition rates (Jonsson and Wardle, 2008, Song et al., 2010). The ground vegetation composition is affected by stand type through different levels of shading, however, the higher shading found in the spruce stand may also reduce the soil temperature and thus reduce the decomposition rates in this stand.

Also at Skiptvet, the sum of all horizons down to approx. 40 cm reflected the differences in the C pool of the original sampling regime, with a higher C pool in the plots favoring spruce (T4) relative to the mixed stands (Figure 3.17). As for Nordmoen, the above and below ground biomass in the spruce stand (T4) was lower over time compared to the other stands (Figure 3.6), which potentially may give a lower litter input from the trees. Thus, both for the Normoen and the Skiptvet stands, decomposition and factors affecting the decomposition rates are expected to be the more dominating processes causing the observed differences in soil C pools between the stands.

Table 3.13. Measured soil C pools in the forest floor and mineral soil in spruce, pine and birch stands at Nordmoen SE Norway. O horizon = forest floor; Sum 1= sum of the 3 mineral soil layers sampled in the original sampling protocol (E, B3-8cm and B18-23 cm); Sum 2 = sum of the additional layers sampled in 2012 (0-3, B8-18, B23-33); Total measured (approx. 40) = sum of O horizon+Sum1 + Sum 2 (measured C pool down to approx. 40 cm soil depth); estimated C pool at 40 - 100 cm soil depth (; and estimated total C pool down to 1 m soil depth= total measure 40 cm + estimated 60 cm. The estimated lower soil (60 cm) was based on C pools in an adjacent age chronosequence of Norway spruce (Kjønaas et al. in prep).

| Layer | Spruce<br>C kg m$^{-2}$ |  | Pine<br>C kg m$^{-2}$ |  | Birch<br>C kg m$^{-2}$ |  |
|---|---|---|---|---|---|---|
|  | mean | stddev | mean | Stddev | mean | stddev |
| **O horizon** | 1.50 | 0.17 | 1.61 | 0.31 | 1.29 | 0.16 |
| **Sum 1** | 1.64 | 0.14 | 1.55 | 0.06 | 1.48 | 0.14 |
| **Sum 2** | 2.12 | 0.14 | 2.04 | 0.12 | 1.98 | 0.19 |
| **Total measured (approx. 40 cm)** | 5.27 | 0.26 | 5.21 | 0.31 | 4.75 | 0.28 |
| **Estimated lower soil (60 cm)** | 1.80 | 0.29 | 1.80 | 0.29 | 1.80 | 0.29 |
| **Estimated total 1 m soil depth** | 7.11 |  | 7.05 |  | 6.59 |  |

Models frequently estimate the soil C pool down to 1 m soil depth, and thus reference data containing C pools to 1m soil depth are preferable. Based on no significant differences in the lower mineral soil layer between the tree species, and no significant difference in the soil C stocks in the lower mineral soil of a nearby Norway spruce chronosequence study at Nordmoen on the same soil type, the data on C stock in the lower mineral soil from the chronosequence study was considered representative for pool estimates down to 1 m soil depth. The mean soil C stock between 40 cm and 1 m soil depth in the 10, 30, 60 and 130 year old stands from the adjacent chronosequence was 1.8 kg C m$^{-2}$ (n=11, Table 3.13, Figure 3.16; Kjønaas et al. in prep.). Altogether, this gave a total C pool down to 1 m ranging between 6.6 and 7.1 kg C m$^{-2}$ for the stands in the current study (Table 3.13).

The total soil C pools down to approx. 40 cm soil depth at Nordmoen was relatively low for all stand types compared to the soil C pools in adjacent 30 and 60 year old spruce stands (Figure 3.16; Kjønaas et al. in prep). This may be due to the removal of all harvest residues following the clear cut in 1973. The total soil C pools down to approx. 40 cm soil at Nordmoen (Figure 3.15) were also low compared to the soil C pools found in Skiptvet, where the total storage varied between 10 kg C m$^{-2}$ and 14.5 kg C

$m^{-2}$ (Figure 3.17). The difference in mineral soil C between the two sites may partly be linked to soil type. The silt loam at Skiptvet contain 26 % clay which will to a larger extent provide physical protection that may hamper decomposition of organic matter in the mineral soil, as compared to the sandy soil at Nordmoen which contain 90-98% sand.

Additionally, the C pool in all stands at Nordmoen were low compared to the median forest floor and mineral soil C pools found for the mineral soil types amongst the approx.1000 NFI plots, which amounted to 7 kg C $m^{-2}$ and 11 kg C $m^{-2}$, respectively (DeWit and Kvindesland 1999). Compared to the mean soil C pools in the NFI plots from Akershus and Østfold (Table 5.1), the soil C pools down to approx. 40 cm at Skiptvet was in the higher range, whereas the soil C pools found at Nordmoen was in the very low end of this range. Management practices which involved prolonged and frequent harvesting to provide fuel to a nearby glass factory approx. 200 years ago may still play a significant role for the generally low soil C pool at Nordmoen, as will the trenching and tilling of the soil when used for agricultural purposes affect the C pool at Skiptvet.

The uncertainty in the estimates of the C stocks and changes over time is dependent on the quality and the accuracy of the data that were used to estimate the soil C stocks. Uncertainty analysis of the soil data will be explored in a coming paper. The estimated uncertainty for the ICP forest level 1 plots of DeWit and Kvindesland (1999) showed an uncertainty of 17 % for the forest floor horizon and 22% for the mineral horizon, giving a total uncertainty for the soil profiles on mineral soils of 28% (two layers). The largest uncertainties in this dataset were connected to limited or no available data on BD and stoniness in the different soil profiles.

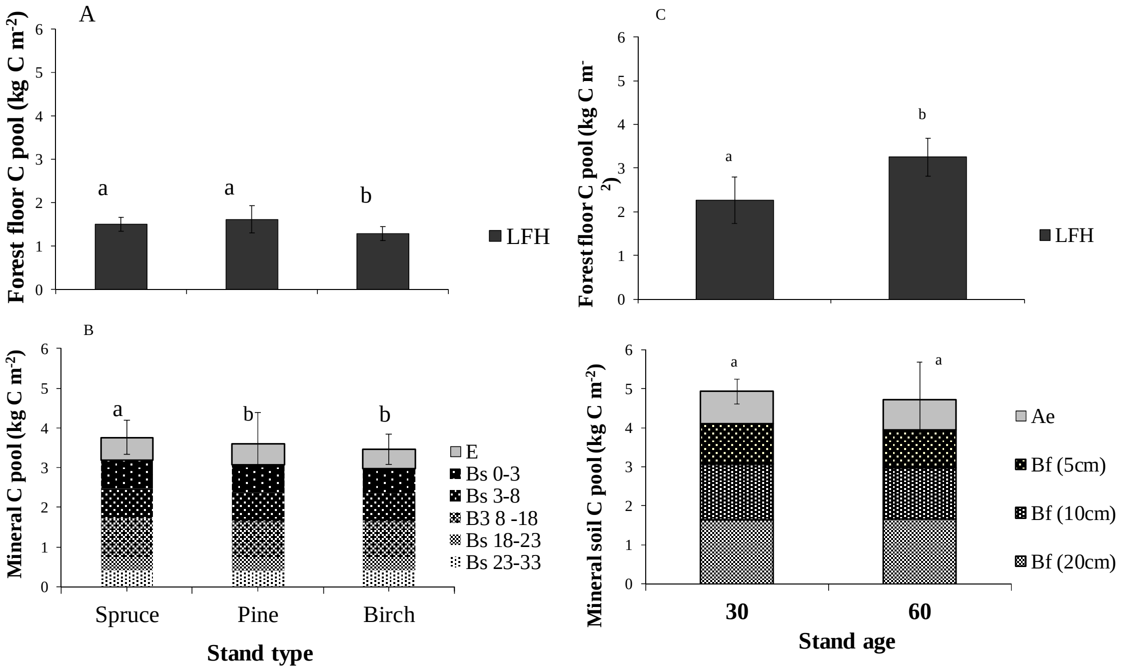


**Figure 3.16.** Soil C pool in the forest floor (A) and the mineral soil (B) of the Spruce, Pine and Birch stands in the current study as compared to the soil C pools in forest floor (C) and mineral soil (D) in two adjacent stands with a stand age of 30 and 60 years (Kjønaas et al. in prep.).

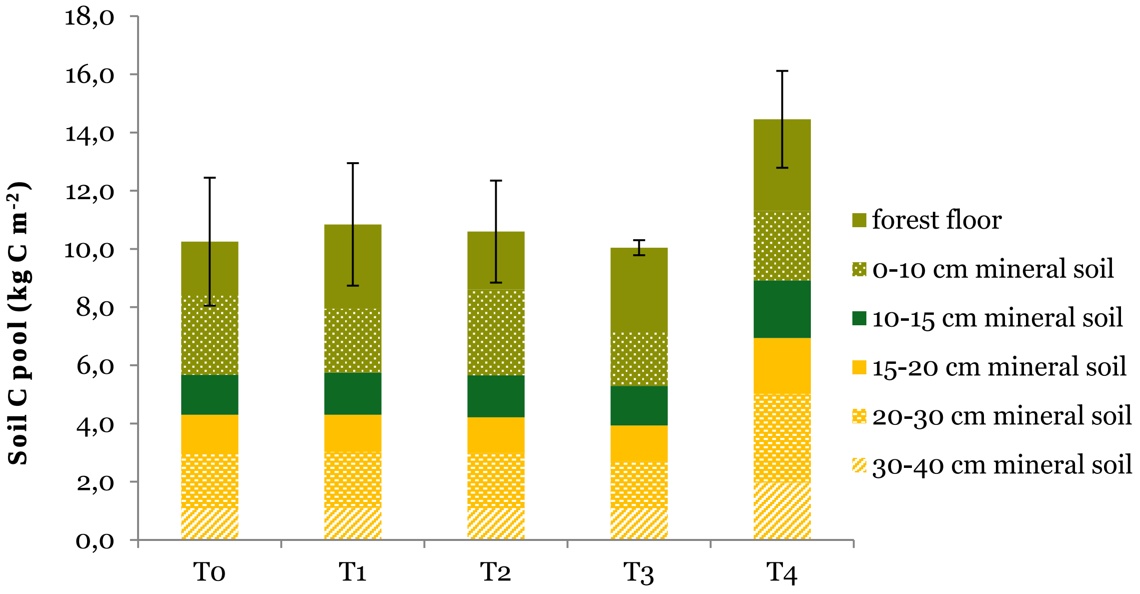


**Figure 3.17** Soil C pool in different soil layers of stands in 2012 with different mixtures of spruce and birch at Skiptvet, SE Norway.

## 3.3.5 Results: Total ecosystem C pools

Differences in tree and ground vegetation biomass will determine the above- and below ground litter flux to the soil as well as the chemistry and quality of the litter, and will again affect the accumulation and loss of the forest floor C pool as well as the soil C pool of the forest ecosystem.

Based on the data from 2012, the different tree species seem to affect the C pool in the total ecosystem somewhat differently: The total tree biomass in the spruce stand at Nordmoen differed significantly from the pine and birch stands ($p=0.01$ and $p<0.0001$, respectively). A similar pattern was found for the living biomass ($p=0.03$ and $p<0.0001$, respectively) and the total ecosystem C pool ($p=0.01$ and $p=0.002$, respectively; Figure 3.18), as well as for the sum of the C pool in mineral soil down to 40 cm ($p=0.03$ for both). As mentioned above, the difference in the mineral soil C pool may be related to differences in podsolization processes. Additionally, differences in the root distribution patterns between the tree species may also affect the mineral soil C pools, with pine and birch being characterized by deeper root systems.

The birch stand differed from the spruce and pine stand regarding the total soil C pool down to approx. 40 cm ($p<0.0001$ and $p=0.03$, respectively) and the C pool in the forest floor ($p=0.01$ and $p=0.03$, respectively). As for the standing dead wood, the C pool in the spruce stand was significantly higher than in the birch stand ($p=0.03$). The total litter layer sampled as part of the ground vegetation biomass harvest was, on the other hand, significantly higher in the pine stand relative to the birch and spruce stands ($p=0.03$, $p<0.0001$, respectively) (Table 3.12), which was also the situation for the ground vegetation biomass ($p=0.01$, $p<0.0001$, respectively).

At Skiptvet, the C pool in the living tree biomass was similar for the treatments T1-T4 (Table 3.14, Figure 3.18). The slightly higher tree biomass for T0 may reflect the very high number of trees, which again is linked to no management at the start of the experiment (Table 3.4, Table 3.14, n=2, no statistics). The distribution of spruce and birch in the different plots did not seem to affect the C pool in the trees, and the suggested higher total pool in the stand favoring spruce (T4) seemed to be mainly related to a higher C pool in the forest floor and mineral soil (Figure 3.18), as also suggested by the one-sample t-test.

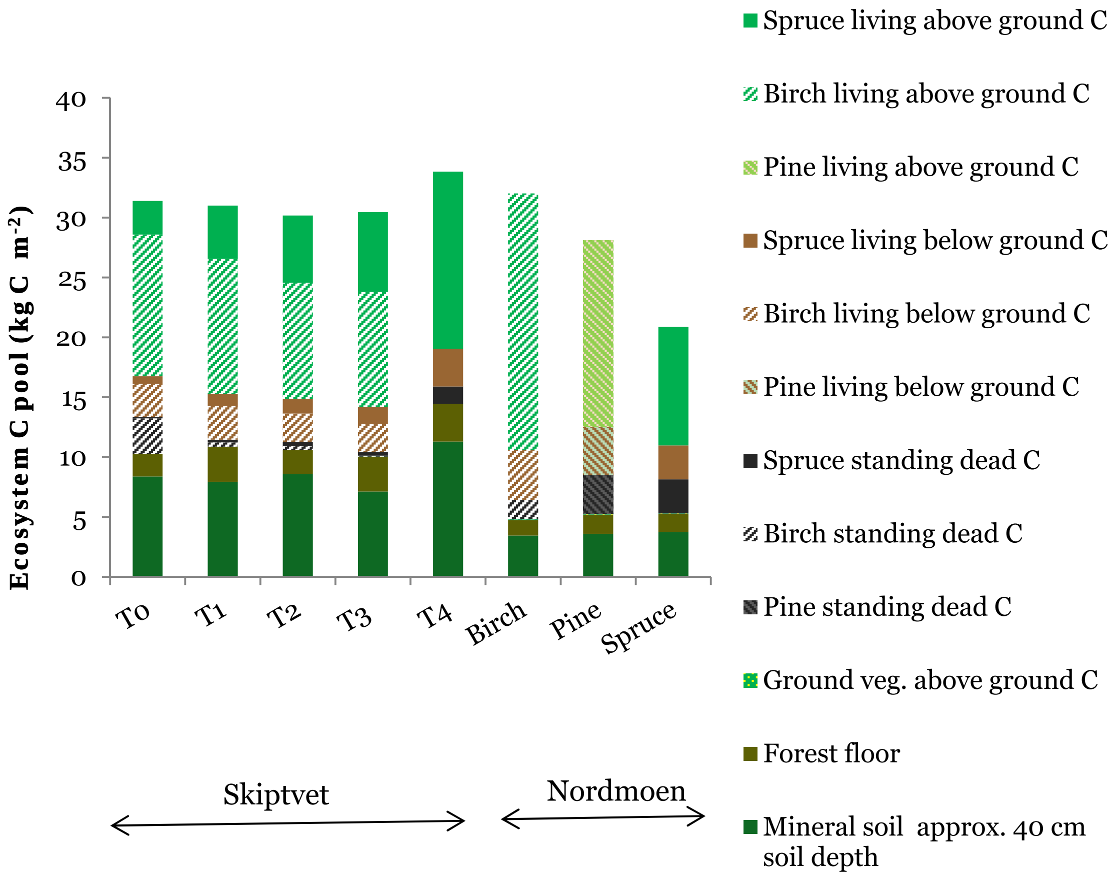


**Figure 3.18. Total C pool in standing living tree biomass, standing dead wood, ground vegetation (above ground), forest floor and mineral soil down to approx. 40 cm soil depth with different mixtures of birch and spruce at Skiptvet SE Norway and in birch, pine and spruce stands at Nordmoen SE.Norway.**

The C pool of the ground vegetation was small compared to the whole ecosystem C pool, but was 10 - 100 times larger at Nordmoen compared to at Skiptvet. When comparing the total ecosystem C pools at the two sites, C pool of the birch stands at Nordmoen and the T0 control stand at Skiptvet, which contained the most birch, were relatively similar (Figure 3.18). On the other hand, the total C pool in the spruce stands at Nordmoen and Skiptvet were at the opposite ends of the scale. This may partly be related to soil type where the soil at Skiptvet is expected to contain a higher supply of water and nutrients, as well as provide a higher physical protection against C decomposition in the mineral soil, relative to the soil at Nordmoen. The total soil C pool at Nordmoen was close to half that of Skiptvet. Both sites tended toward a higher total soil C pool in the spruce stands relative to birch or mixed stands.

Differences in the soil as well as the biomass pools affected the C soil:vegetation ratio, as limited to the soil down to approx. 40 cm depth. The range was quite large both for the different stand types as well as when comparing the two sites (Table 3.14), however, at both sites, the C pool of the soil down to 40 cm was considerably lower than in the biomass.

**Table 3.14** C pool in trees (standing living biomass+ dead wood), ground vegetation (above ground), soil down to approx. 40 cm mineral soil, total forest ecosystem, and the ratio between the C pool in soil and vegetation in different stand types at Nordmoen and Skiptvet, S.E. Norway.

| Site | Treatment | Trees biomass kg C m$^{-2}$ | Ground veg. above gr. kg C m$^{-2}$ | Total soil (approx. 40 cm) kg C m$^{-2}$ | Total Ecosystem kg C m$^{-2}$ | C pool ratio Soil:vegetation |
|---|---|---|---|---|---|---|
| **Nordmoen** | Spruce | 15.56 | 0.04 | 5.27 | 20.87 | 0.34 |
| **Nordmoen** | Pine | 22.82 | 0.09 | 5.21 | 28.11 | 0.23 |
| **Nordmoen** | Birch | 27.21 | 0.05 | 4.75 | 32.01 | 0.17 |
| | | | | | | |
| **Skiptvet** | T0 | 24.25 | 0.0004 | 10.25 | 34.50 | 0.42 |
| **Skiptvet** | T1 | 20.78 | 0.0010 | 10.84 | 31.62 | 0.52 |
| **Skiptvet** | T2 | 20.23 | 0.0001 | 10.60 | 30.83 | 0.52 |
| **Skiptvet** | T3 | 20.80 | 0.0001 | 10.04 | 30.84 | 0.48 |
| **Skiptvet** | T4 | 20.82 | 0.0047 | 14.45 | 35.28 | 0.69 |

# 4 Site specific simulation studies

Holger Lange, Signe K. Borgen, Silje Skår, Lise Dalsgaard, O. Janne Kjønaas and Kjell Andreassen

## 4.1 Background

The ability of soil carbon models to reproduce carbon stocks from repeated measurements at the two sites Nordmoen and Skiptvet were investigated. We used two models, Yasso07 and Romul, which have rather different approaches. For Yasso07, model simulations were made with two separate objectives: first, to produce realistic simulations using plausible initialization approaches and measured biomass inputs, and second, to explore various spin-up conditions (initial pool values and biomass inputs) that would be necessary to reproduce the measured soil C stocks and changes. For Romul, no spin-up procedure is required for initialization as measured stocks are used to define the starting condition in the model. In contrast to Yasso07, calibration is needed and two process parameters were used to calibrate the model. We also discuss the importance of litter production as the most crucial model input, and the uncertainty of estimates for ground vegetation litter.

## 4.2 Materials and methods

### 4.2.1 Romul

ROMUL (model of Raw humus, mOder and MULl) is a process-oriented model for soil organic matter (SOM) dynamics (Chertov et al. 2001). Besides soil carbon, it also allows the calculation of plant-available nitrogen in the mineral soil. ROMUL is a litter "cohort" model, where each cohort is defined via its ash, nitrogen and lignin content. Both above-ground and belowground cohorts are considered (Figure 4.1). The maximum number of cohorts possible is 14; for this report, we have been using six cohorts, reflecting the biomass fractions calculated from biomass models (foliage, living branches, dead branches, fine roots, coarse roots) and ground vegetation, as described for Yasso07 below. Organic litter and humus transformations are described by first-order linear differential equations with changing coefficients. A difference is made between above-ground and below-ground cohorts.

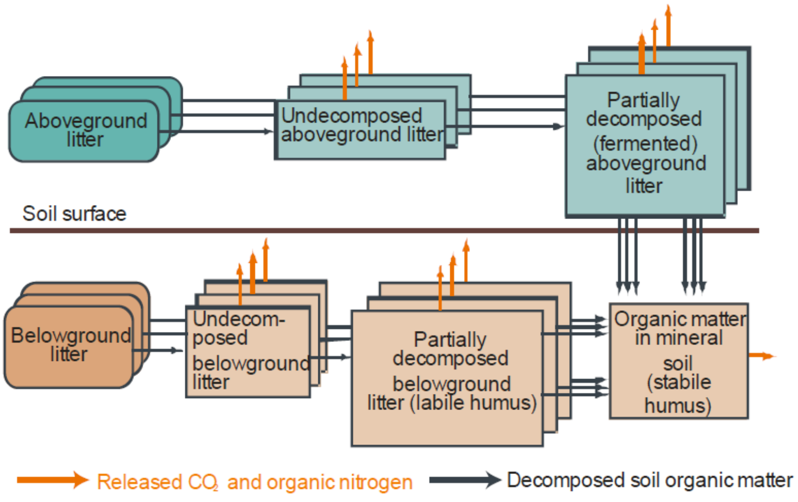


**Figure 4.1.** **Conceptual drawing of the Romul model. Rounded boxes refer to litter input; rectangular boxes represent the litter pools processed by the model. After Chertov et al. 2001, adapted.**

The model distinguishes between the L, F and H horizon in the organic layer. Belowground, there is a litter, a labile humus and a stable humus pool. The decomposition rates are driven by the ash and N contents of the litter, i.e. these concentrations are important input parameters which are not always easily available. This is even more the case for the lignin content of the different litter fractions. For the current parametrization, we used data from a Finnish study (Hakkila and Parikka 2002) on N, ash and lignin content of the different litter fractions.

Decomposition processes are strongly impacted by soil climate. Thus, Romul needs input data for soil temperature and soil moisture. As these two time series are not available routinely from field measurements, a separate soil climate generator developed by the same modelling group, the Soil CLImate Statistical Simulator (Scliss (Bykhovets and Komarov 2002)) was used that requires air temperature, precipitation, and soil physical and hydrological properties as input. At the Nordmoen site, data on soil temperature and moisture of adjacent sites were available for a limited number of years. Scliss was able to reproduce observed soil temperatures in an excellent ($r^2 > 0.8$) manner, and the soil moisture could be reproduced reasonably well ($r^2 \approx 0.6$). The initial values for soil temperature and moisture at the beginning of the simulation had very little impact on the remainder of the results after approx. 6 months. Therefore, we used the Scliss-generated time series for soil temperature and moisture for the whole simulation period.

Romul does not use an equilibrium assumption and thus does not require spinup runs. Simulations start with the first year of observation, or the beginning of the climate record. As for Yasso07, the sum of labile and stable carbon fractions from the forest floor and the humus and mineral soil layer is meant to be representative for the C stocks down to 1 m depth, although the model lacks an explicit spatial resolution (no partial differential equations); neither does Yasso07. As a consequence, model and measurements will not be fully comparable for the Skiptvet site (Table 3.14) since the C stocks measured there extend only down to approx. 40 cm, whereas for Nordmoen soil C stocks have been estimated down to one meter Table 3.13). Input time series for temperature, precipitation and amount of litterfall are required at monthly resolution. We used the same climate station data as for Yasso07 to produce monthly series for temperature and precipitation. For litterfall, we assumed it to be equally distributed throughout the year, except for birch foliage which falls off exclusively in September and October each year. The same turnover rates for the calculation of litterfall were used as for Yasso07 (Table 4.1), i.e. both models received identical litter input apart from the temporal resolution.

**Table 4.1** Litter turnover rates ($yr^{-1}$) per biomass component, associated references, and resulting mean annual litter input, averaged over all the treatments, at the two sites.

| Biomass component | Values ($yr^{-1}$) | Source | Mean litter production ($g\ C\ m^{-2}\ yr^{-1}$); Nordmoen, Skiptvet |
|---|---|---|---|
| Foliage (spruce, pine, birch) | 0.143, 0.33, 1.0 | DeWit et al. 2006 | 160, 109 |
| Branches (spruce, pine, birch) | 0.0125, 0.027, 0.025 | DeWit et al. 2006 / Peltoniemi et al. 2004 | 33, 27 |
| Root litter (> 2mm) (spruce, pine, birch) | 0.0125, 0.027, 0.025 | DeWit et al. 2006/ Peltoniemi et al. 2004/ | 31, 36 |
| Fine root litter(< 2mm) (spruce, pine, birch) | 0.6, 0.6, 0.6 | Matamala et al. 2003 | 96, 16884 |
| Ground vegetation: (mosses, lichens, shrubs, herbs); aboveground | 0.33, 0.01, 0.25, 1 | Peltoniemi et al. 2004 | 26, 13 |
| Ground vegetation: (shrubs, herbs); belowground | 0.33, 0.33 | Peltoniemi et al. 2004 | Included in aboveground |

## 4.2.2 Yasso07

Yasso07 (Tuomi et al. 2009, Tuomi et al. 2011a,b) is a compartmental soil organic matter decomposition model. Carbon pools of different decomposability represent C in soil organic matter that is acid-soluble (A), water-soluble (W), ethanol-soluble (E), non-soluble (N), as well as C in the humus pool. The pool decay rates are driven by litter quality and modified by climatic variables. The majority of the $CO_2$ emitted during litter decomposition occurs from the W pool (Figure 4.2).

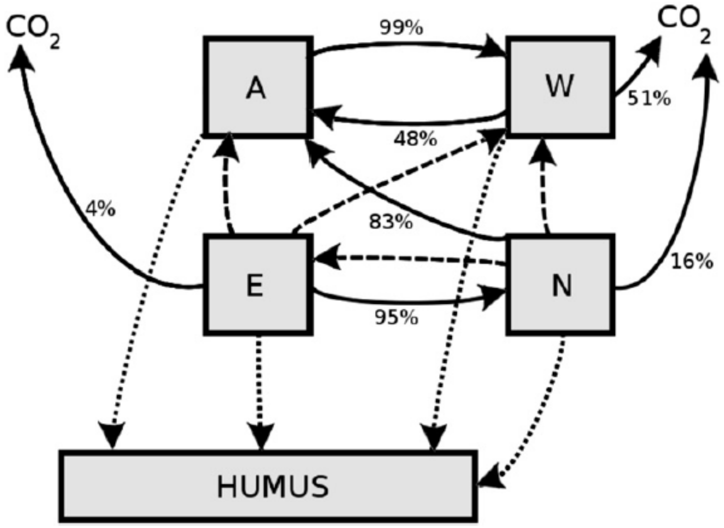


**Figure 4.2.** Conceptual drawing of the Yasso07 models and the relative magnitude of mass flows between the pools (Tuomi et al. 2011b).

The simulations were made on an annual time step for 35 years (Nordmoen) and 37 years (Skiptvet). The model takes C inputs (litterfall expressed as C) and climatic variables (mean annual temperature, temperature amplitude, and annual precipitation) at each time step. Carbon inputs from litter derived from standing biomass and ground vegetation were considered. Preparation of C inputs is done in six steps:

1. conversion of living tree measurements into biomass estimates per tree component (foliage, living branches, dead branches, stem, bark, roots, fine roots and stumps),
2. interpolation between measurement years to derive annual biomass estimates,
3. estimation of litter inputs using turnover rates (Table 4.1),
4. conversion from biomass to carbon (50% C),
5. distribution of C inputs per tree component into AWEN model pools, and
6. compilation of AWEN pools in the following size classes: non-woody; foliage and fine roots; fine woody; living and dead branches, root biomass and bark, coarse woody; stems and stumps.

To simplify calculations, litter inputs caused by natural mortality (self-thinning) were not considered, although initial stand density was high, and thus some self-thinning (and intentional thinning) occurred. A detailed description of the spinup process can be found in chap. 4.2.4.

### 4.2.3 Input data

Annual means of temperature and precipitation were derived from daily climate data taken from the closest weather stations available from the Meteorological Institute of Norway (met.no). For Nordmoen, the station “Gardermoen” is located 4.2 km from the site. For Skiptvet, the closest weather station with available temperature data covering the whole simulation period (1976-2012) was “Rygge”, located 27.2 km from the site, whereas precipitation data were derived from the station "Fløter", 8.6 km away from the Skiptvet plots. In addition to the annual precipitation and mean temperature, Yasso07 requires the annual temperature amplitude, which was calculated as $T_{amp} = (T_{max} – T_{min})/2$ , based on monthly series.

Tree diameter and height was measured on four occasions at Nordmoen and six occasions at Skiptvet (Table 3.1). Estimates of biomass for foliage, living and dead branches, and coarse roots (diameter ≥ 2 mm) were derived from modelled biomass data in each site and stand type (chap. 0). Fine roots (diameter < 2 mm) biomass was estimated as 30% of the foliage biomass, based on actual measurements at adjacent sites at Nordmoen (Kjønaas et al. in prep.).

As the biomass production grows nonlinear with time, a shape-preserving interpolation technique based on Hermite polynomials was used to estimate the *annual* stocks of each biomass component. The biomass of the ground vegetation was estimated based on stand age and tree species (Muukkonen and Mäkipää 2006). Litter turnover rates were applied to each tree and ground vegetation component (Table 4.1). Fine root turnover rates are crucial for the rate of litter production, and have been subject to much debate lately (Ahrens et al. 2014, Brunner et al. 2013). Nevertheless, we used the value of 0.6 $yr^{-1}$ as default value to be consistent with the national GHG inventory reporting (Anonymous, 2014). A simple uncertainty analysis was carried out by deviating from this value, cf. below.

At Nordmoen, the Finnish ground vegetation biomass model (Muukkonen and Mäkipää, 2006) was rescaled using our 2012 estimates of total living biomass. The model overestimated biomass roughly by a factor of two for ground vegetation biomass for the spruce and pine stands, and underestimated that of the birch stands by approximately the same factor. The whole time series was multiplied by these species-dependent correction factors, preserving the dynamics as predicted by the model.

At Skiptvet, measurements indicated that virtually no ground vegetation was present in 2012 in these very dense stands (Table 3.9). A correction of the Finnish model would have been pointless. Instead, we simulated using this model, and tested for the impact of ground vegetation litter at the end of the simulation period by simulating one of the treatments (T0) with zero litter production from the ground vegetation.

Biomass for the belowground parts of shrubs and herbs is assumed to be twice as that of the aboveground parts (Peltoniemi et al. 2004). Due to the turnover rates, root biomass was the largest contributor of the litter inputs on both sites for spruce. The second largest was the litter inputs from foliage.

For both sites, the tree biomass calculations were based on measurements at the individual tree level. The litter calculation was performed at the tree species level. For Skiptvet, information on the tree species composition for the individual treatments was available, and the calculation of litter production was done separately for each tree species and summed up for each treatment. The ground vegetation litter was estimated based on the dominating tree species for each treatment, (Muukkonen and Mäkipää, 2006; Peltoniemi et al. 2004). No measurements of ground vegetation (or tree) litter were available from the two sites.

### 4.2.4 Model initialization - Yasso07

The initialization of the model pools is decisive for the result of the simulation. To better imitate the C input history on the two sites we developed a spin-up (pre-simulation) strategy based on our best assumptions regarding the site history. The spin-up strategy differed slightly between the two sites. For Nordmoen the three steps were: 1) a period of 5000 years using mean climate (1978-2012) and mean regional litter inputs from a forest with site index 17, 2) one spruce rotation (81 years) using annual litter input from the region with site index 17 and annual climate (1978-2012 recycled), and 3) two years of no litter inputs. For Skiptvet the three steps were 1) a period of 5000 years using mean climate (1976-2012) and mean regional litter inputs from a forest with site index 20, 2) one spruce rotation (71 years) using annual litter input from the region with site index 20 and annual climate values (1976-2012 climate recycled), and 3) the 10 first years of the rotation including litter inputs from harvest residues. For Skiptvet this is a simplification in that the site has been used for agricultural purposes previous to the last forest rotation. The regional litter inputs to the pre-simulations were derived from back-casted NFI registrations (Anonymous 2014) in the Akershus County (chap. **Feil! Fant ikke referansekilden.**). The spin-up strategies were developed to reflect the distinct events prior to trial establishment on each site (see site description). On Nordmoen, all harvest residues were removed and on Skiptvet, only stems were removed at harvest. Yasso07 may also be initiated using measured soil C, however, the distribution of the chemical model pools based on C solubility (AWEN) is not known and to avoid instability in the simulation it is recommended to use a spin-up start value. Also, if the start values for the soil C stocks are very different from the theoretical equilibrium, then the resulting change estimation would be unrealistic.

## 4.3 Results

### 4.3.1 Romul

Simulations for Nordmoen were made for each tree species separately, but no differences between the original experimental treatments were made, i.e. means over the original experimental treatments were made per species (Table 3.1). Most of the model parameters were either fixed to observed values, or taken from literature, or set to values considered typical and reasonable. However, an initial value for the organic matter stock in the forest floor and the organic layer (both with separate labile and stable fractions) had to be chosen. As model experiments with constant litter input show, these initial values are important for the first approx. 20 years which is the time scale where Romul equilibrates for constant input. After that, the details of the initialization are "forgotten" by the model due to the history of litter input. However, the first field observations of soil carbon are from the very start of the stands development, thus the initial values are important for model-data comparison at the start. However, the observed values are not separated according to the very same (model-internal) biomass pools. On the other hand, the impact of the detailed distribution of the total soil carbon into the four pools at the beginning seems to be of minor significance. Thus, for simplicity, the four pools were initialized with 25% of the respective measured soil carbon values each. No attempt was made to optimize the fitting parameters using an objective function in an automatic manner.

In Figure 4.3, results for the Nordmoen spruce plots for both Romul and Yasso07 are shown. For Romul, a relatively high (i.e. at the upper end of the recommended range) mineralization rate for the stable humus allows for the reproduction of the repeated measurements. It was adjusted to reproduce the measurements for Norway spruce; the very same values for the two mineralization parameters were also used for pine and birch, i.e. in this context it was assumed that the soils on which the three species grow do not differ in that respect. This leads to a peculiar initial dip in the SOC stocks for the birch stands, much more pronounced than the small decrease for spruce and pine (Figure 4.3). Unfortunately, no measurements constrain this behavior further. The annual cycle is clearly visible, although not very pronounced. The slightly lower value for the last measurement (2012) could not be reproduced; to the contrary, an increasing carbon stock on long time scales is an inevitable feature of the model once litter input is steadily increasing. This is the case for the growing stands both at Nordmoen and Skiptvet. The three time series start with a common value (as determined by the first set of measurements), diverge for the next two decades, and seem to follow a common trajectory more or less towards the end of the simulation. For the last few years, the birch stands seem to show a higher slope than the two coniferous stands; this might be an indication that a common parameterization of the model is perfectly reasonable for pine and spruce, but for birch stands a different one could have been justified as well.

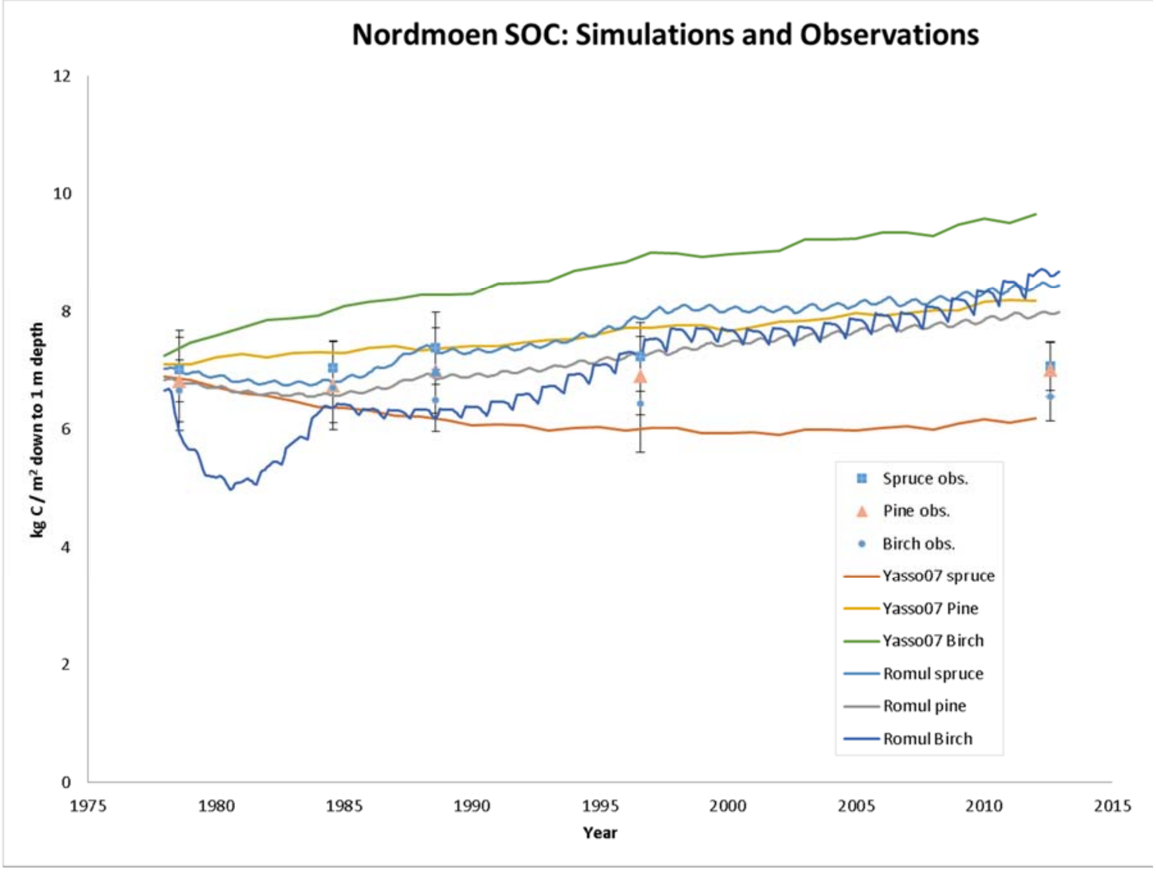


**Figure 4.3** Comparison of Romul and Yasso07 simulations with observations at the Nordmoen site. Observed soil carbon values are shown estimated down to 1 m depth; their standard deviations are estimated from the measurements and the assumed uncertainty of the extrapolation down to 1 m depth using error propagation.

At the Skiptvet site, all five treatments were simulated separately (Figure 4.4). More precisely, the treatments differ only in their respective litter input time series, based on the biomass and species distributions obtained from the inventory. This leads to five simulated time series which are not very far from each other. The first SOC measurements, when the stands were very young, are much higher than at Nordmoen. Given the tiny amounts of litter production for the seedlings, Romul predicts a decomposition of soil carbon outweighing the input by far, and a minimum in soil carbon after approx. 12-15 years. This is not confirmed by the second set of measurements which show almost unchanged values. The last observations (from 2012) are met by the simulation, apart from treatment T4 which is basically a pure spruce stand, where the observations are significantly higher than the simulation.

Since the importance of ground vegetation is unclear for Skiptvet – whereas currently there is hardly any ground vegetation, which certainly was different at earlier stages (but has not been observed), a simulation variant was run where the ground vegetation litter was set to zero for the control treatment ("T0 without ground vegetation" in Figure 4.4). This hardly makes any difference; the soil carbon content at the end of the simulation is just 0.23 kg $m^{-2}$ (or a mere 2.5%) lower than with ground vegetation "switch on".

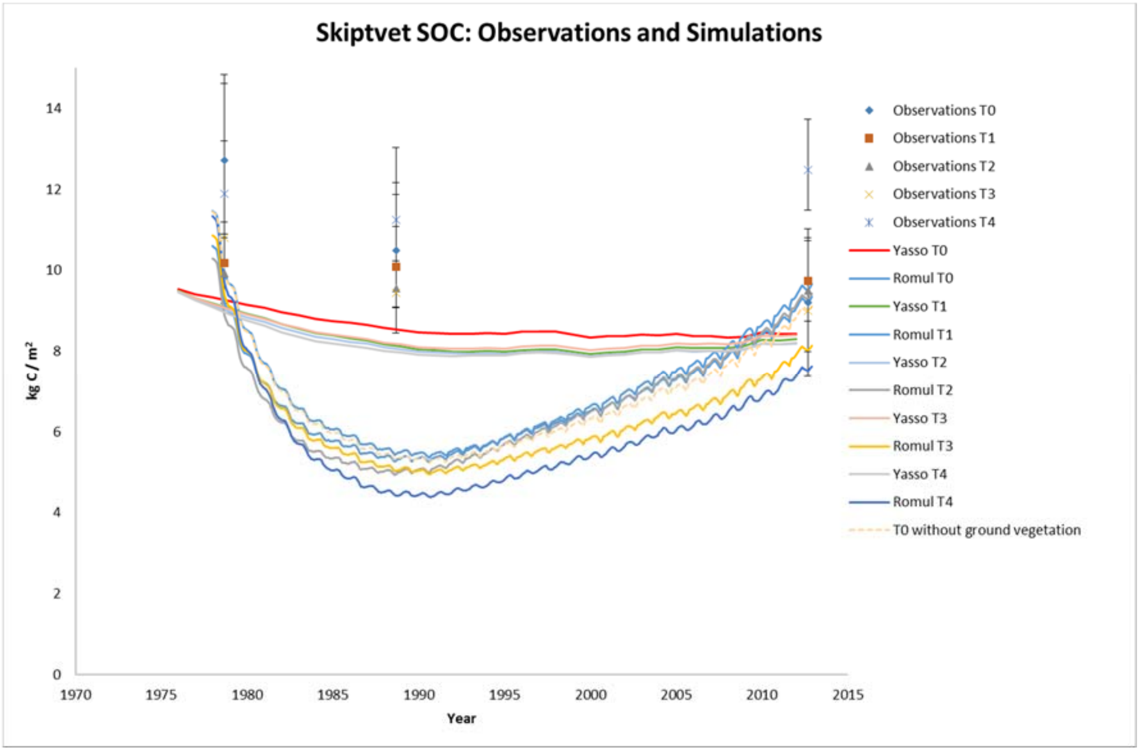


Figure 4.4 Comparison of Romul and Yasso07 simulations with observations at the Skiptvet site.

## 4.3.2 Yasso07

### 4.3.2.1 Model simulations

At Nordmoen, the first observations from 1978 were met by the model very well (Figure 4.3), indicating that the spinup runs represent the “equilibrium situation” at this site very well. From there onwards, the soil C trajectories diverge for the three species: whereas pine and birch show increases, resulting in resp. approx. 1 kg C $m^{-2}$ (pine) and 2 kg C $m^{-2}$ (birch) higher values at the end of the simulation period, the spruce simulations show a decrease of around 1 kg C $m^{-2}$, with a clear tendency to level off and stabilize towards most recent years. As a consequence, pine and in particular birch soil C content is overestimated by the model, whereas that of the spruce stands is underestimated, albeit only slightly. Thus, for pine and birch the accumulations are overestimated and for spruce more or less within the measured range or slightly underestimated (loss).

An investigation into the different pools shows that the majority of the soil C was derived from the non-woody biomass, i.e. biomass from foliage and fine roots, which is in accordance with the large litter inputs coming from foliage and fine roots (Table 4.1).

The Yasso07 simulations of the Skiptvet site (Figure 4.4) were performed separately for each of the five treatments in the same manner as for Romul. The initial values are too low compared to the observations for Skiptvet in 1978 (measured 9.9-12.7 kg C $m^{-2}$; model 9.5) considering that the measurements do not include all carbon to 1 m. Independent of the treatment, the simulations show a decrease in soil C of ca. 1.2 kg C $m^{-2}$; the model estimates for 2012 are 8.2-8.4 kg C $m^{-2}$. This decrease is slightly less than the decrease indicated by measurements, but considering the uncertainties the model dynamics does reflect the lack of dramatic changes quite well. The indications of measured increase in observations for T4 (pure spruce stand) is not reflected in the simulation. While not clearly visible in the figure, simulations for most of the treatments tend to slowly increase from around year 2000.

It seems that the estimates from Yasso07 reflect the amount of living tree biomass present at the sites; soil C estimates over time are ranked birch>pine>spruce which is the same ranking as for living tree biomass. Measured living tree biomass in Skiptvet are relatively similar across experimental treatments which is also the case for the Yasso07 soil simulations. However, the effects indicated by soil C measurements on the effect of tree species seem not be well represented in the simulations.

#### 4.3.2.2 Sensitivity analyses of the AWEN fractionation

We analyzed the sensitivity of the Yasso07 model simulations against the distribution of needle litter into the solubility pools ("AWEN", Figure 4.2), focusing on the spruce treatment on Nordmoen. We applied the AWEN fractionation for two variants representing the highest and lowest input values for the A fraction measured for coniferous species in the temperate and boreal climate zone (Liski et al. (2009). For the first variant, the distribution was 0.5, 0.13, 0.06, 0.31 of A, W, E, and N pools, respectively, and for second variant, the distribution was 0.3, 0.18, 0.09, 0.43. The simulated SOC changes over the trial period showed very little sensitivity to these changes in the distribution of needle foliage vegetation litter (Figure 4.5). An increase in the amount of non-soluble litter by around 30% has almost no impact on the carbon pool. However, using two extreme versions of AWEN fractionation (all litter in the non-soluble (N) fraction only, or all litter in the water-soluble (W) fraction) indicated that there is a dependency (results not shown). In this (unrealistic) case, the soil C content for the only-N variant was around 2 kg C m$^{-2}$ higher than for the only-W variant.

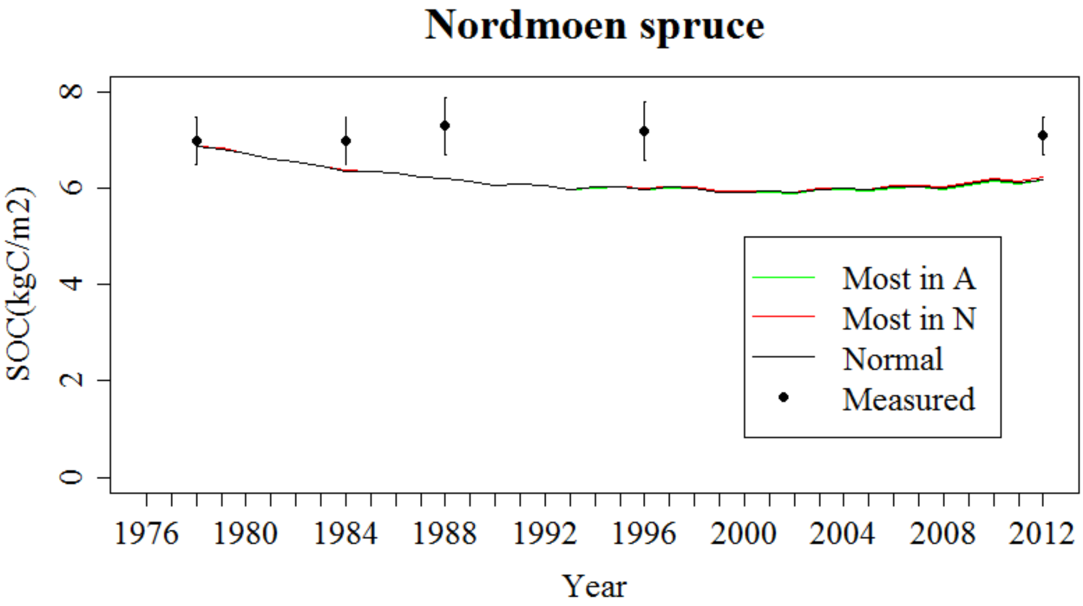


**Figure 4.5.** **Sensitivity of AWEN fractionation of the foliage litter input. Simulation using the standard AWEN distribution (black), placing most foliage litter in the non-soluble component N (red), or placing most foliage litter in the acid-soluble component A (green).**

We also tested the sensitivity of litter turn-over rates used for fine-root input. The simulated C stock responded mostly to the doubling of the input rate of the fine-roots Figure 4.6). Considering that the difference accumulates over the lifetime of the forest stands, the effect might not be negligible. Based on this analysis, it seems that an increase of around 1 kg C $m^{-2}$ for one rotation period (80 years) is reasonable when the fine-root litter input rate is doubled.

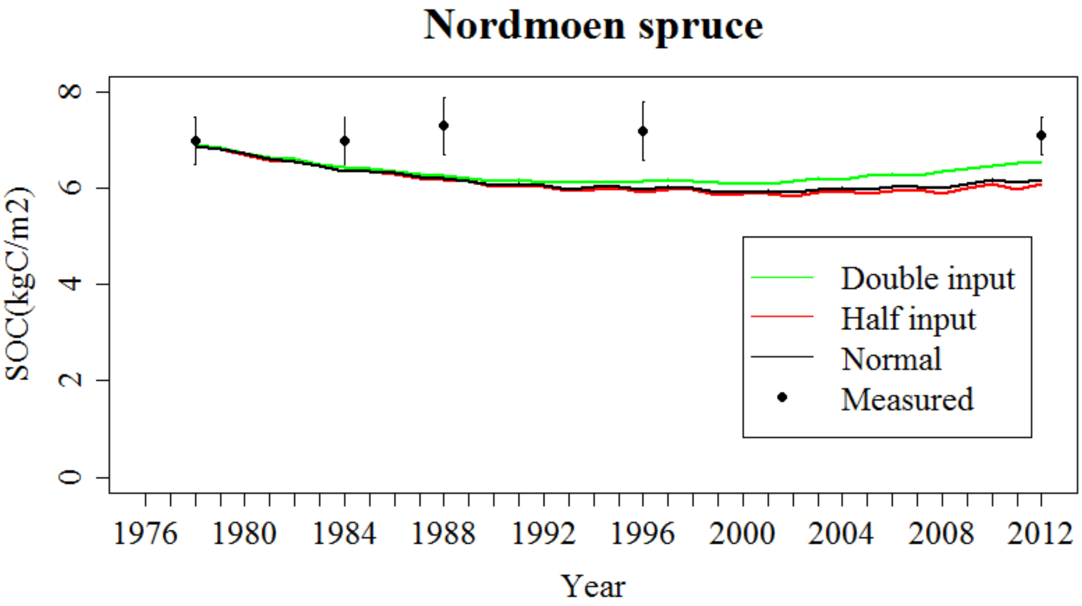


**Figure 4.6** Sensitivity of the fine root litter input rates used for Nordmoen spruce. Simulation using the normal litter turnover rate of 0.6 (black), double the C input (green), and half the C input (red).

# 5 Field and simulation studies in a GHG inventory context

Lise Dalsgaard and Ingeborg Callesen

## 5.1 Introduction

The methodology for estimating forest soil C changes for the GHG inventory has up until 2012 been based on the Yasso model using one aggregated input time series for model calculations representing all forest areas in the country (Liski et al. 2005, DeWit et al. 2006). Beginning from the 2013 inventory, the Yasso07 model was applied with parallel runs and input time series for each NFI (National Forest Inventory, cf. chap. 2) plot (Tuomi et al. 2009, Tuomi et al. 2011a, 2011b, Anonymous 2013). In addition, estimation of litter production and input of weather data was changed as i) stand level biomass models were replaced by individual tree biomass models and ii) fixed model parameter values were replaced by Yasso07 model parameters modified according to plot climate estimated specifically for the NFI plots by the Norwegian Meteorological Institute. Thus, significant changes in the methodology have taken place after 2012 and development of methods has continued also after the 2013 GHG inventory. A general description and evaluation of the methods used in the GHG inventory was not originally included in the site-specific project described in this report (see Introduction). However, the methodological changes mentioned above in the GHG inventory warrants a Quality Assurance activity and the reference group contracted for the site-specific project (see Introduction) agreed to include this as a part of their assignment. The current individual plot approach enables the comparison of the NFI simulations and the site-specific simulations at Nordmoen and Skiptvet as presented in the previous chapter.

GHG/country scale issues as well as site specific issues were presented and discussed during both reference group project seminars (Appendix 4, Appendix 5). The forest soil inventory data base from the ICP level I sites (sampling during 1988-1992; Esser and Nyborg 1992, Esser 1994) were discussed. Since these data have a potential to be used for soil C model development, an evaluation of them was carried out by Ingeborg Callesen (University of Copenhagen); see Callesen and Dalsgaard (2013) and Chapter 5.3.

Chapter 5 gives i) an overview of the methodology used for forest soil C change estimation in the GHG inventory, ii) an evaluation of the soil C reference database, iii) soil inventory estimates and model output for two selected counties (Akershus and Østfold), together with a comparison to results from the specific site studies detailed in chap. 4, (iv) preliminary comparison of model C stocks with soil inventory data, and simulated changes at the country scale.

## 5.2 Yasso07 estimation methodology for the GHG inventory

Input data is estimated from National Forest Inventory (NFI) registrations (cf. chapter 2). In total, there are approx. 12000 individual forest plots on mineral soil in the NFI database. For each registration found on an NFI forest plot on mineral soil, a soil C estimate using Yasso07 is produced. In the NFI, mineral soil plots are defined by the depth of the organic layer (< 0.4 m). Individual tree biomass models are used (Marklund 1988, Petersson and Ståhl 2006). Ground vegetation biomass is included as a function of stand age (Muukkonen et al. 2006, Muukkonen and Mäkipää 2006). For each plant/tree component (foliage, branches, roots) a species specific turnover rate (references in: DeWit et al. 2006, Peltoniemi et al. 2004) determines the litter production rate (cf. chapter 4). Downscaled weather data (Engen-Skaugen et al., 2008) are used for each of the ca. 11300 relevant plots. Plots are permanent and were established 1986-1993 and a regular rotation of 5 year cycles across all plots was implemented from 1994. Input from natural mortality and harvest is from tree registrations (commercial thinning and final harvest) or from look-up tables established for this purpose based on NFI data (Antón-Fernández and Astrup 2012). The soil C stock used to start the model off (i.e. prior to 1990) has effects on the estimation of changes in the following years (a "memory effect", e.g. DeWit et al. 2006). This effect is inherent in the Yasso07 model structure (as well as in many other models). A theoretically well-defined start value is the equilibrium C stock found after simulation with constant input until a constant stock is reached. This approach also ensures that the distribution among the five chemical soil pools (Figure 4.2) is consistent at the beginning of the simulation. However, while this ensures well defined conditions, it is unlikely that the soil was in an equilibrium prior to 1990. Thus, to reflect a dynamic state and to maintain the consistency among chemical pools, a realistic forest time series was constructed from NFI registrations. Early NFI registrations on prior land use and forest management activities were used to establish a pre-simulation time series 1960-1990 (back-cast). The equilibrium spin-up is made at ca. 1960. The back-cast time series has the same format as the NFI registrations i.e. a 5 year systematic cycle. A similar methodology with a spin-up time series (starting 1926) was used in Ortiz et al. (2013). Back-cast was introduced in the 2014 GHG inventory.

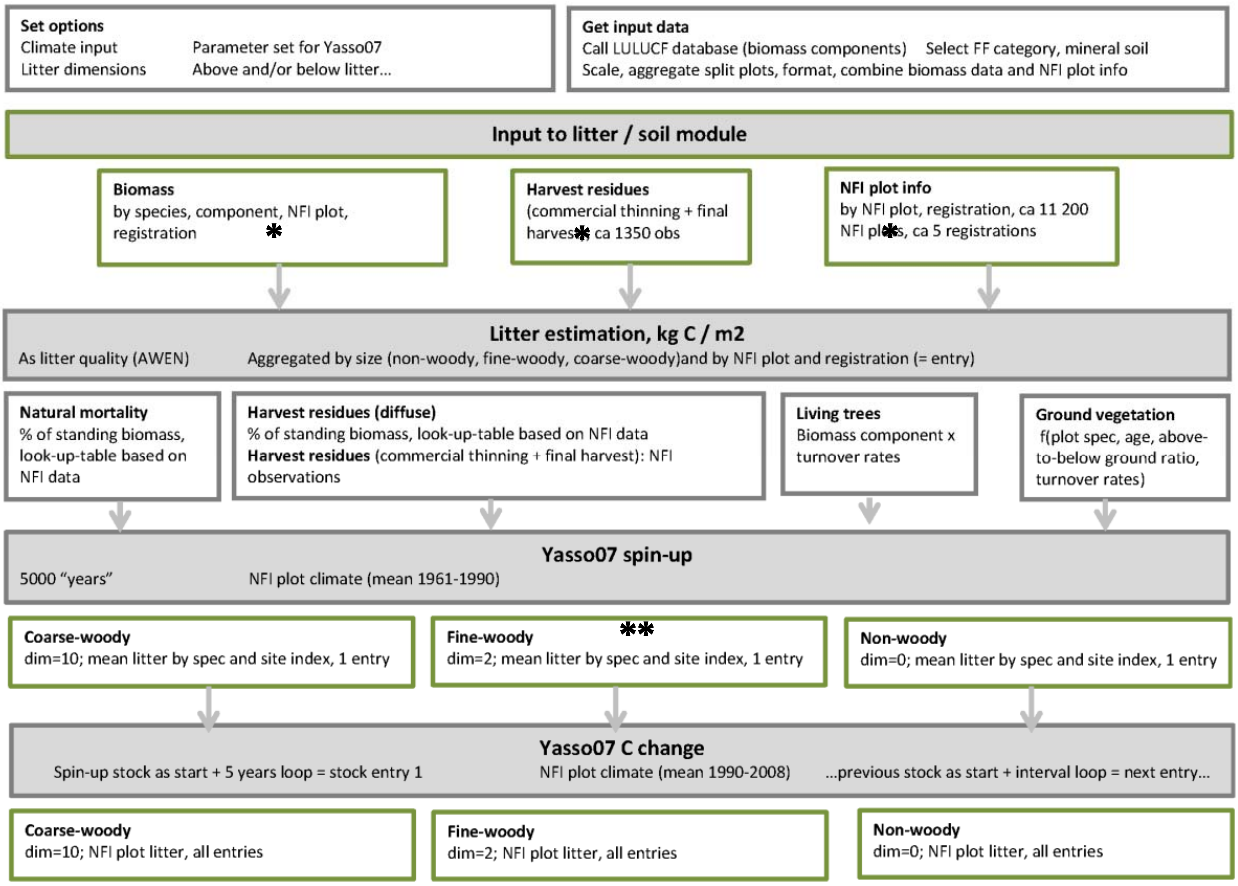


**Figure 5.1** The principle behind the forest soil C change estimate for the GHG inventory. The spin-up time series (extended time series 1960-1990, back-cast) was applied in the GHG inventory for 2014 (*) and Yasso07 C change was calculated for the back-cast time series as well as for the NFI registrations (**).

Soil C changes are calculated for each NFI plot from the estimated soil C stocks (Figure 5.1). The output from the soil C estimation procedure is scaled to the whole country in the same way as for estimates for C changes in living biomass in forest which means that the final estimates reported take into consideration the area represented by each NFI plot; see details in the National Inventory Reports.

A more detailed description is found in the National Inventory Report 2013 and 2014 (Anonymous 2013, 2014)[2].

## 5.3 Evaluation of soil inventory data for C stock estimation

Soil C stocks have been calculated based on soil samples taken for 1024 profiles across the country during the forest soil inventory 1988-1992 (OPS level I, Esser and Nyborg 1992, Esser 1994, cf. chapter 2). This database may be used to aid model development and validation. Because estimates from this database are high compared to e.g. Swedish estimates on soil C stocks (see below) and because the soil inventory was carried out for other purposes than soil C estimation, the applicability of these data was evaluated during the project (Callesen and Dalsgaard 2013). Generally, the data were evaluated to be of a high quality, but since the calculation of total carbon for a soil profile relies on field registrations of horizon thickness, gravel and stone content, soil sampling, and on laboratory measurements of carbon concentration, a consideration of uncertainties on the profile level should be made. In the report it was found that the Norwegian soil inventory database is a standard multi-purpose pedological database with field descriptions and chemical analyses required for soil classification according to different classification systems. Some expert judgment and gap filling is needed in order to calculate SOC (soil organic carbon). The calculations carried out by Line Tau Strand, NMBU (Strand et al. 2016), are based on sound judgment and gap filling procedures. Due to systematic sampling in a grid across Norway, the soil profiles reflect the national variation in climate, geomorphology (profile depth) and soil forming processes.

The uncertainty involved in SOC stock estimates in each profile may be as high as 20 - 30% depending on the assessment of stone content. This corresponds to uncertainty estimates from DeWit and Kvindesland (1999) of 17% and 22% for the organic layer and the mineral soil layer, respectively. The Norwegian soil inventory data have a high degree of completeness on all important parameters for SOC determination, and the missing observations are few and not systematic. The number of profiles ensures that estimates based on larger groups of profiles (upon stratification) are less affected by random error.

The quality check involved a comparison between the SOC estimates in Sweden (Jämtland, Dalarne and Värmland, SFSI Swedish Forest Soil Inventory) and Norway (Østfold, Akershus and Hedmark). Minimum SOC values were comparable, but the share of high SOC estimates and the magnitude of extreme values are higher in the Norwegian dataset. Soil profiles are generally deep, and the share of shallow profiles is low in both datasets. Norwegian SOC estimates were higher for comparable soil classes and the main reasons seemed to be:

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[2] The methodology is continuously developed; for the current most up to date application please refer to the newest NIR available

- Norwegian profiles covered all drainage classes including strongly groundwater affected soils, whereas Swedish sites are not groundwater affected.
- Norwegian SOC estimates refer to the profile depth (up to 137 cm), the Swedish estimates refer to forest floor + 0-50 cm soil depth.
- Norwegian profiles were sampled in genetic horizons including the C horizon. Swedish SFSI estimates involved estimation (based on smaller/external dataset) of topsoil carbon concentrations. A-material is included in O horizons, which may cause negative bias on SOC estimates.
- In strongly layered soils carbon is distributed by eluviation and illuviation processes such as in humus rich podzols. There are no objective arguments for interpolation of carbon concentrations in such cases. The specific design of the SFSI sampling protocol should compensate for this (sampling the upper 5 cm of any Bh or Bhs horizon), but it is unclear how it is used in SOC calculations. (The SFSI sampling strategy can be difficult to comprehend, even though it is the result of experience-based adaptation of the monitoring program over many years).
- The two sets of SOC estimates from Norway and Sweden are not directly comparable due to differences in sampling and query strategy. Given the possible negative biases in the Swedish data and the completeness of the Norwegian database, there is no reason to question the robustness of the Norwegian SOC estimates. SOC stocks are higher in parts of Norway which coincides with a warm and wet coastal climate.

Analyses of Norwegian data showed that horizon thickness combined with median carbon concentration at county level (fixed bulk densities) yielded high SOC levels in forest floors and the mineral soil horizons A and B primarily in the regions in Western Norway (a combined effect of horizons thickness and carbon concentrations). In B horizons, high SOC levels are seen in Southern and Western Norway. Using an empirical model relating soil C stocks to climate variables (Callesen et al. 2003) the relationship for the observed Norwegian soil inventory data and model predictions was significant (R2=0.69). However, this was only observed when the Norwegian soil data were restricted to drainage classes of excessively to moderately well drained soils, for which the model was developed. The correspondence between the empirical model (developed on a soil database covering Scandinavia) and the independent Norwegian soil data supports the conclusion that the Norwegian inventory soil data is of a good quality. The model underestimated the Norwegian inventory data by 12% on average (slope 0.88). However, the prediction error was large (8.3 kg C $m^{-2}$). The model was in this case extrapolated outside its climatic range, which did not seem to cause a strong bias for the well-drained soils. It may be concluded that forest soils in Norway have a strong representation of soils with hydromorphic properties which have bearings on SOC stocks.

The Norwegian forest soil inventory database is a soil profile database that demonstrates the nationwide variability in soil profile formation and the SOC estimates generated from it reflects the diversity in soil formation and a combination of parent material, vegetation and climate that yields high SOC stocks in comparison with other boreal forest areas.

## 5.4 Forest soil C stocks and C change in Akershus and Østfold

In the soil inventory 1988-1992, 43 plots were measured in Akershus and Østfold county (Table 5.1) and 3 of these were classified to "nonsoils". The soil inventory data (Esser and Nyborg 1992, Esser 1994, DeWit and Kvindesland 1999, Strand et al. 2016) range from 3.3 to 27.1 kg C $m^{-2}$; the 3 "nonsoils" plots ranged from 0.03 to 2.4 kg C $m^{-2}$). These estimates are adjusted to account for the coverage of bare surface rock on the plot and they cover a wide range in site index, stand age, soil profile depth and drainage characteristics as well as different tree species.

Selecting a subset from the 43 plots of those with a site index (>14) and drainage characteristics (moderately to well drained = class 3-4) similar to the Nordmoen and Skiptvet sites, leaves 8 soil inventory data points for Akershus and Østfold county. Five are spruce, two pine and one is birch. The mean estimated soil C stock is 8.4 kg C $m^{-2}$ (model) and 12.6 kg C $m^{-2}$ (measured). Uncertainties around each of these estimates have not been considered specifically for these profiles but an uncertainty of 20-30 % is realistic for the measured stock (chapter 5.3).

However, a larger discrepancy is indicated when selecting the opposite end of the site index range (<17) for moderately to well drained sites where SOC estimates (n=24) are 4.7 kg C $m^{-2}$ (model) and 13.4 kg C $m^{-2}$ (measured). The level of discrepancy among model estimates and measurement based SOC stocks as well as their causes may be explained by a large number of variables (including but not limited to site index). Eg. the annual precipitation in Akershus and Østfold county is in the intermediate range where Yasso07 may not perform well (Figure 5.3). The spatial variability in soil C can be expected to be substantial in forest (eg. Muukkonen et al. 2009). Further, the estimates of coarse fragments and bulk density used for calculating C stocks based on the soil survey were not ideal. All in all the sampling methodology used in the soil survey was not sufficient to quantify soil C for comparison on an individual plot level thus comparisons of measured and modeled estimates should ideally be performed at the national level or on relatively large strata. Final results of such analyses are not presented here.

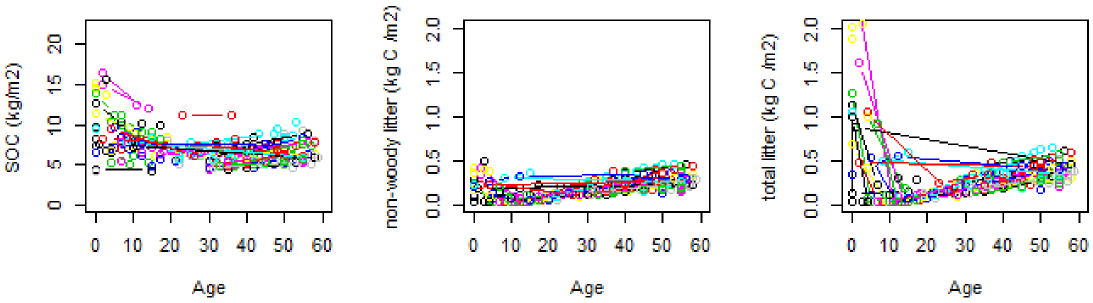
**Table 5.1** Soil inventory registrations for Akershus and Østfold fylke and some stand and plot variables. Drainage classes are aggregates of more detailed classes from the field registrations; 1 is poorly drained, 4 is well drained, 2,3 are intermediately drained. Site index express stand height at age of 40 years. T: mean annual temperature, P: mean annual precipitation. Tree species are 1: spruce, 2: pine, 3: deciduous. Bare surface rock is a class variable; the higher the number the more of the plot surface was covered with rock. Classification is according to the Canadian soil classification system.

| Site index | T (°C) | P (mm) | Measured C-stock, mean (kg $m^{-2}$) | Predicted C-stock (kg $m^{-2}$) | Tree species | Stand age (years) | Soil profile depth (cm) | Drainage | bare surface rock | (1) Soil classification |
|---|---|---|---|---|---|---|---|---|---|---|
| **4** | 5.8 | 800 | 0 | 2.7 | 2 | 83 | 6 | 4 | 8 | N-OIL (NONS) |
| **4** | 5 | 898 | 9.7 | 2.8 | 2 | 86 | 26 | 4 | 3 | P-HFP(O) |
| **4** | 5.7 | 846 | 2.4 | 2.7 | 2 | 125 | 9 | 4 | 5 | N-OIL (NONS) |
| **4** | 5 | 858 | 0.1 | 3 | 2 | 147 | 5 | 4 | 7 | N-OIL (NONS) |
| **6** | 4.5 | 820 | 16.1 | 5 | 2 | 125 | 39 | 3 | 5 | P-FHP(O) |
| **8** | 4.7 | 903 | 18.5 | 5.6 | 2 | 100 | 60 | 4 | 1 | P-HFP(O) |
| **8** | 3.4 | 773 | 11.8 | 4.1 | 2 | 65 | 55 | 3 | 6 | P-HFP(O) |
| **8** | 3.6 | 760 | 17.8 | 6 | 2 | 90 | 26 | 3 | NA | P-FHP(O) |
| **8** | 1.9 | 892 | 5.5 | 6.2 | 1 | 105 | 23 | 1 | NA | R-R(O) |
| **8** | 5.7 | 877 | 17.1 | 4 | 1 | 80 | 40 | 4 | 5 | P-HFP(O) |
| **8** | 6.5 | 740 | 7.2 | 3.5 | 2 | 85 | 27 | 4 | 6 | B-DYB(O) |
| **8** | 5.2 | 889 | 4.7 | 4.7 | 2 | 130 | 28 | 4 | 7 | P-FHP(O) |
| **8** | 4.6 | 817 | 13.1 | 4.8 | 2 | 170 | 65 | 4 | 6 | P-HFP(O) |
| **11** | 3.8 | 927 | 22.6 | 6.7 | 1 | 137 | 42 | 3 | NA | P-FHP(O) |
| **11** | 3.6 | 843 | 20.7 | 4.6 | 1 | 115 | 65 | 4 | NA | P-HFP(O) |
| **11** | 3.5 | 698 | 9.9 | 6.1 | 2 | 110 | 40 | 3 | 5 | B-DYB(E) |
| **11** | 5.3 | 875 | 24.4 | 4.7 | 2 | 110 | 60 | 3 | 2 | P-FHP(O) |
| **14** | 4.4 | 774 | 13.5 | 6.1 | 2 | 100 | 65 | 3 | 3 | B-DYB(E) |
| **14** | 4.5 | 824 | 8.7 | 4.5 | 1 | 52 | 52 | 4 | 3 | B-DYB(E) |
| **14** | 3.2 | 746 | 22.8 | 5.6 | 1 | 70 | 90 | 3 | 5 | P-HFP(GL) |
| **14** | 2.7 | 939 | 9.5 | 6.5 | 1 | 65 | 49 | 3 | NA | P-HFP(O) |
| **14** | 6 | 795 | 15.4 | 3.3 | 2 | 50 | 40 | 4 | 5 | P-FHP(O) |
| **14** | 5.2 | 881 | 19.4 | 5.9 | 1 | 110 | 50 | 1 | 3 | B-DYB(E) |
| **14** | 5.3 | 881 | 23.2 | 6.2 | 1 | 95 | 43 | 2 | 2 | P-HFP(GL) |
| **14** | 5.6 | 851 | 25.6 | 7 | 2 | 80 | 50 | 3 | 1 | P-HFP(O) |
| **14** | 5.7 | 790 | 14.7 | 5.3 | 1 | 75 | 90 | 2 | 6 | P-HFP(GL) |
| **14** | 5.5 | 821 | 10.2 | 4.1 | 1 | 95 | 28 | 2 | 4 | R-HR(O) |
| **14** | 5.3 | 881 | 13.9 | 4.4 | 1 | 55 | 50 | 3 | 3 | B-DYB(E) |
| **14** | 4.5 | 771 | 16.2 | 4.3 | 2 | 33 | 67 | 4 | 3 | P-HFP(O) |
| **17** | 3.4 | 738 | 10.9 | 3.9 | 3 | 30 | 70 | 3 | NA | P-HFP(SM) |
| **17** | 4 | 741 | 15.7 | 7 | 1 | 50 | 55 | 2 | NA | P-HFP (GLSM) |
| **17** | 3.5 | 878 | 17.1 | 5.2 | 1 | 32 | 43 | 2 | NA | P-HFP(O) |
| **17** | 3 | 869 | 3.3 | 8 | 1 | 55 | 65 | 4 | 7 | P-HFP(O) |
| **17** | 5.7 | 865 | 18.2 | 5 | 1 | 45 | 55 | 2 | 2 | G-G(O) |
| **17** | 6 | 784 | 6.2 | 4.8 | 1 | 32 | 53 | 2 | 2 | B-SB(GL) |
| **17** | 5.2 | 815 | 19.7 | 8 | 1 | 100 | 50 | 2 | 1 | P-FHP(O) |
| **17** | 4.8 | 785 | 15.7 | 9.6 | 2 | 0 | 100 | 4 | 1 | B-DYB(E) |
| **17** | 4.6 | 728 | 10.6 | 6.7 | 2 | 28 | 73 | 4 | 1 | B-DYB(E) |
| **20** | 3.6 | 775 | 10.1 | 10.5 | 1 | 70 | 52 | 3 | NA | P-HFP(SM) |
| **20** | 4.9 | 831 | 14.6 | 13 | 1 | 2 | 60 | 4 | 1 | P-HFP(O) |
| **20** | 5.6 | 839 | 27.1 | 7.4 | 1 | 40 | 88 | 2 | 3 | G-HG(R) |
| **20** | 5.3 | 857 | 21 | 7.8 | 1 | 60 | 70 | 3 | 1 | P-HFP(GL) |
| **23** | 5.1 | 871 | 14.8 | 7.8 | 1 | 32 | 80 | 4 | 1 | P-HFP(SM) |

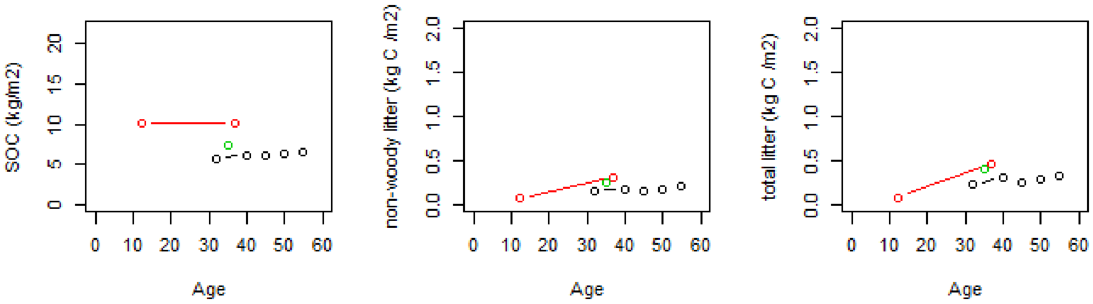
[1] Soil order and great group. Subgroup is indicated in parenthesis (abbreviated). Soil order abbreviations are: P: podzol, B: brunisol, G: gleysol, R: regosol.

To put the field site results (Chapter 3 and 4) in the context of the GHG inventory estimates, the time series of litter input and estimated soil C from the NFI for Akershus and Østfold county with similar site index were extracted (Figure 5.2). Most observations are found for G17 (G: spruce; site index 17 i.e. height (m) at age 40 years) and soil C stock estimates are 5-8 kg C $m^{-2}$ at age ca. 30 years. Annual non-woody litter input is ca. 0.25 kg C $m^{-2}$ at age 30; similar or somewhat lower than the estimated annual non-woody litter input to the models at the Nordmoen spruce site which was 0.28 kg C $m^{-2}$ taken as a mean over the whole simulation period (Table 4.1). Both site specific simulations (Nordmoen and Skiptvet) estimate stocks within the range found in the NFI time series. Estimated SOC stocks seem similar across species only with deciduous forest possibly in the lower range. The soil C stocks measured in Nordmoen and Skiptvet (data in Chapter 3) are also matched by the soil C estimates in the NFI time series (Figure 5.2). The NFI time series show an increase in soil C stock beginning at age ca. 30.

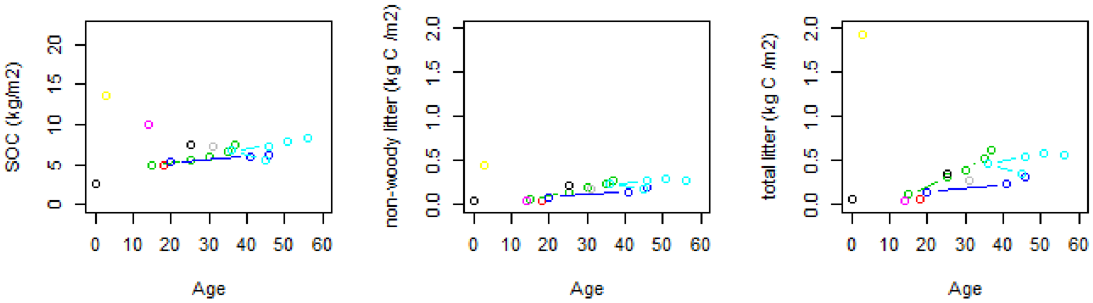
G17: Spruce height at age 40 = 17 m



F20: Pine height at age 40 = 20 m



L23: Deciduous height at age 40 = 23 m



G23: Spruce height at age 40 = 23 m

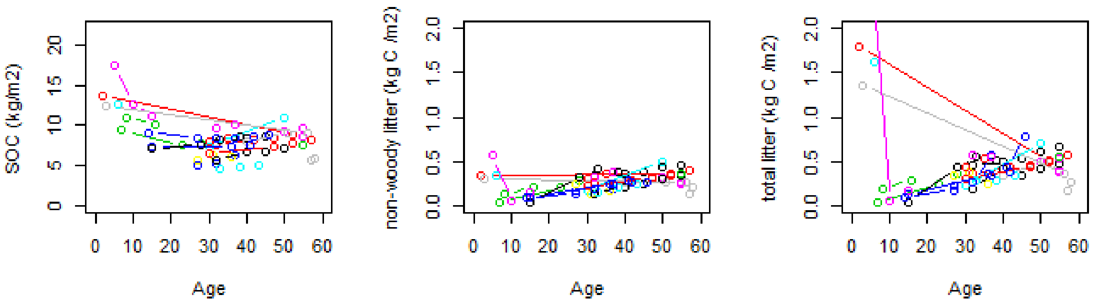


**Figure 5.2** NFI plot time-series of estimated soil C and input of non-woody litter and total litter to Yasso07. Plot or stand age < 60 years are shown. Site index (stand height at age 40 years) by species are shown. NFI plots from Akershus and Østfold county are included.

## 5.5 Comparison of measured and simulated C stocks on a country level - preliminary results

The tables below (Table 5.2 through Table 5.5) present the C-stock estimates from measurements (OPS level 1, cf. chapter 5.3) and model distributed to some coarse groups. The data used on measured soil C stocks (Strand et al. 2016) are based on the bulk density function of Baritz et al. (2010) which is somewhat different from earlier estimates from these data by DeWit and Kvindesland (1999). Only soil profiles classified as mineral soils (Canadian soil classification, Grønlund and Solbakken 1987) are included. The profiles which could not be uniquely identified in the current NFI grid were not included. Profile estimates based on measurements are adjusted to the plot level using field registrations on the amount of bare rock surface on the plot. Shown below are a number of scatterplots of measured and modeled soil C for individual plots. It is important to note that in the current tables and scatterplots a number of variables have not been considered; this includes topography, detailed information on tree species distribution and climate, ground vegetation and drainage, soil chemical or physical variables and soil classification. Analyses including all relevant parameters will be carried out at a later stage.

Measured C-stocks were considerably higher than predicted C-stocks regardless of species (Table 5.2), site index (Table 5.3), region/county (Table 5.4) and drainage class (Table 5.5). However, predicted C-stock was higher for spruce and pine than for deciduous forest plots, which is in accordance with measured C-stocks. Predicted C-stocks were highest for high site index which was also found in the measured C-stocks.

**Table 5.2** Soil C stocks from the soil inventory 1988-1992 and from model predictions on NFI plots distributed to dominant tree species.

| Species | Predicted C-stock (kg m$^{-2}$) | n | Measured C-stock, mean (95% conf. limits) | Standard deviation, measured C stock | Measured C-stock, median |
|---|---|---|---|---|---|
| **spruce** | 5.9 | 280 | 16.8 (15.8-17.9) | 8.8 | 15.0 |
| **pine** | 4.9 | 239 | 14.2 (13.2-15.2) | 8.0 | 12.9 |
| **deciduous** | 3.1 | 136 | 13.8 (12.7-14.9) | 6.6 | 12.8 |

**Table 5.3** Soil C stocks from the soil inventory 1988-1992 and from model predictions on NFI plots distributed to classes of site index (stand height at age 40). Some groups contained very few observations.

| Site index | Predicted C-stock (kg m$^{-2}$) | n | Measured C-stock, mean (95% conf. limits) | Standard deviation, measured C stock | Measured C-stock, median |
|---|---|---|---|---|---|
| **4** | 2.3 | 69 | 13.6 (11.6-15.7) | 8.6 | 13.7 |
| **6** | 3.9 | 69 | 14.3(12.3-16.3) | 8.5 | 11.8 |
| **8** | 4.5 | 145 | 15.2(14-16.4) | 7.1 | 14.2 |
| **11** | 5.3 | 141 | 15.1(13.6-16.6) | 8.9 | 13.7 |
| **14** | 5.7 | 126 | 14.5(13.4-15.6) | 6.3 | 13.5 |
| **17** | 6.8 | 67 | 17.9(15.3-20.4) | 10.6 | 15.2 |
| **20** | 6.8 | 25 | 19.0(15.6-22.5) | 8.8 | 15.6 |
| **23** | 5.9 | 12 | 16.5(13.0-20.0) | 6.2 | 15.9 |
| **26** | 3.3 | 1 | 18.5 | | 18.5 |

**Table 5.4** Soil C stocks from the soil inventory 1988-1992 and from model predictions on NFI plots split by region (fylke). Some groups contained very few observations.

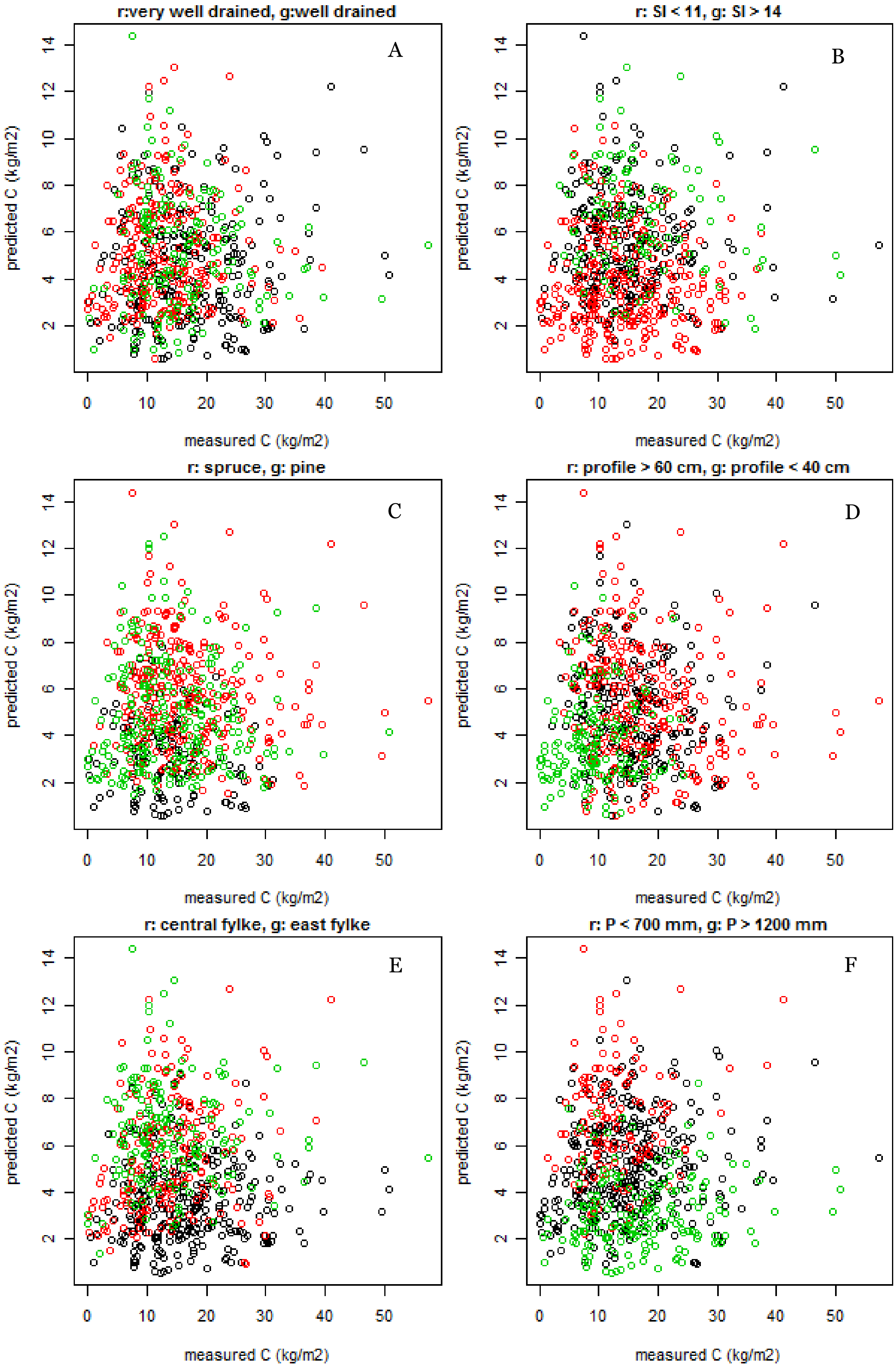
| Fylke | Predicted C-stock (kg m$^{-2}$) | n | Measured C-stock, mean (95% conf. limits) | Standard deviation, measured C stock | Measured C-stock, median |
|---|---|---|---|---|---|
| Østfold | 5.4 | 26 | 14.1 (11.2-17) | 7.5 | 15.1 |
| Akershus | 6.1 | 17 | 13.7(11-16.4) | 5.7 | 13.5 |
| Oslo | 6.2 | 1 | 37.4 | | |
| Hedmark | 6.8 | 127 | 14.2(12.7-15.7) | 8.8 | 12.1 |
| Oppland | 6.8 | 64 | 13.6(12-15.3) | 6.7 | 13.0 |
| Buskerud | 5.9 | 53 | 15.3(13.3-17.3) | 7.4 | 13.7 |
| Vestfold | 6.6 | 3 | 17.5(15.1-20) | 2.2 | 18.7 |
| Telemark | 4.3 | 68 | 12.9(11-14.9) | 8.1 | 12.3 |
| Aust-Agder | 3.7 | 33 | 14.9(12.4-17.3) | 7.2 | 14.4 |
| Vest-Agder | 2.9 | 25 | 20(15.7-24.4) | 11.1 | 16.8 |
| Rogaland | 4.8 | 5 | 22(15.4-28.5) | 7.5 | 25.3 |
| Hordaland | 3.2 | 18 | 18.1(14.6-21.6) | 7.6 | 16.1 |
| Sogn og Fjordane | 3.5 | 19 | 15.6(12.4-18.8) | 7.1 | 15.9 |
| Møre og Romsdal | 2.8 | 19 | 18.1(13.6-22.6) | 10 | 17.8 |
| Sør-Trøndelag | 4.2 | 46 | 19.1(16.2-21.9) | 9.8 | 17.3 |
| Nord-Trøndelag | 4.2 | 53 | 16.1(14.2-18) | 7.1 | 15.1 |
| Nordland | 3 | 57 | 14.5(12.6-16.5) | 7.6 | 13.3 |
| Troms | 4 | 21 | 13.9(11.8-16) | 4.9 | 14.4 |

**Table 5.5** Soil C stocks from the soil inventory 1988-1992 and from model predictions on NFI plots distributed to aggregated classes of drainage.

| Aggregated drainage class | Predicted C-stock (kg m$^{-2}$) | n | Measured C-stock, mean (95% conf. limits) | Standard deviation, measured C stock | Measured C-stock, median |
|---|---|---|---|---|---|
| 1 (poor) | 4.8 | 63 | 19.9(17.6-22.2) | 9.2 | 19.4 |
| 2 | 5.2 | 126 | 17.2(15.7-18.7) | 8.6 | 15.9 |
| 3 | 5.2 | 156 | 15.9(14.6-17.3) | 8.5 | 14.0 |
| 4 (well) | 5.2 | 247 | 12.9(12.1-13.8) | 6.8 | 12.2 |

Highest predicted C-stocks were found in the eastern and central parts of Norway which is generally where the measured C-stocks seem to be lowest (Table 5.4). Predicted C-stocks did not depend on drainage class while measured C-stocks indicate higher stocks on sites with poor drainage (Table 5.5).

Scatterplots indicate that areas and regions with a high annual precipitation seem to be poorly represented by the C-stock estimates from the model (Figure 5.3 E,F). These are generally plots also with a relatively high mean annual temperature (Figure 5.3  G) and in these cases the model underestimates the measured C-stock. Deciduous forest plots (Figure 5.3 C) with low site index (Figure 5.3 B) and many of them in coastal or northern regions (Figure 5.3 E) stand out as a group where model estimates are particularly poor. The aggregated drainage classes alone seem to have little explanatory power which is also the case for soil profile depth (Figure 5.3 A,D); however, they may contain information when used in combination with other variables. Many variables may be confounded eg. site index and soil depth or site index and drainage.


r:very well drained, g:well drained
A
r: SI < 11, g: SI > 14
B
r: spruce, g: pine
C
r: profile > 60 cm, g: profile < 40 cm
D
r: central fylke, g: east fylke
E
r: P < 700 mm, g: P > 1200 mm
F
predicted C (kg/m2)
measured C (kg/m2)
2
4
6
8
10
12
14
0
10
20
30
40
50

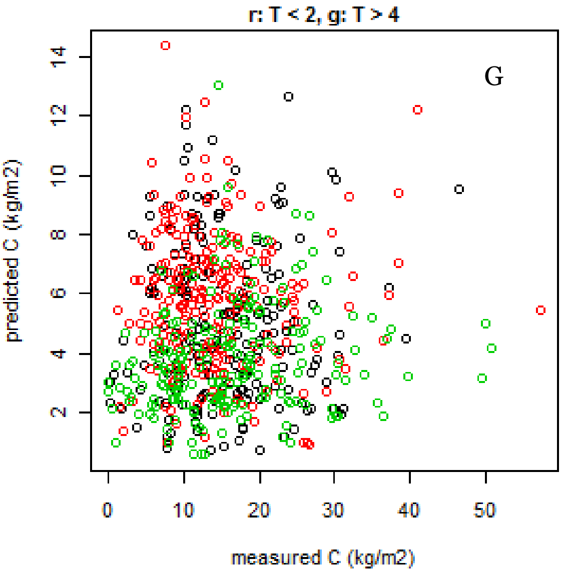


**Figure 5.3** Scatter plots of predicted and measured C-stocks in forest in Norway. Note different scales on the two axes. r=red, g=green, black symbols represent the remaining observations. SI: site index (height in m at age 40 years), T: mean annual air temperature (°C), P: mean annual precipitation.

The median for C stocks in the Norwegian forest soil inventory (DeWit and Kvindesland 1999) was reported to 13.2 kg C $m^{-2}$ for productive forest and 12.5 kg C $m^{-2}$ for unproductive forest. The mean for measured C stock in upland forests of Southern Finland was approximately 6.7 kg C $m^{-2}$ (Rantakari et al. 2012). In Sweden a national mean for spruce dominated stands was 9.2 kg C $m^{-2}$ and for pine dominated stands it was 5.7 kg C $m^{-2}$ (Stendahl et al. 2010). For all forest in Sweden a mean of 7.3 +/- 1.0 kg C $m^{-2}$ based on soil inventory data was reported by Ortiz et al. (2013) who reported similar values based on two different models; 6.9 +/- 0.9 kg C $m^{-2}$ (Yasso07) and 6.7 +/- ca. 1.0 kg C $m^{-2}$ (Q-model). Olsson et al. (2009) reported a mean of 8.2 kg C $m^{-2}$ for podzols in Sweden where soil hydrological class had a strong influence on the stocks (range 6.7and 9.7 kg C $m^{-2}$ for dry and slightly moist sites respectively). As discussed in chap. 5.3, forest soil C stocks based on field inventory data are affected by the sampling strategy and -depth, the accuracy of coarse fragment registrations and the soil types included. The field methods and soil type delineation may differ among country specific inventories which complicates any comparison. The estimated C stock of Norwegian forest soils are high compared to those for Sweden and Finland. Some of these differences may be explained by differences in inventory methods. However, gradients in precipitation and temperature were shown to explain 68% of the variability in C stock in coarse textured Nordic forest soils (Callesen et al. 2003), implying that some of the differences may be climate related. The database in Callesen et al. (2003) contained 234 well drained forest soil profiles and C stocks were 2.6-30.4 kg C $m^{-2}$. It indicated an increase in SOC of 3-5 kg C $m^{-2}$ in the nemoral zone going from an annual precipitation of 600 to 800 mm. In the boreal zone the indicated increase in SOC with increase in precipitation (600 to 1200 mm) was approx. 8 kg C $m^{-2}$. Smithwick et al. (2002) found large differences among old-growth forest soil C stocks (only mineral horizons) in coastal (36.5 and 19.5 kg C $m^{-2}$), mountain (12.2 and 11.7 kg C $m^{-2}$) and dry inland (3.7 kg C $m^{-2}$) areas of Washington and Oregon. High soil C stocks seem to be characteristic of highly productive forests in regions with high precipitation. As mentioned above, many factors may be involved in the explanation of why the high forest soil C stocks found in Norwegian forests are not reproduced by the model. Yasso07 has been found to underestimate soil C stocks in other studies presumably due to insufficient calibration data and/or model structure in areas with high precipitation (Jari Liski, Pers. Comm.).

## 5.6 Model estimates of forest soil C stocks and changes on a country scale

Over the project period (2012-2013) a number of changes were applied to the GHG inventory methodology, some of which are illustrated in the tables below: The parameter set used in Yasso07 was changed from that in Rantakari et al. (2012) to that of the version known as the GUI; Graphical User Interface (Tuomi et al. 2011b). This choice was based on expert judgment/personal communication from Jari Liski. who represents the Finnish model development group. This is the same Yasso07 parameter set as is currently used for the site-specific model application (Chapter 4). Also during the project period, the back-cast time series was introduced. This was done in several steps due to this being a large computation task. A simple sensitivity analyses described the change in model estimates of C change and C stocks when doubling the litter input from fine roots which is a litter input element that is difficult to measure and highly uncertain (Table 5.6: "GUI incr. litter"). The fine root turnover rates were chosen to be 0.6 yr$^{-1}$ (standard value) or 1.2 yr$^{-1}$ (double).

Not all presented simulation versions in tables Table 5.6 and Table 5.7 are comparable (due to differences in the stage of back-cast development). Letters in these tables denote which simulations may be compared to express an effect of parameter set (A), fine root litter input (B) and overall back-cast (C). Changing the Yasso07 parameter set only increased the estimated soil C stocks (Table 5.6). The GUI parameter set is considered the currently most robust parameter set whereas the parameters in Rantakari et al. (2012) were developed specifically for use in the Finnish GHG inventory (Liski, pers.comm). Applying the back-cast time series decreased C stocks and increased the change rates (Table 5.6). As growing volume has been steadily increasing in Norwegian forests over the last 100 years (Anonymous 2013, 2014) this was an expected outcome of the back-cast: From a time series of increasing forest biomass the estimated litter input to the model is also increasing over time and a spin-up in 1960 is characterized by a lower litter input than would be the case for eg.1990. In Table 5.6 it is illustrated that simulated soil C stocks are generally very low for birch/deciduous forest relative to coniferous forest and change rates for birch forest is almost an order of magnitude less than for coniferous forest. Increasing the root litter input generally increased change as well as stock estimates in the long term (see also chapter 4Table 5.6 for the importance of the time horizon considered). However, this is not a straight forward relationship as increased litter input also increases the equilibrium stock used to initialize the model and factors such as the weather data (spin-up weather vs. time series weather) and forest growth rates and –demographics may come into play and affect the outcome of the simulations. The estimates from the "GUI NIR2014" (see Table 5.6) are identical to those used in the GHG inventory for 2014 and include more NFI data than the other estimates which were all run in 2013 due to one more year of data in the NFI.

**Table 5.6** Average model estimates of forest soil C change and C stock for NFI forest plots dominated by spruce, pine and birch/deciduous forest respectively. Values are calculated as a mean for all entries where an entry is any combination of NFI plot and registration year. Change rates are expressed as annual changes thus from changes occurring between subsequent inventories on individual plots and divided by 5; in the majority of cases registrations are every 5 years; for some plots in the early inventories this may deviate from 5. Excluding registration years with more or less than 5 years between inventories did not change the order of magnitude or overall pattern in the variability of the output. Back-cast entries were not included in the means. "GUI" indicates that the Yasso07 parameter set from Tuomi et al. (2011b) was used: Graphical User Interface. "RA" indicates that the Yasso07 parameter set in Rantakari et al. (2012) was used (this was used in the GHG inventory in 2013). In "GUI incr. litter" fine root litter was doubled compared to the other runs (see text). "BC" indicates if back-cast was applied. Letters A, B and C denote simulations that may be compared.

| | Yasso07 change (g C $m^{-2}$ $year^{-1}$) | | | | | Yasso07 stock (Kg C $m^{-2}$) | | | | | n |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | ÷BC | | +BC | | | ÷BC | | +BC | | | |
| | RA (A) | GUI (A) (C) | [1]GUI (B) | GUI incr. litter (B) | [2]GUI NIR 2014 (C) | RA (A) | GUI (A) (C) | GUI (B) | GUI incr. litter (B) | GUI NIR 2014 (C) | |
| Spruce | 24 | 24 | 24 | 30 | 30 | 3.6 | 6.4 | 6.5 | 8.4 | 5.9 | 18067 |
| Pine | 10 | 10 | 16 | 20 | 18 | 3.0 | 5.6 | 4.9 | 6.2 | 4.7 | 14927 |
| Birch | 4 | 4 | 4 | 2 | 6 | 1.7 | 3.1 | 3.1 | 3.6 | 2.8 | 18368 |

[1] For technical reasons it was necessary to implement the back-cast slightly differently in this run as compared to the GHG inventory in 2014.

[2] For the GHG inventory in 2014 n is higher than shown in the table. See text.

Generally predicted stocks increase with increasing site index (Table 5.7). And in most cases, when comparing simulations, stocks decreased and changes increased after applying the back-cast time series (columns marked with C). The use of spin-up litter from 1960 results in a smaller stock as the overall forest volume (biomass) is lower at this time than in 1990 (or later). Due to model properties, these lower soil C stocks generally make the model simulate a more pronounced increase in stocks since the litter input amounts are steadily increasing.

**Table 5.7** Average model estimates of forest soil C change and C stock across site index classes. Site index express height (m) at age 40 years except for site index 4 which are all plots characterized as unproductive forest (< 1 $m^3$ volume increment $ha^{-1}$ $year^{-1}$). Values are calculated across all entries but not including the back-cast entries. Change rates are expressed as annual changes thus from changes occurring between subsequent inventories on individual plots and divided by 5; in the majority of cases registrations are every 5 years; for some plots in the early inventories this may deviate from 5. Excluding registration years with more or less than 5 years between inventories did not change the order of magnitude or overall pattern in the variability of the output. "GUI" is the parameter set from Tuomi et al. (2011b). "RA" is the parameter set in Rantakari et al. (2012) which was used in the GHG inventory in 2013 (NIR2013). "BC" indicates if back-cast was applied. . Letters A, B and C denote simulations that may be compared.

| Site index | Yasso07 change (g C $m^{-2}$ $year^{-1}$) | | | | | Yasso07 stock (Kg C $m^{-2}$) | | | | | n |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | ÷BC | | +BC | | | ÷BC | | +BC | | | |
| | RA (A) | GUI (A) (C) | [1]GUI (B) | GUI incr. litter (B) | [2]GUI NIR 2014 (C) | RA (A) | GUI (A) (C) | GUI (B) | GUI incr. litter (B) | GUI NIR 2014 (C) | |
| 4 | 4 | 4 | 8 | 10 | 10 | 1.4 | 2.6 | 2.2 | 2.9 | 2.1 | 10206 |
| 6 | 2 | 2 | 10 | 12 | 10 | 2.3 | 4.4 | 3.7 | 4.7 | 3.7 | 5202 |
| 8 | 6 | 6 | 14 | 18 | 16 | 2.6 | 5.0 | 4.2 | 5.3 | 4.0 | 12091 |
| 11 | 10 | 10 | 14 | 16 | 16 | 3.1 | 5.7 | 5.3 | 6.6 | 5.0 | 9896 |
| 14 | 22 | 20 | 16 | 18 | 20 | 3.3 | 6.0 | 6.3 | 7.8 | 5.7 | 7361 |
| 17 | 38 | 38 | 22 | 28 | 34 | 4.0 | 7.0 | 8.1 | 10.0 | 7.0 | 4207 |
| 20 | 50 | 52 | 24 | 32 | 44 | 4.3 | 7.4 | 9.9 | 11.8 | 7.8 | 1714 |
| 23 | 56 | 56 | 38 | 50 | 62 | 4.3 | 7.3 | 9.3 | 11.2 | 7.1 | 624 |
| 26 | 44 | 46 | 24 | 36 | 58 | 4.6 | 8.0 | 12.2 | 14.4 | 8.0 | 61 |

[1] For technical reasons it was necessary to implement the back-cast slightly differently in this run as compared to the GHG inventory in 2014.

[2] For the GHG inventory 2014 (NIR2014) n is higher than shown in the table.

As expected, estimated change rates were very high or negative in the beginning of stand development reflecting a high litter input after harvest followed by a time period primarily with soil C losses due to little input (Figure 5.4).

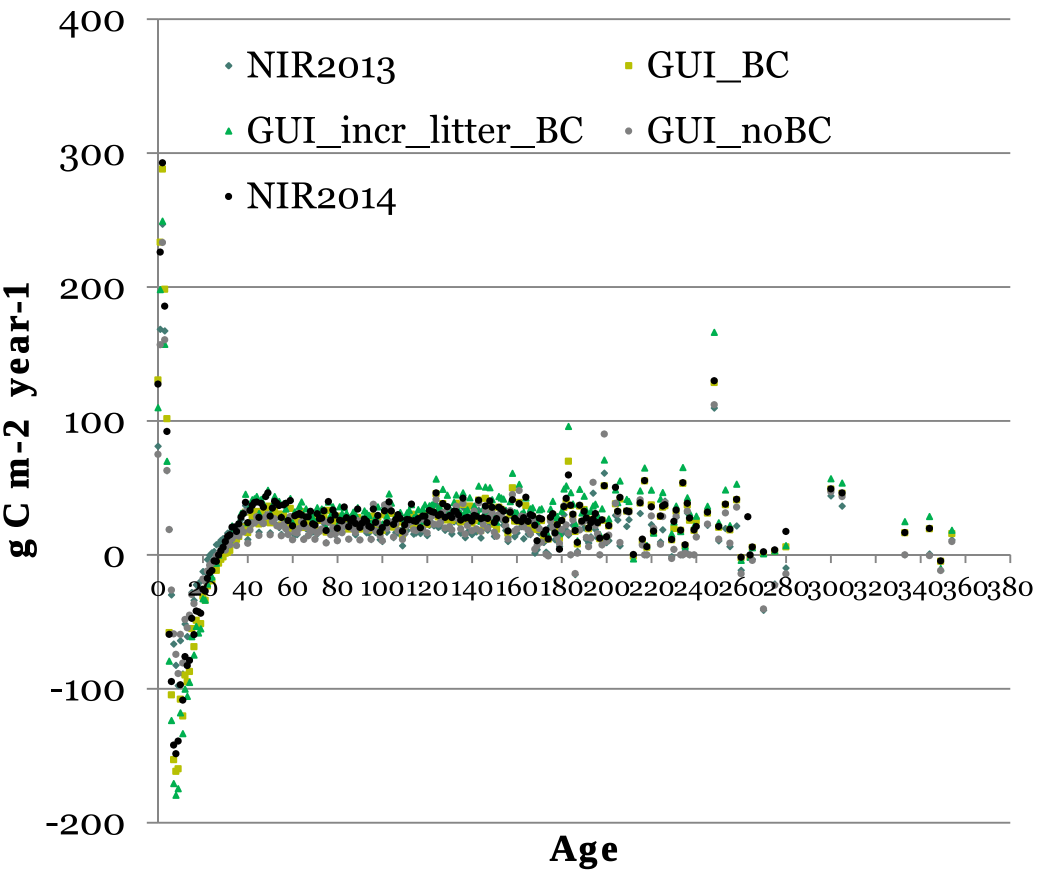


**Figure 5.4** Average model estimates of forest soil C change across NFI stand age. For all data points < ca. 160 years there are a minimum of 10 observations, whereas for very old stands, there are just a few or even a single stand included. Values are calculated across all entries but not including the back-cast entries. Change rates are expressed as annual changes thus from changes occurring between subsequent inventories on individual plots and divided by 5; in the majority of cases registrations are every 5 years; for some plots in the early inventories this may deviate from 5. Excluding registration years with more or less than 5 years between inventories did not change the order of magnitude or overall pattern in the variability of the output but removed some extreme values in old forest plots. "GUI" is the parameter set from Tuomi et al. (2011b). In the GHG inventory in 2013 (NIR2013) the parameter set in Rantakari et al. (2012) was used. "BC" indicates if back-cast was applied. For technical reasons the back-cast was implemented slightly differently for "GUI_BC" and "NIR2014" and "NIR2014" include data not included in the other estimates.

We cannot evaluate if the change rates reported (Table 5.6, Table 5.7) are realistic for Norwegian conditions on a national scale because measurements are basically not available. However, the few available studies from other countries may aid to evaluate if the current model estimates are in a realistic range. The comparison need to take into account the geographical scale. The estimated changes on a plot level may be compared to measured changes from field studies (if sufficiently large populations/strata are concerned), whereas overall changes reported in the national GHG inventory may be compared to other national level estimates. In addition, while the model estimate from Yasso07 represents the total change in soil, litter and downed and standing dead wood, measured estimates at the plot level often exclude dead wood and measures of deep soil carbon. Further, the pool definitions may differ between studies. This complicates any comparison of estimates.

The average model output estimates on plot level (Table 5.6, Table 5.7) indicate a large variation in the annual change from 6-10 g C $m^{-2}$ $year^{-1}$ (lowest site index; deciduous forest) to 30-60 g C $m^{-2}$ $year^{-1}$ (high site index; spruce forest). A representative estimate for 50-100 year old forest (Figure 5.4) may be 25-40 g C $m^{-2}$ $year^{-1}$. A typical Norwegian forest may be represented by site index 14 for which the simulated changes are between 16 and 22 g C $m^{-2}$ $year^{-1}$. In comparison, measured change rates (increase in the organic layer) from a random sample of middle-aged boreal forest on podzolic soils in Southern Finland (n=38) were 20-30 g C $m^{-2}$ $year^{-1}$ (mean was 23 +/- 2 g C $m^{-2}$ $year^{-1}$; Häkkinen et al. 2011). Repeated soil measurements (Biosoil data of Finnish NFI; time span 1986 (1995) - 2006; Rantakari et al. 2012) in upland forests in Finland showed an average change rate in the organic layer of 11-12 +/- 5 g C $m^{-2}$ $year^{-1}$ as a mean value across different stand types, stand ages, tree species and basal area.  The sequestration rate in the humus layer of forests on podzolic soil in Sweden was estimated to an average of 25 g C $m^{-2}$ $year^{-1}$ (Berg et al. 2009). These estimates do not include changes in mineral soil horizons or in dead wood.

Comparisons on the plot level indicate that for typical Norwegian forest (assumed site index 14) the model estimated change are in the lower end of the range found in Finnish and Swedish field studies, in spite of more pools included in the Norwegian calculation.

A repeated soil survey in Great Britain (Emmett et al. 2007) gave no clear indication of the change in forest soil C stocks in 0-15 cm depth over ca. 30 years (1978-2007); for coniferous woodland forest soil C stocks showed a tendency to decrease in England, Scotland and in Great Britain as a whole while there was an increasing tendency in Wales. However, none of these changes were significant. Deciduous and mixed woodlands showed an increasing tendency but a significant increase was only found in England (approximately 3 g C $m^{-2}$ $year^{-1}$). Climate, vegetation, soils and management are all likely to be quite different to Norwegian conditions and the relevance of a simple comparison of stock changes may be limited in this context.

On an aggregated scale, change rates found directly from values reported in the GHG inventories (UNFCCC 2014) are average rates based on whole country change per whole country forest area. For the upscaled (and reported) estimates for Norway,  which represent the total forested area on mineral soil, the change in dead organic matter and soil was 18 g C $m^{-2}$ $year^{-1}$ (Anonymous 2014, average for 2008-2012). An average change rate of 11-12 g C $m^{-2}$ $year^{-1}$ was estimated for Finland in their GHG reporting on the soil and dead organic matter pools (UNFCCC 2014). The value reported for Sweden (for soil and dead organic matter) is an average change rate of 18 - 20 g C $m^{-2}$ $year^{-1}$ (UNFCCC 2014). On the other hand, the mean long term (1926-2000) model based change rate for forest soil C in Sweden (Ortiz et al. 2013) was 6 and 8 g C $m^{-2}$ $year^{-1}$ (Yasso07 and Q-model respectively). Another model estimate for long term forest soil C change in Sweden (1926-2000) was 12-13 g C $m^{-2}$ $year^{-1}$ with an expectation that this may be an underestimation (Ågren et al. 2007).

The reported change rate (UNFCCC 2014) for Sweden is close to that estimated for Norway.
A generally dryer climate in Finland than in Norway or differences in forest stand age distribution may cause lower forest productivity and litter production. However, this is speculative and not further quantified here.

Generally, there is no specific reason to expect similar rates of changes for the three countries. There are differences in climate, growth and/or management, which may be reflected in differences for carbon stocks and changes as well. Nevertheless, the differences in the estimates between the countries are not pronounced.

The mechanisms in the estimation methodology are sensitive to assumptions in model input estimation and initialization procedures (back-cast, spin-up) and these should all be studied in detail in the future and compared to relevant empirical data as these become available.

The overall structure of the GHG inventory application of Yasso07 is considered to be fixed. Within the current application and data structures, improvements will continue as new data and information become available, eg. new biomass models and litter turnover rates. The importance of the time scale in weather data for the estimates of C change rates needs to be explored as well as which variables explain the discrepancy between measured and predicted C-stocks. Any new and improved parameter sets from the Finnish model development team will be tested and applied. A Yasso07 parameterization where the Norwegian soil inventory data are used is planned[3].

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[3] The soil data shown in Figure 5.3, the national Yasso07 application and a comparison of simulated and measured soil carbon stocks have been documented in Strand et al. 2016, Dalsgaard et al. 2016a, Dalsgaard et al. 2016b. These were compiled after the main text of this report was finalized. Conclusions from these papers are included in the report discussion.

# 6 Discussion and conclusions

Changes in soil carbon stocks are a key issue to understand the connections between climate, land-use and the carbon cycle. In this project, we investigated and revisited two long-term forest reference sites with repeated measurements of soil carbon. Including the re-sampling in this project, the data represent the most frequently sampled and arguably also longest time series of soil carbon measurements in forest soils existing in Norway. This implies that they are the best suited candidates for modeling efforts towards carbon dynamics.

In this section first the main findings from chapter 3 “Repeated sampling of two tree species experiments in S.E. Norway”, chapter 4 “Site specific simulation studies” and chapter 5 “Field and simulation studies in a GHG reporting context” are briefly summarized. This is followed by a discussion of the issues and expectations stated in the project aim (chapter 1). Finally a conclusion is presented.

## 6.1 Chapter 3: Repeated sampling of two tree species experiments in S.E. Norway – Summary of results.

The repeated soil sampling at Nordmoen and Skiptvet generated the longest time series for soil C from Norwegian forests. This allowed for an investigation on long-term trends for SOC, dependent on tree species and forest management. In addition, living and dead biomass for trees were calculated based on repeated tree measurements. For the last observation year 2012, data on ground vegetation biomass were also available. This allowed for the estimation of the total ecosystem C pools.

Based on these data from 2012, the different tree species at Nordmoen seem to affect the total ecosystem C pool somewhat differently. The total C pool in the spruce stands was significantly lower than the one in the pine and birch stands (Figure 3.18). This was also the case for total tree biomass and living biomass.

The birch stand had significantly lower total soil C pool down to approx. 40 cm than the spruce and pine stand. This was also true for the C pool in the forest floor as well as for standing dead wood.

The carbon pools in the forest floor exhibited a tendency to decrease over time. The total soil C pools of the layers in the original sampling regime were generally stable during 34 years of observation, apart from the birch stand which showed a slight decrease (Figure 3.12 and Figure 3.15). The slight decrease in the forest floor of all stands at Nordmoen may be underestimated due to the possible compression of the forest floor during the initial acid rain experimental period. This will again affects the C pool estimates of the total soil, as well as the uncertainty of the C pool estimates. On the other hand, as compared to the uncertainties of the soil C estimates for the ICP forest level 1 plots of DeWit and Kvindesland (1999), the pool estimates of the current study is not affected by uncertainties connected to stone content, and the uncertainty of the BD, which is based on measurements in 2012, is expected to be relatively small.

The ground vegetation biomass was highest in pine stands and lowest in spruce stands. For spruce, bryophytes dominate the ground vegetation in terms of biomass and C pools; for pine and birch, wooded species are most important. The total ground vegetation C pool is no more than around 1% of the soil C pool in these stands.

We established regression relations between vegetation biomass and areal coverage, which might be utilized in further studies since coverage is much less demanding to obtain in the field and is available for many sites in Norway.

At Skiptvet, the total ecosystem C pool was comparable between the treatments T0 up to T3, whereas treatment T4 (pure spruce stands) showed a tendency towards a higher pool (Figure 3.18). The latter seemed to be mainly related to a higher C pool in the forest floor and mineral soil. For the remaining treatments, the soil C pools were about the same (Figure 3.17).

The carbon pools in the forest floor exhibited a tendency to decrease over time, apart from the pure spruce stand (T4) which showed a slight increase. The negative trend was even more apparent for the total soil C pool, again with the exception of T4 which exhibited an increase (Figure 3.14).

The sites at Skiptvet are very dense and did not allow any substantial amount of ground vegetation to develop.

The level of total soil C is very different between Nordmoen and Skiptvet; typical values are 5 kg C $m^{-2}$ for Nordmoen and 12 kg C $m^{-2}$ for Skiptvet. Differences in soil type may play a key role. Additionally, at Nordmoen, management practices which involved prolonged and frequent harvesting to provide fuel to a nearby glass factory approx. 200 years ago may still play a significant role for the generally low soil C pool, as will also the trenching and tilling of the soil when used for agricultural purposes affect the C pool at Skiptvet.

## 6.2 Chapter 4: Site specific simulation studies

The soil carbon measurements at Nordmoen and Skiptvet revealed a rather different level of total carbon (down to 40 cm; at Nordmoen extrapolated to 1 m) for the two sites. This is probably related to the soil type, however, different stand management and site histories will also play a role for long term accumulation of soil C. Contingencies from previous land use and tree generations are difficult to represent within the models, and are thus challenging. Romul can be provided with initial values to reflect site conditions shortly after planting, but the subsequent simulation course is largely determined by the litter input, which is very small for newly planted stands. For Yasso07, the spinup underestimates the initial carbon content for Skiptvet, but hits close to the target for Nordmoen.

The measured rate of change in soil C is observed to be small, although a significant negative change in the birch stand at Nordmoen, and indicatively positive change for the spruce treatment at Skiptvet was suggested. Thus, the measured carbon stocks for most stands did not increase following clear cut and plating of new forests as the stands were growing. The change in the soil following harvest at Nordmoen is in accordance with, but in the lower end of the range in the meta-analysis of Nave et al (2010). The magnitude of the loss following harvest, and the time it takes for soil to start accumulating C again, varies between studies. Yasso07 spruce at Nordmoen and the general trend for Skiptvet were close to reflecting the measured trends for soil C pools. Provided our estimates for litter production are roughly correct, this stagnancy or even decrease is difficult to reproduce with models sensitive to the litter dynamics which is quickly growing as the stands age in concordance with the biomass growth. This may indicate that in some cases the models underestimate the decomposition processes. In the current Romul simulation, it was assumed that the soil under the different trees species had the same decomposition rates. This is expected to be the case during the initial years after harvesting and planting. However, as the stands grow and the quality of the litter input changes, mineralization rates may also change. This is supported by the results from Hansen et al (2013), where C mineralization rates in a birch stand were found to be significantly higher than in a spruce and pine of a common garden experiment. This resulted in a lower soil C pool in the birch stand, which is in accordance with the observed lower soil C pool in the birch stand at Nordmoen in 2012. Differences in C mineralization rates is most probably a key process behind the lower soil C in the birch stand at Nordmoen (Figure 3.15) as well as the suggested higher C pool in the spruce stand at Skiptvet (Figure 3.17. The similar decomposition rates in the model runs of the different species and stand types, may thus possibly explain the relatively similar time trends of the Romul results for the different tree species and treatments at Nordmoen and Skiptvet. A general decreasing or constant development in soil C as observed in measurements were reflected in most of the treatments when using Yasso07, however, where Yasso07 estimates seem to reflect the amount of living tree biomass (and the expected production of litter) on the sites, simulated species effects as indicated by the measurements (or lack of effects) were not found.

Yasso07 is a very simplistic representation of soil processes and their dynamics. The chemical differentiation of litter according to solubility (AWEN) seems like a tuning option for the model at first sight. Our sensitivity analysis, however, points to a rather minor effect of changing the chemistry within the model as long as the solubility is kept within the range defined by measurements in coniferous forest trees. Similarly, changes in the turnover rates within reasonable ranges lead to only slightly altered carbon dynamics within the time horizon of this study. With much longer time scales, however, this could have a more pronounced effect, exemplified by the 28% increase in stocks with a 100% increase in fine root litter input reported by Dalsgaard et al. (2016b). The uncertainty analyses performed only focused on a limited number of parameters used in the input litter estimation, and did not touch the basic parameterization of the internal model dynamics.

Romul is a process model of intermediate complexity, and some of the parameters required are usually not available in field studies. We focused on two of the parameters known the least, both related to mineralization. Similar to Yasso07, the sensitivity to these parameters is not very pronounced (not shown). Since the model simulations are crucially determined by the litter dynamics, efforts and care should be spent in particular on high-quality data for this input. However, improvements in the representation of decomposition processes are also needed for the modes to better reflect changes in the soil C stocks with time.

This current study includes only two models and two sites. A possible extension would be a model-data comparison for a whole ensemble of available models. An ensemble study using 8 different models for estimating changes in soil carbon  is provided by Palosuo et al. (2012); including both Yasso07 and Romul, albeit analysis is restricted to just one site. The results showed a wide range in soil carbon stocks (down to 30 cm) and stock change estimates, where the latter had both signs (i.e. accumulation as well as loss were predicted by different models), and the absolute values of change ranged from almost zero to 1% yr$^{-1}$ (relative to stocks). In Palosuo et al. (2012), the stock changes predicted were three times higher for Yasso07 than for Romul, and both models did not even present the extremes among all models. The observed (i.e. measured) decrease in SOC stocks was much more pronounced than any of the 8 models predicted, which is in accordance with the current study in Nordmoen, where the modeled soil C was generally increasing. This reflects the substantial uncertainties to be expected in model estimates, due to the model structure, applied parameters, different input information and assumptions applied during the modelling processes (Palosuo et al. 2012).

## 6.3 Chapter 5: Field and simulation studies in a GHG reporting context

The simulation results show that modeling stocks and modeling changes are two different things. On the national scale, Yasso07 is clearly underestimating the observed stocks[4]. This is true also when

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[4] Median stocks were 5.0 kg C m$^{-2}$ (simulated) and 14.5 kg C m$^{-2}$ (measured) with the differences relating mainly to climate, drainage characteristics, soil depth and site index and with a clear indication of the importance of soil type (Strand et al. 2016, Dalsgaard et al. 2016b). Stocks were also shown to depend – to a limited extent – on the spatial scale of model application (Dalsgaard et al. 2016a) but this effect was small relative to the difference between model stocks and measured stocks.

considering known uncertainties due to the field sampling procedure – particularly coarse fragments - (ca. 20-30%) and the observation that increasing fine root litter input by a factor two resulted in a 20-30% increase in simulated soil C stocks. The estimated stocks from Norway are higher than those reported for Sweden and Finland. The changes estimated for Norway, on the other hand, seem to fit reasonably well (judged by comparison to Sweden and Finland and not by Norwegian data per se)[5]. The impact of the errors in simulated stocks on uncertainties in simulated change estimates is unknown. Generally, there is no specific reason to expect similar rates of changes for the three countries as differences in for example climate and long term management could warrant differences also in change rates (and stocks).

In the context of Yasso07 simulations on the national scale, the crucial question seems to be how far the current model carbon stock is from an equilibrium state within the model, where litter input and decomposition are in balance. This distance from equilibrium depends among others on model representation of stand history and management, which in turn influences litter production.

While the available soil C estimates from the soil inventory cover the entire country and is based on representative data, one could argue that the approx. 1040 plots with soil data may not cover the natural variability in soil types over the Norwegian forest landscape to the extent that is necessary for reliably scaling up to a total national soil C stock estimate[6]. Specific considerations on this issue may be relevant in the future. However, even with a denser grid measured for soil C stocks (denser than the current 1040 plots) it is unlikely that measured and model estimates of soil C stocks (with the current modeling approach) will show a significantly better agreement. The needed number of plots will depend on the purpose. A lower number of plots is necessary for estimating soil C stocks than for estimating changes. The number of plots for estimating change may vary depending on the time between measurements and the level of statistical significance that is viewed acceptable. Clearly, the needed number of plots would be higher than the 1040 that are available today (see for example Saby et al. 2008). As an example, based on the observed total variance within the 1040 samples, which is considered representative (identical) to the variance of infinitely many samples, and requiring a detection level of 1% change in stocks between two successive sampling rounds, which for Norway equals a change amounting to approximately 130-140 g C $m^{-2}$ ( which equals the approximately 10 years of change according to the current model simulations), and with a confidence level of 95% for this change, around 17000 samples are needed.

In comparison, the Swedish Forest Soil Inventory collects soil samples from approximately 20000 plots distributed evenly over Sweden, in order to monitor changes of soil carbon and nutrients in natural ecosystems (sampling depth varies fx. 25% of plots are sampled in mineral soil). The sampling is part of the environmental monitoring program of the Swedish Environmental protection agency. The turnaround time for this sampling regime is 10 years, and in 2012 the third cycle of repeated soil sampling was finished. (https://www.slu.se/centrumbildningar-och-projekt/markinventeringen/om-markinventeringen/). The Swedish NFI plots are part of the Swedish Forest Soil Inventory and include a total number of 3400 soil inventory plots (estimation of soil C changes including the mineral soil) which covers a total forest area in Sweden of 23 mill hectares. These are sampled in the rotating soil

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[5] Simulated changes were shown to be very sensitive to the temporal resolution of climatic input data i.e. the current change estimates (with constant mean climate) would be drastically different if temporally changing climate (increase in temperature and precipitation) were used (Dalsgaard et al. 2016a).

[6] A rough estimate – based on the 1040 profiles available for Norway – was presented in Strand et al. (2016) to be 1.83 Gt C (95% confidence interval 1.71 – 1.95 Gt C).

survey resulting in repeated measurements (Ortiz et al. 2013). In a total forest area in Finland of 23 mill hectares, the total number of NFI plots is ca. 3000 (Mäkipää and Heikkinen 2003) where repeated sampling of soil C took place in 486 plots in 1986-1989 / 1995 and again in 2006 (Rantakari et al. 2011). In contrast, Mäkipää et al. (2008) showed that to detect a change of 11 g C $m^2$ $yr^{-1}$ it would be necessary to implement soil sampling on 3000 plots on a 10 year rotation. On a total forest area in Norway of 12 mill hectares soil C was sampled on ca. 1040 NFI inventory plots with no current plan to resample. When it comes to distribution, Sweden have the best coverage of soil inventory on its forest area, Finland has the least coverage and Norway is intermediate. Norway is, however, lacking an inventory that enables measurements of soil carbon changes. In Norway, the high variability in forest ecosystem type/climate, magnitude of sampling error in different ecosystems etc. will warrant that higher coverage would be needed relative to in other countries.

It is important to note that along with repeated inventories of soil C stocks in Sweden and Finland, considerable funding is also allocated to modelling changes in soil C stocks in these countries. This underlines the importance of continuously improvements of the models and the model applications in Norway, along with the need for careful design of future surveys of Norwegian forest soils.

The comparison of measured and simulated soil C stocks across the country showed that the model produced higher soil C stocks for spruce forest than for forest dominated by pine or deciduous trees. This ranking among forest types agreed with measurements. Similarly, model estimates of soil C stocks generally increased with increasing site index which is also in agreement with measurements. In contrast, measured soil C stocks tended to decrease with increasing drainage and this was not reflected in model estimates which were similar across drainage classes. Thus, processes related to drainage/soil moisture are likely poorly represented in the model.

For the two counties of Akershus and Østfold (the counties in which the two site-specific studies are found) a comparison of simulated and measured soil C stocks in the NFI plots indicated that simulated stocks were closer to measured stocks for stands of relatively high site index. With mean estimated soil C stocks of 8.4 kg C $m^{-2}$ (model) and 12.6 kg C $m^{-2}$ (measured) for plots with high site index, and a consideration that both types of estimates have uncertainties of around 20%, the two estimation methods almost have overlapping ranges. However, for low site indices the underestimation by the model was much more severe (these comparisons were limited to well- or intermediately drained plots). This may indicate that the model (soil model and litter estimation models) have a better representation of the build-up of soil C in dense and productive stands possibly due to poor representation of the vegetation dynamics in low productivity stands and/or soil processes important in such stands. However, rigorous analyses of the residuals for soil C stocks (measured-minus-simulated stocks) across the whole country should include a wide range of soil, climate and vegetation variables.

The soil C stocks measured in the site-specific studies were similar (Skiptvet) and lower (Nordmoen) than the measured stocks in the soil inventory for Akershus and Østfold. This point to the inherent variability in soil C stocks over the landscape also within the same climatic region and to the care that must be taken when drawing conclusions based on data from a few intensively sampled sites.

The comparison of model estimates of stocks and changes with measurements (inventory, literature and site-specific studies) has provided a starting point for further evaluation. The weaknesses of site specific studies (given the large variability in soil conditions in a national context) and uncertaintes in model estimates are identified.

## 6.4 Conclusions

The project had the overall aim to contribute to the establishment of reference data for forest soil C changes, and to compare and validate models for forest soil C changes using these reference data. Results from the project were expected to i) support the choice of model used on a national level, ii) contribute to the validation of national level estimates for soil C changes and iii) contribute to the knowledge on soil C changes on two sites differing in soil type and tree species.

As part of the project, repeated soil sampling and lab work was carried out to establish a time series of soil C as well as living tree biomass. Soil time series of this length are rare and will potentially be used in several studies over time and should be extended in due time when possible. The special characteristics of the sites (Nordmoen low soil C stocks) must be kept in mind in any future use of the data, however, there is no reason to expect this is not representing a variability that can be found across Norwegian forests. The relatively well defined treatments/stand types offer a valuable opportunity to compare across stand type as well as between sites. These two sites can only represent the geographical region where they are found i.e. regions with a more coastal or a more continental climate are not represented in these time series.

Simulations have been performed at the plot level in both the site-specific studies and in the GHG inventory. Thus, these two are comparable methodologically. The two sites from the case study which comprise the three most common Norwegian tree species, are different with respect to soil type, productivity and management, but are exposed to rather similar climatic conditions. Thus, our evaluation is restricted to this climatic range.

Based on the site-specific studies in Nordmoen, Romul and Yasso07 (birch and pine) generally showed an increase in soil C with time where measurements showed no change or a slight decrease; thus model response to an assumed increasing litter input was not reflected in measurements. Yasso07 for Skiptvet showed an initial decrease followed by stabilization/slow increase and Romul showed a net loss resulting from a large loss followed by a fast accumulation. In Skiptvet, measurements showed no changes or a slight increase in spruce. The carbon dynamics of Yasso07 is less pronounced than that of Romul, and thus closer to observations.  Based on this rather limited comparison, it seems that Romul is less suited for this type of sites where comparatively small changes take place and there is a tendency that it generally overestimates changes, whereas Yasso07 shows a more stable behavior, and seems to be better adapted to sites with small or almost no changes; however, still overestimates were observed for some cases. The latter (i.e. no or small observed changes) is the case for the two field sites; to which extent this holds also on a large scale is unknown for Norway.

The stronger responsiveness of Romul is accompanied by a more sophisticated parametrization procedure. Thus, additional information on site-specific conditions (e.g., information on hydrology) is an advantage, but not routinely available at many sites. In practical situations, routine application of Romul on a large scale (or many plots) is a challenging task.

Site-specific studies gave support to Yasso07 as a relatively conservative and robust model although we clearly see that it does not reproduce the observed soil C stocks on the national scale. Changes on the national level were in the range observed for other Nordic countries.

The field measurements on Nordmoen and Skiptvet showed unexpected results in terms of rather stable soil C stocks with only slight decrease or increase in soil C stocks over time. Expected trends were a stronger decrease after clear cut, eventually followed by a buildup of the soil C after canopy closure. Further, tree species/stand types were expected to have shown larger differences. The measured patterns represents a challenge for the models investigated and will make up the basis for further studies.

# References

Abrahamsen, G., Stuanes, A.O. and Tveite, B. (Eds.) 1994. Long-term experiments with acid rain in Norwegian forest ecosystems. Ecological Studies 104. Springer-Verlag. 342pp. ISBN 0-387-94119-3.

Ahrens, B., Hansson, K., Solly, E.F. and Schrumpf, M. 2014. Reconcilable differences: a joint calibration of fine-root turnover times with radiocarbon and minirhizotrons. New Phytologist 204 (4), 932-942.

Anonym. 1984. Overvåkning av langtransportert forurenset luft og nedbør. Statens program for forurensingsovervåkning. Staten forurensningstilsyn. Rapport 201/85

Anonymous. 2005. Emissions and removals of greenhouse gases from land use, land-use change and forestry in Norway. NIJOS report 11/2005. ISBN 82-7464-352-6.

Anonymous. 2013. National Inventory Report. Climate and Pollution Agency. TA 3030.

Anonymous. 2014. Greenhouse Gas Emissions 1990-2012, National Inventory Report. Norwegian Environment Agency Report M-137-2014.

Antón-Fernández, C., Astrup, R. 2012. Empirical harvest models and their use in regional business-as-usual scenarios of timber supply and carbon stock development. Scandinavian Journal of Forest Research 27:379-392.

Bakkestuen, V., Aarrestad, P.A., Stabbetorp, O.E., Erikstad, L., Eilertsen, O. 2010. Vegetation composition, gradients and environment relationships of birch forest in six reference areas in Norway. - Sommerfeltia 33: 237 pp.

Baritz R., Seufert, G., Montanarella, L., Van Ranst, E. 2010. Carbon concentrations and stocks in forest soils of Europe. Forest Ecology and Management 260:262-277.

Berg, B., Johansson, M., Nilsson, Å., Gundersen, P., Norell, L. 2009. Sequestration of carbon in the humus layer of Swedish forests - direct measurements. Canadian Journal of Forest Research 39:962-975.

Braathe, P. 1992. Forsøk med gran og bjørk i blanding. In: Halvorsen, B. (ed.) 1992. Norsk institutt for skogforskning 75 år. Rapport fra Skogforsk 12/92: 692 s.

Braastad H. 1966. Volumtabeller for bjørk. Meddelelser fra Det norske Skogforsøksvesen 21: 23-78.

Braastad,H.1966.Volumtabeller for bjørk. Meddelelser fra Det norske Skogforsøksvesen 21: 23-78

Brantseg, Alf. 1967. Furu sønnafjells. Kubering av stående skog. Funksjoner og tabeller. Meddelelser fra Det norske Skogforsøksvesen 22: 689-739.

Brunner, I., Bakker, M.R., Björk, R.G., Hirano, Y., Lukac, M., Aranda, X., Børja, I., Eldhuset, T.D., Helmisaari, H.S., Jourdan, C., Konôpka, B., López, B.C., Miguel Pérez, C., Persson, H. and Ostonen, I. 2013. Fine-root turnover rates of European forests revisited: an analysis of data from sequential coring and ingrowth cores. Plant and Soil 362: 357-372.

Bykhovets, S.S., Komarov, A.S. 2002. A simple statistical model of soil climate with a monthly step. Eurasian Soil Sci., 35 (4): 392–400.

Callesen, I., Dalsgaard, L. 2013. Quality control of forest soil carbon (C, kg C m-2) estimates based on field registrations and chemical analyses derived on 1033 NFI plots (1986-1993) as a part of ICP level I in Norway. 42 p. Internal report, 2013/working paper. Department of Geosciences and Natural Resource Management, University of Copenhagen and Skog og Landskap, Ås, Norway.

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 9:358-370.

Chertov, O.G., Komarov, A.S., Nadporozhskaya, M., Bykhovets, S.S., Zudin, S.L., 2001. ROMUL -- a model of forest soil organic matter dynamics as a substantial tool for forest ecosystem modeling. Ecological Modelling 138, 289-308.

Corder, G.W. and Foreman, D.I. (2014): Nonparametric Statistics: A Step-by-Step Approach. Wiley, New York. ISBN 978-1118840313.

Dalsgaard, L., Astrup, R., Anton-Fernandez, C., Borgen, S. K., Breidenbach, J., Lange, H., Lehtonen, A., Liski, J. 2016a. Modeling soil carbon dynamics in northern forests: effects of spatial and temporal aggregation of climatic input data. PLOS ONE. Doi 10.1371/journal.pone.0149902.

Dalsgaard, L., Lange, H., Strand, L. T., Callesen, I., Borgen, S. K., Liski, J., Astrup, R. 2016b. Underestimation of boreal forest soil carbon stocks related to soil classification and drainage, dx.doi.org/10.1139/cjfr-2015-0466.

DeWit, H.A., Kvindesland, S. 1999. Carbon stocks in Norwegian forest soils and effects of forest management on carbon storage. Rapport fra skogforskningen, supplement 14.

DeWit, 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 225:15-26.

Emmet, B.A., Reynolds, B., Chamberlain, P.M., Rowe, E., Spurgeon, D., Brittain, S.A., Frogbrook, Z., Hughes, S., Lawlor, A.J., Poskitt, J., Potter, E., Robinson, D.A., Scott, A., Wood, C., Woods, C. 2007. Countryside Survey: Soils Report from 2007. CS Technical Report No. 9/07. Centre for Ecology & Hydrology.

Engen-Skaugen, T., Haugen, J. E., Hanssen-Bauer, I. 2008. Dynamically downscaled climate scenarios available at the Norwegian meteorological Institute (per December 2008). In Met.no report 24: Norwegian meteorological Institute.

Esser J.M., Nyborg Å. 1992. Jordsmonn i barskog - en oversikt for Norge. Rapport nr. 3/92. NIJOS. Norsk Institutt for Jord- og Skogkartlegging.

Esser, J.M. 1994. Jordsmonn i bjørkeskog - en oversikt for Norge. Rapport nr. 4/94. NIJOS, Norsk Institutt for Jord- og Skogkartlegging.

FAO-Unesco. 1990. FAO/Unesco Soil Map of the World. Revised Legend. ISRIC, Wagningen, pp.1-140.

Grønlund, A., Solbakken, E. 1987. Jordsmonnkartleggingen (3rd Edition). Jordregisterinstituttet, Ås.

Hakkila, P., Parikka, M., 2002. Fuel Resources from the Forest. In: Richardson, J., Björheden, R., Hakkila, P., Lowe, A.T., Smith, C.T. (Eds.), Bioenergy from Sustainable Forestry. Springer Netherlands, pp. 19-48.

Hanedalen, P.-I. 2004. Gran og bjørks påvirkning på jordens fysiske egenskaper og vannbalanse i leirjord. Hovedfagsoppgave ved Institutt for plante- og miljøvitenskap, Norges Landbrukshøyskole.

Hansson, K., Froberg, M., Helmisaari, H. S., Kleja, D. B., Olsson, B. A., Olsson, M., and Persson, T. (2013). Carbon and nitrogen pools and fluxes above and below ground in spruce, pine and birch stands in southern Sweden. *Forest Ecology and Management* **309**, 28-35

Häkkinen, M., Heikkinen, J., Mäkipää, R. 2011. Soil carbon stock increases in the organic layer of boreal middle-aged stands. Biogeosciences 8:1279-1289.

IPCC. 2003. Good Practice Guidance for Land Use, Land-Use Change and Forestry. Institute for Global Environmental Strategies (IGES).

Jensen, A. 1993. Jordstatus på intensivt overvåkede forskningsflater. Endringer etter 5 år. Rapp. Skogforsk 1/93. 23 s.

Jensen, A. og Frogner, T. 1994. Jordstatus på intensivt overvåkede forskningsflater. Endringer etter 5 år. 1978 - 1992. Rapp. Skogforsk 8/94. 23 s.

Jonsson, M., Wardle, D.A., 2008. Context dependency of litter-mixing effects on decomposition and nutrient release across a long-term chronosequence. Oikos 117, 1674-1682.

Kjønaas, O.J., Skre O., Tau Strand L., Børja I., Clarke N., de Wit H. A., Eldhuset T. D., Lange H. Understorey vegetation matters: Above- and belowground carbon and nitrogen pools and accumulation rates in a Norway spruce forest chronosequence, SE Norway. In preparation.

Kruskal, W.H. and Wallis, W. Allen. 1952. Use of Ranks in One-Criterion Variance Analysis. Journal of the American Statistical Association 47 (260):583-621.

Liski, J., Palosuo, T., Peltoniemi, M., Sievänen, R. 2005. Carbon and decomposition model Yasso for forest soils. Ecological Modelling 189:168-182.

Liski, J., Tuomi, M., Rasinmäki, J. 2009. Yasso07 user-interface manual. http://www.syke.fi/projects/yasso.

Littell, R. C., Milliken, G. A., Stroup, W. W., and Wolfinger, R. D. 1996. SAS® system for Mixed Models, Cary, NC: SAS Institute Inc. 633 pp.

Liu, H.Y., Økland, T., Halvorsen, R., Gao, J.X., Liu, Q.R., Eilertsen, O. & Bratli, H. 2008. Gradient analyses of forests ground vegetation and its relationships to environmental variables in five subtropical forest areas, S and SW China. Sommerfeltia 32: 1-196.

Mäkipää R, Heikkinen J. 2003. Large-scale changes in abundance of terricolous bryophytes and macrolichens in Finland. Journal of Vegetation Science 14:497-508.

Mäkipää R, Häkkinen M, Muukkonen P, Peltoniemi M. 2008. The costs of monitoring changes in forest soil carbon stocks. Boreal Environment Research 13(suppl. B): 120-130.

Matamala, R., Gonzales-Meler, M. A., Jastrow, J. D., Norby, R. J. and Schlesinger, W. H. 2003. Impacts of Fine Root Turnover on Forest NPP and Soil C Sequestration Potential. Science, 302, 1385-1387.

Marklund, L.G. 1988. Biomass functions for pine, spruce and birch in Sweden. Department of Forest Survey, Report 45. Sveriges Lantbruksuniversitet.

Minchin, P. R. 1987. An evaluation of the relative robustness of techniques for ecological ordination. Vegetatio 69:89-107.

Muukkonen, P., Mäkipää, R. 2006. Empirical biomass models of understorey vegetation in boreal forests according to stand and site attributes. Boreal Environment Research 11:355-369.

Muukkonen, P., Mäkipää, R., Laiho, R., Minkkinen, K., Vasander, H., Finér, L. 2006. Relationship between Biomass and Percentage Cover in Understorey Vegetation of Boreal Coniferous Forests. Silva Fennica 40(2):231-245.

Muukkonen, P., Häkkinen, M., Mäkipää, R. 2009. Spatial variation in soil carbon in the organic layer of managed boreal forest soil – implications for sampling design. Environ. Monit. Assiss 158:67-76.

Nave L. E., Vance E. D., Swanston C. W., Curtis P. S. 2010. Harvest impacts on soil carbon storage in temperate forests. Forest Ecology and Management 259, 857–866.

Nilsson M.-C., Wardle,D. A. 2005. Understory vegetation as a forest ecosystem driver: evidence from the northern Swedish boreal forest. Frontiers in Ecology and the Environment, 3: 421–428. doi:10.1890/1540-9295(2005)003[0421:UVAAFE]2.0.CO;2.

Nurmi, Juha 1993. Heating values of the above ground biomass of small-sized trees. Acta Forestalia Fennica 236. 30 p.

Nurmi, Juha 1997. Heating values of mature trees. Acta Forestalia Fennica 256. 27 p.

Ogner, G., Wikstrøm, T., Remedios, G., Gjelsvik, S., Hensel, G.R., Jacobsen, J.E., Olsen, M., Skretting, E. and Sørlie, B. (1999): The chemical analysis program of the Norwegian Forest Research Institute 2000. Norwegian Forest Research Institute Chemical Laboratories, 23 pp.

Oksanen, J. 2013. Multivariate Analysis of Ecological Communities in R: vegan tutorial. http://cc.oulu.fi/~jarioksa/opetus/metodi/vegantutor.pdf.

Olsson, M.T., Erlandsson, M., Lundin, L., Nilsson, T., Nilsson, A., Stedahl, J., 2009. Organic carbon stocks in Swedish Podzol soils in relation to soil hydrology and other site characteristics. Silva Fennica 43 (2): 209–222.

OPS (Overvåkningsprogram for skogskader). 1998a. Overvåkingsprogram for skogskader - Årsrapport 1986. Norsk Institutt for Skogforskning. Ås. 55s.

OPS (Overvåkningsprogram for skogskader). 1998b. Overvåkingsprogram for skogskader - Årsrapport 1987. Norsk Institutt for Skogforskning. Ås. 53s.

Ortiz, C.A., Liski, J., Gärdenäs, A.I., Lehtonen, A., Lundblad, M., Stendahl, J., Ågren, G.I., Karltun, E. 2013. Soil organic carbon stock changes in Swedish forest soils - A comparison of uncertainties and their sources through a national inventory and two simulation models. Ecological Modelling 251:221-231.

Palosuo, T., Foereid, B., Svensson, M., Shurpali, N., Lehtonen, A., Herbst, M., Linkosalo, T., Ortiz, C., Todorovic, G.R., Marcinkonis, S., Li, C.S. and Jandl, R. 2012. A multi-model comparison of soil carbon assessment of a coniferous forest stand. Environmental Modelling & Software 3:, 38-49.

Peltoniemi, M., Mäkipää, R.,Liski, J., Tamminin, P. 2004. Changes in soil carbon with stand age - an evaluation of a modelling method with empirical data. Global Change Biology 10:2078-2091.

Petersson, H., Ståhl, G. 2006. Functions for below-ground biomass of Pinus sylvestris, Picea abies, Betula pendula and Betula pubescens in Sweden. Scandinavian Journal of Forest Research 21(7):84-93.

Quinn, G.P and Keough, M.J. 2002. Experimental design and data analysis for biologists. Cambridge University Press, Cambridge, United Kingdom.

R Development Core Team. 2011. R: A language for statistical computing. R Foundation for Statistical Computing, Available from http://cran.r-project.org.

Rantakari, M., Lehtonen, A., Linkosalo, T., Tuomi, M., Tamminen, P., Heikkinen, J., Liski, J., Mäkipää, R., Ilvesniemi, H., Sievänen, R. 2012. The Yasso07 soil carbon model - Testing against repeated soil carbon inventory. Forest Ecology and Management 286:137-147.

Repola, Jaakko 2008. Biomass Equations for Birch in Finland. Silva Fennica 42(4): 605–624

Saby, N.P.A., Bellamy, P.H., Morvan, X., Arrouays, D., Jones, R.J.A., Verheijen, F.G.A., Kibblewhite, M.G., Verdoodt, A., Üveges, J.B., Freudenschuß, A. and Simota, C. 2008. Will European soil-monitoring networks be able to detect changes in topsoil organic carbon content? Global Change Biology 14 (10): 2432-2442.

SAS Institute INC. 1989. SAS/STAT® User's Guide, Version 6, Fourth Edition, Volum 2, Cary, NC: SAS Institute Inc. 846 pp.

Smithwick, E.A.H., Harmon, M.E., Remillard, S.M., Acker, S.A., Franklin, J.F. 2002. Potential upper bounds of carbon stores in forests of the Pacific Northwest. Ecological Applications 12(5):1303-1317.

Soil Survey Staff.1999. Soil Taxonomy. A Basic System of Soil Classification for Making and Interpreting Soil Surveys. United States Department of Agriculture, Natural Resources conservation Service.

Song, F., Fan, X., Song, R., 2010. Review of mixed forest litter decomposition researches Acta Ecologica Sinica 30, 221–225

Stendahl, J., Johansson, M., Eriksson, E., Nilsson, Å., Langvall, O. 2010. Soil Organic Carbon in Swedish Spruce and Pine Forests - Differences in Stock Levels and Regional patterns. Silva Fennica 44(1):5-21.

Strand, L., Callesen I., Dalsgaard, L., de Wit, H.A. Carbon and nitrogen stocks in Norwegian forest soils – the importance of soil formation, climate, and vegetation type for organic matter accumulationCanadian Journal of Forest Research 46, 1459-1473.

Stuanes, A.O., Abrahamsen, G., Tveite, B. and Bjor, K. 1994a. Study area. In: Abrahamsen, G., Stuanes, A.O., Tveite, B. (Eds.). 1994. Long-term experiments with acid rain in Norwegian forest ecosystems. Ecological Studies Vol. 104: 1-342.

Stuanes, A.O., Abrahamsen, G., Tveite, B. and Bjor, K. 1994b. Experiments. In: Abrahamsen, G., Stuanes, A.O., Tveite, B. (Eds.). 1994. Long-term experiments with acid rain in Norwegian forest ecosystems. Ecological Studies Vol. 104: 1-342.

Tomter, S. M., Hylen, G., & Nilsen, J. E. 2010. Norway country report. In: Tomppo, E., Gschwantner, T., Lawrence, M. & McRoberts, R. E. (eds.) National Forest Inventories: Pathways for Common Reporting. Springer, Dordrecht.

Tuomi, M. Laiho, R., Repo, A., Liski, J. 2011a. Wood decomposition model for boreal forests. Ecological Modelling 222:709-718.

Tuomi, M., Rasinmäki, J., Repo, A., Vanhala, P., Liski, J. 2011b. Soil carbon model Yasso07 graphical user interface. Environmental Modelling & Software 26:1358-1362.

Tuomi, M., Thum, T., Järvinen, H., Fronzek, S., Berg, B., Harmon, M., Trofymow, J.A., Sevanto, S., Liski, J. 2009. Leaf litter decomposition - Estimates of global variability based on Yasso07 model. Ecological Modelling 220:3362-3371.

Tveite, Bjørn, and Braastad, Helge 1981. Bonitering av gran, furu og bjørk. Norsk skogbruk 1981(4):17-22.

UNFCCC. 2005. Report of the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol on its first session, held at Montreal from 28 November to 10 December 2005. FCCC/KP/CMP/2005/8/Add.3.

UNFCCC 2014. http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/7383.php (April 12th 2014).

Vesterdal, L., Clarke, N., Sigurdsson, B.D. and Gundersen, P. (2013): Do tree species influence soil carbon stocks in temperate and boreal forests? Forest Ecology and Management 309, 4-18.

Vestjordet, Egil 1967. Funksjoner og tabeller for kubering av stående gran. (Functions and tables for volume of standing trees. Norway spruce). Communications from the Norwegian forest research institute. 22(84): 539-574.

Økland, R.H., Eilertsen, O. 1993. Vegetation-environment relationships of boreal coniferous forests in the Solhomfjell area, Gjerstad, S Norway. – Sommerfeltia 16: 1-254.

Økland, T. 1988. An ecological approach to the investigation of a beech forest in Vestfold, SE Norway. – Nord. J. Bot. 8: 375-407.

Økland T. 1996. Vegetation-environment relationships of boreal spruce forests in ten monitoring reference areas in Norway. - Sommerfeltia 22: 1-349.

Økland, T., Rydgren, K., Økland, R.H., Storaunet, K.O., Rolstad, J. 2003. Variation in environmental conditions, understorey species number, abundance and composition among natural and managed Picea abies forest stands – For. Ecol. Mgmt. 177:17-37.

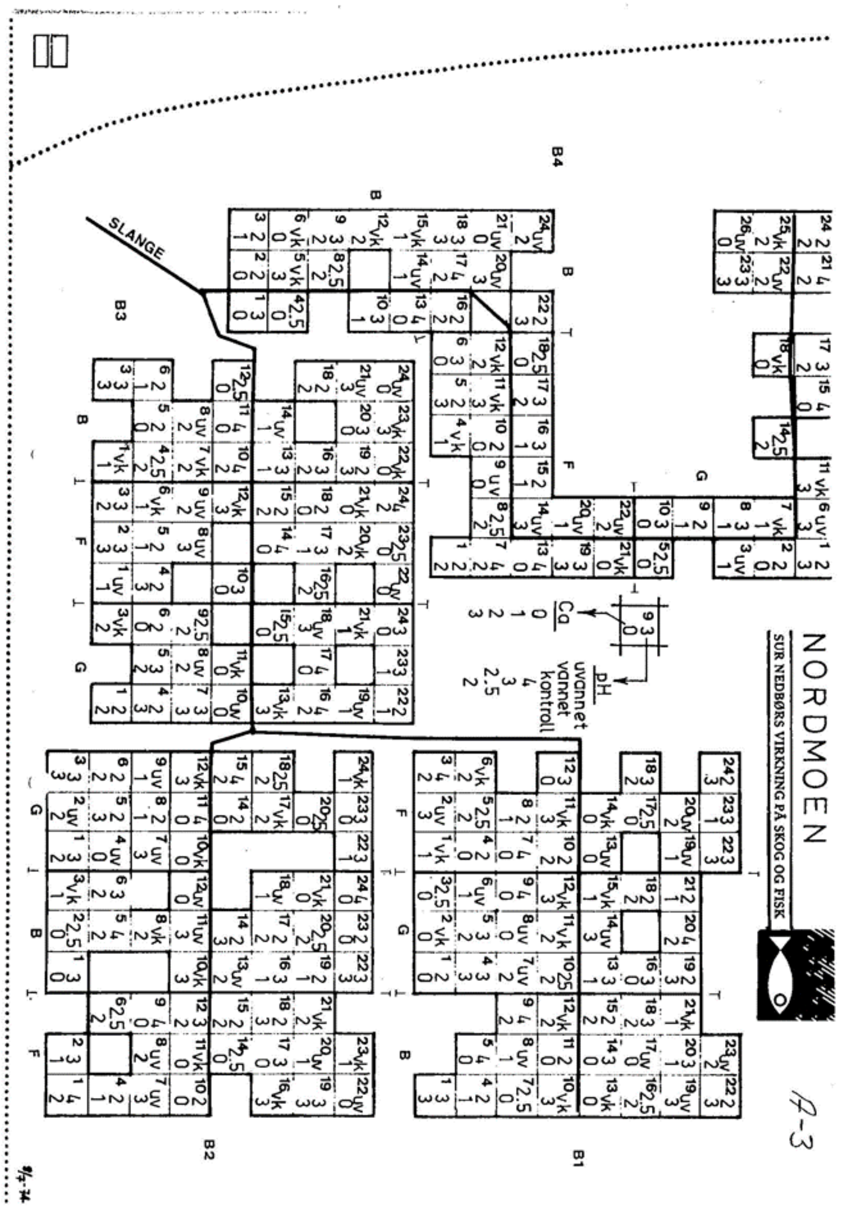
Økland, T., J.-F. Nordbakken, H. Lange, I. Røsberg, N. Clarke. 2016. Short-term effects of whole-tree harvesting on understory plant species diversity and cover in two Norway spruce sites in southern Norway. Scandinavian Journal of Forest Research: 31: 766-776.

Ågren, G.I., Hyvönen, R., Nilsson, T. 2007. Are Swedish forest soils sinks or sources for CO2 - model analyses based on forest inventory data. Biogeochemistry 82:217-227.

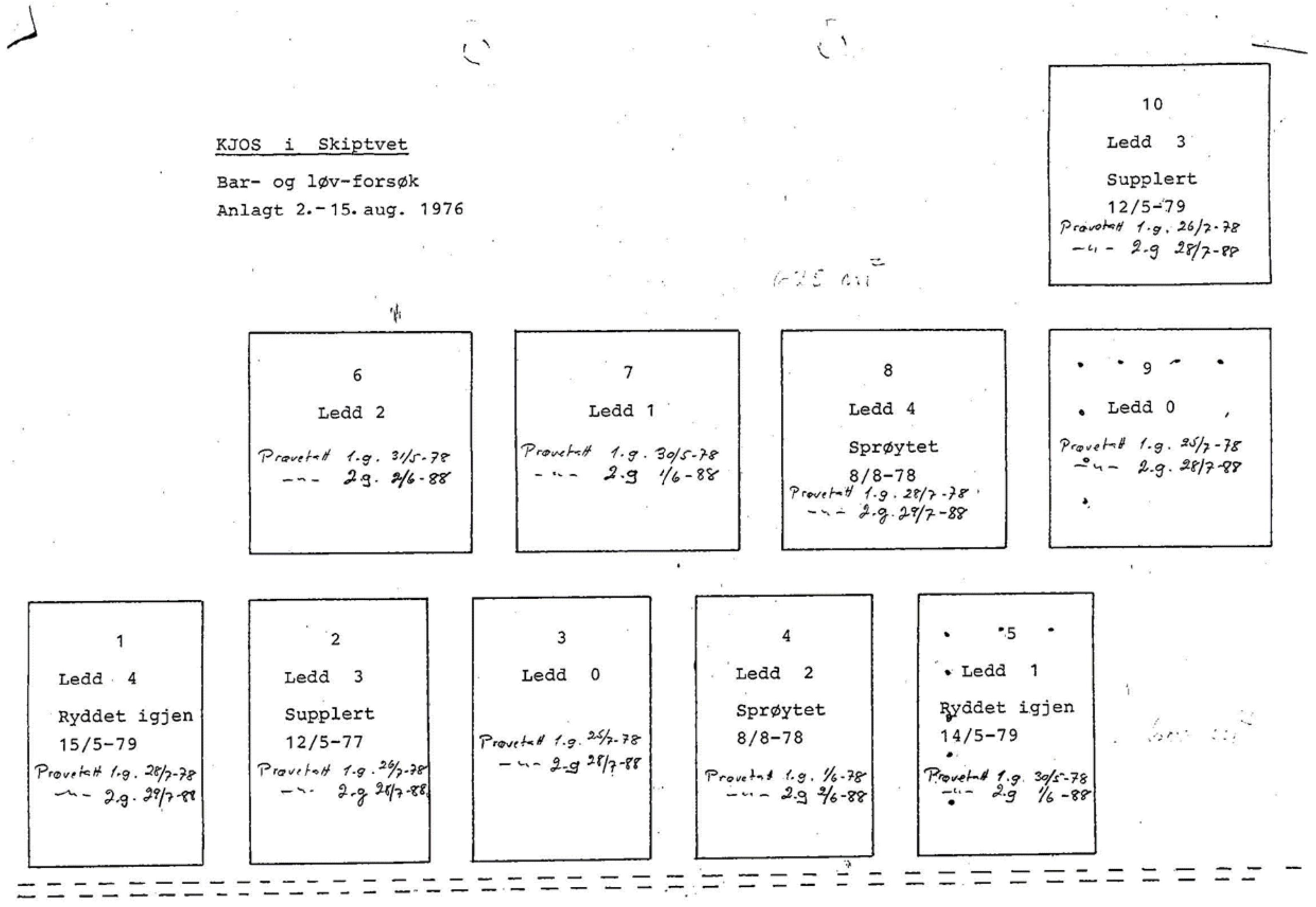
# Appendix

## Appendix 1

Experimental design at Nordmoen,  Akershus County



# Appendix 2



KJOS i Skiptvet

Bar- og løv-forsøk
Anlagt 2.-15. aug. 1976

10
Ledd 3
Supplert
12/5-79
Prøvetatt 1.g. 26/7-78
-"- 2.g 28/7-88

6
Ledd 2
Prøvetatt 1.g. 31/5-78
-"- 2.g. 2/6-88

7
Ledd 1
Prøvetatt 1.g. 30/5-78
-"- 2.g 1/6-88

8
Ledd 4
Sprøytet
8/8-78
Prøvetatt 1.g. 28/7-78
-"- 2.g. 29/7-88

9
Ledd 0
Prøvetatt 1.g. 25/7-78
-"- 2.g. 28/7-88

1
Ledd 4
Ryddet igjen
15/5-79
Prøvetatt 1.g. 28/7-78
-"- 2.g. 29/7-88

2
Ledd 3
Supplert
12/5-77
Prøvetatt 1.g. 26/7-78
-"- 2.g 28/7-88

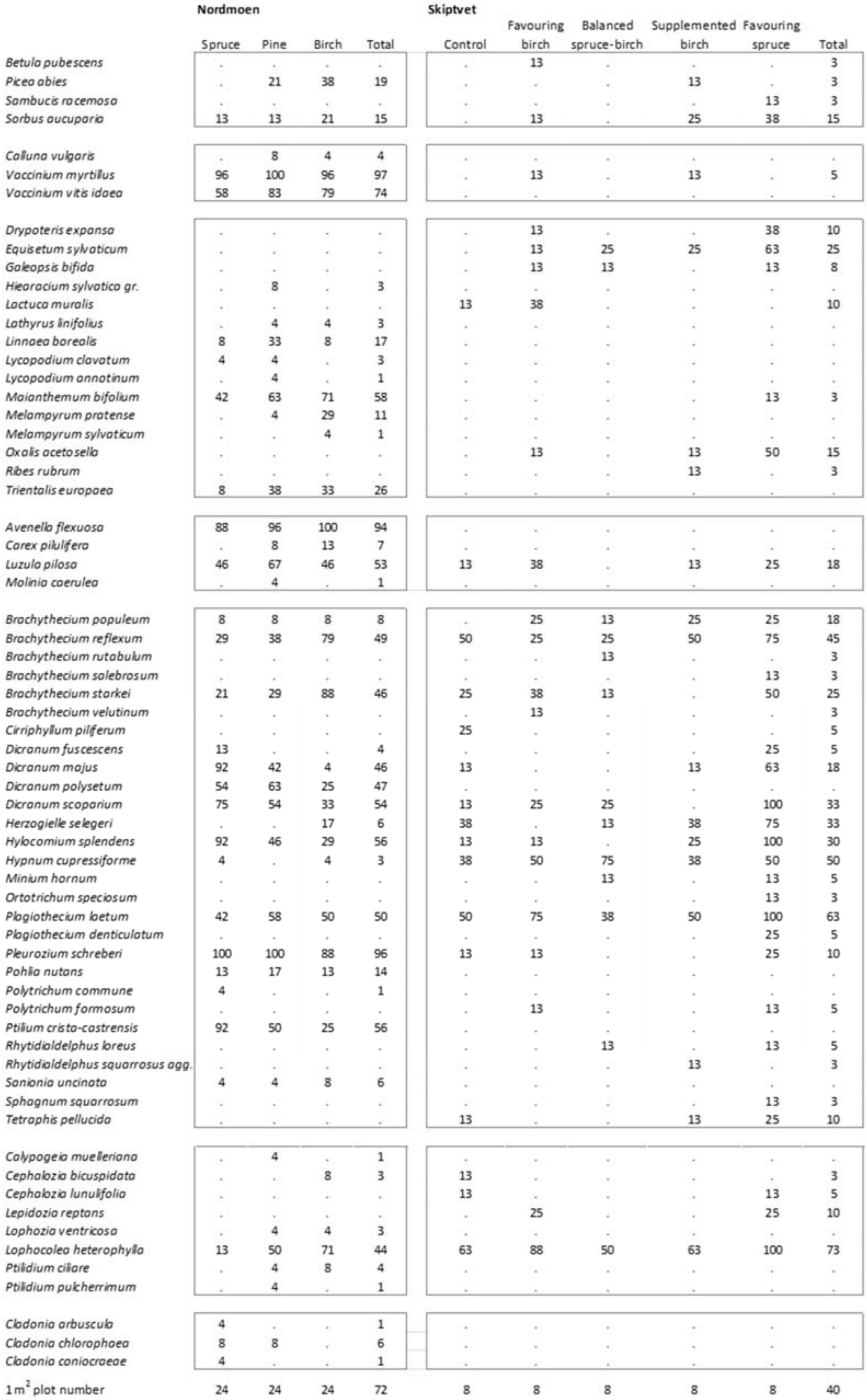
3
Ledd 0
Prøvetatt 1.g. 25/7-78
-"- 2.g 28/7-88

4
Ledd 2
Sprøytet
8/8-78
Prøvetatt 1.g. 1/6-78
-"- 2.g 2/6-88

5
Ledd 1
Ryddet igjen
14/5-79
Prøvetatt 1.g. 30/5-78
-"- 2.g 1/6-88

# Appendix 3

Percentage of 1 m$^2$ vegetation plots (within treatments and total) at Nordmoen and Skiptvet containing recorded species.



| | Nordmoen | | | | Skiptvet | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spruce | Pine | Birch | Total | Control | Favouring birch | Balanced spruce-birch | Supplemented birch | Favouring spruce | Total |
| *Betula pubescens* | . | . | . | . | . | 13 | . | . | . | 3 |
| *Picea abies* | . | 21 | 38 | 19 | . | . | . | 13 | . | 3 |
| *Sambucis racemosa* | . | . | . | . | . | . | . | . | 13 | 3 |
| *Sorbus aucuparia* | 13 | 13 | 21 | 15 | . | 13 | . | 25 | 38 | 15 |
| *Calluna vulgaris* | . | 8 | 4 | 4 | . | . | . | . | . | . |
| *Vaccinium myrtillus* | 96 | 100 | 96 | 97 | . | 13 | . | 13 | . | 5 |
| *Vaccinium vitis idaea* | 58 | 83 | 79 | 74 | . | . | . | . | . | . |
| *Drypoteris expansa* | . | . | . | . | . | 13 | . | . | 38 | 10 |
| *Equisetum sylvaticum* | . | . | . | . | . | 13 | 25 | 25 | 63 | 25 |
| *Galeopsis bifida* | . | . | . | . | . | 13 | 13 | . | 13 | 8 |
| *Hiearacium sylvatica gr.* | . | 8 | . | 3 | . | . | . | . | . | . |
| *Lactuca muralis* | . | . | . | . | 13 | 38 | . | . | . | 10 |
| *Lathyrus linifolius* | . | 4 | 4 | 3 | . | . | . | . | . | . |
| *Linnaea borealis* | 8 | 33 | 8 | 17 | . | . | . | . | . | . |
| *Lycopodium clavatum* | 4 | 4 | . | 3 | . | . | . | . | . | . |
| *Lycopodium annotinum* | . | 4 | . | 1 | . | . | . | . | . | . |
| *Maianthemum bifolium* | 42 | 63 | 71 | 58 | . | . | . | . | 13 | 3 |
| *Melampyrum pratense* | . | 4 | 29 | 11 | . | . | . | . | . | . |
| *Melampyrum sylvaticum* | . | . | 4 | 1 | . | . | . | . | . | . |
| *Oxalis acetosella* | . | . | . | . | . | 13 | . | 13 | 50 | 15 |
| *Ribes rubrum* | . | . | . | . | . | . | . | 13 | . | 3 |
| *Trientalis europaea* | 8 | 38 | 33 | 26 | . | . | . | . | . | . |
| *Avenella flexuosa* | 88 | 96 | 100 | 94 | . | . | . | . | . | . |
| *Carex pilulifera* | . | 8 | 13 | 7 | . | . | . | . | . | . |
| *Luzula pilosa* | 46 | 67 | 46 | 53 | 13 | 38 | . | 13 | 25 | 18 |
| *Molinia caerulea* | . | 4 | . | 1 | . | . | . | . | . | . |
| *Brachythecium populeum* | 8 | 8 | 8 | 8 | . | 25 | 13 | 25 | 25 | 18 |
| *Brachythecium reflexum* | 29 | 38 | 79 | 49 | 50 | 25 | 25 | 50 | 75 | 45 |
| *Brachythecium rutabulum* | . | . | . | . | . | . | 13 | . | . | 3 |
| *Brachythecium salebrosum* | . | . | . | . | . | . | . | . | 13 | 3 |
| *Brachythecium starkei* | 21 | 29 | 88 | 46 | 25 | 38 | 13 | . | 50 | 25 |
| *Brachythecium velutinum* | . | . | . | . | . | 13 | . | . | . | 3 |
| *Cirriphyllum piliferum* | . | . | . | . | 25 | . | . | . | . | 5 |
| *Dicranum fuscescens* | 13 | . | . | 4 | . | . | . | . | 25 | 5 |
| *Dicranum majus* | 92 | 42 | 4 | 46 | 13 | . | . | 13 | 63 | 18 |
| *Dicranum polysetum* | 54 | 63 | 25 | 47 | . | . | . | . | . | . |
| *Dicranum scoparium* | 75 | 54 | 33 | 54 | 13 | 25 | 25 | . | 100 | 33 |
| *Herzogielle selegeri* | . | . | 17 | 6 | 38 | . | 13 | 38 | 75 | 33 |
| *Hylocomium splendens* | 92 | 46 | 29 | 56 | 13 | 13 | . | 25 | 100 | 30 |
| *Hypnum cupressiforme* | 4 | . | 4 | 3 | 38 | 50 | 75 | 38 | 50 | 50 |
| *Minium hornum* | . | . | . | . | . | . | 13 | . | 13 | 5 |
| *Ortotrichum speciosum* | . | . | . | . | . | . | . | . | 13 | 3 |
| *Plagiothecium laetum* | 42 | 58 | 50 | 50 | 50 | 75 | 38 | 50 | 100 | 63 |
| *Plagiothecium denticulatum* | . | . | . | . | . | . | . | . | 25 | 5 |
| *Pleurozium schreberi* | 100 | 100 | 88 | 96 | 13 | 13 | . | . | 25 | 10 |
| *Pohlia nutans* | 13 | 17 | 13 | 14 | . | . | . | . | . | . |
| *Polytrichum commune* | 4 | . | . | 1 | . | . | . | . | . | . |
| *Polytrichum formosum* | . | . | . | . | . | 13 | . | . | 13 | 5 |
| *Ptilium crista-castrensis* | 92 | 50 | 25 | 56 | . | . | . | . | . | . |
| *Rhytidialdelphus loreus* | . | . | . | . | . | . | 13 | . | 13 | 5 |
| *Rhytidialdelphus squarrosus agg.* | . | . | . | . | . | . | . | 13 | . | 3 |
| *Sanionia uncinata* | 4 | 4 | 8 | 6 | . | . | . | . | . | . |
| *Sphagnum squarrosum* | . | . | . | . | . | . | . | . | 13 | 3 |
| *Tetraphis pellucida* | . | . | . | . | 13 | . | . | 13 | 25 | 10 |
| *Calypogeia muelleriana* | . | 4 | . | 1 | . | . | . | . | . | . |
| *Cephalozia bicuspidata* | . | . | 8 | 3 | 13 | . | . | . | . | 3 |
| *Cephalozia lunulifolia* | . | . | . | . | 13 | . | . | . | 13 | 5 |
| *Lepidozia reptans* | . | . | . | . | . | 25 | . | . | 25 | 10 |
| *Lophozia ventricosa* | . | 4 | 4 | 3 | . | . | . | . | . | . |
| *Lophocolea heterophylla* | 13 | 50 | 71 | 44 | 63 | 88 | 50 | 63 | 100 | 73 |
| *Ptilidium ciliare* | . | 4 | 8 | 4 | . | . | . | . | . | . |
| *Ptilidium pulcherrimum* | . | 4 | . | 1 | . | . | . | . | . | . |
| *Cladonia arbuscula* | 4 | . | . | 1 | . | . | . | . | . | . |
| *Cladonia chlorophaea* | 8 | 8 | . | 6 | . | . | . | . | . | . |
| *Cladonia coniocraeae* | 4 | . | . | 1 | . | . | . | . | . | . |
| 1 m$^2$ plot number | 24 | 24 | 24 | 72 | 8 | 8 | 8 | 8 | 8 | 40 |

# Appendix 4

Summary with issues and specific recommendations from the reference group seminar held April 4-5, 2013, Ås.

Lise Dalsgaard

The main experiences and recommendations from the seminar were:

### General

Measured soil C on the two sites will be a result of site history – it is crucial that this be reflected in the analyses and simulations.

It will most likely be difficult to get measured values to agree with simulations particularly when only two sites are available – be aware of any bias in the measurements and be prepared to find large uncertainties. However – these could be valuable data. Be ready to use studies outside of Norway to complement the findings.

Be aware that soil C dynamics is a result of many biological processes of which you in your measurements (the two sites) only have few represented. Fx below ground C input to the soil is not measured.

When publishing results from the study sites you will have to satisfy both scientific ambitions, expectations in the National System and UN reviewers of the GHG inventory. Be ready to publish results in international journals as this is often a good basis for a positive review.

### Yasso07 specific

Studies around the world indicate that Yasso07 tends to give low C stocks in areas with high precipitation (where measured C stocks can be high). Investigating why stocks may be biased is important even though estimation of C changes seem realistic. Development of Yasso07 is ongoing and soil C stock data from Norway will be used in this process.

A comparison of measured C stocks near the Norwegian/Swedish border will be necessary and useful to clarify why Norwegian C stocks seem to be higher than Swedish.

The general approach of using Yasso07 in a spatially explicit manner (as in Norway) is good. Be aware of differences among published parameter sets.

### Summary of day 1 and day 2

Present were: In reference group: Britta Hoem, Lars Vesterdal, Mikael Ohlson, Per Arild Arrrestad, Jari Liski. Project participants Tonje Økland, Janne Kjønaas, Kjell Andreassen, Signe K. Borgen, Lise Dalsgaard, seminar participants: Jogeir Stokland, Rasmus Astrup, Arnold Arnoldussen.

The first part of the seminar (day 1) focused on the approach chosen – why the two sites were selected and what issues should be carefully considered in the further work with data and simulations.

From the start presentation by Janne Kjønaas it was shown that while measuring the rate of C change in forest soil on a national scale may be preferable – this is difficult or irrelevant in Norway for different reasons: large scale re-measuring of ICP level I[7] soil data is costly and may present difficulties in a setup otherwise based on non-destructive measurements. Other data sets exist (ICP level II data, 17 sites; SFT soil chemistry monitoring program[8], 8 sites). These data sets are limited by difficulties associated with sampling methodology. Detailed studies on two sites to complete a 30+ year long time series of soil C has therefore been selected as an alternative way. 30 years is considered a very long time series for soil C.

Analyses on the measured soil C data from the two sites were preliminary and discussion focused on identifying recommendations for the future work. Former forest type and land use, site preparation at establishment and fire history will influence the results (the measured soil C) and model applications must reflect this. Be aware of risk of bias due to slight changes in sampling methodology over time. Use whole profile C and not individual soil horizons. The very small experimental plots may warrant aggregation of existing treatments. Models take different input (drivers) such as climate and litter input to the soil. These determine the simulated soil C dynamics and must be used to interpret results and suggest reasons for any difference between model and measurements. If soil samples are unbiased and input can be well quantified – these two sites should make up valuable data sets.

After the presentations on soil samples the focus turned to the vegetation studies on the two sites. It was emphasized that this project covers above ground biomass of ground vegetation, but depends on other data to quantify below ground biomass as well as litter production. Roots and mycorrhizae are important sources of C input to the soil – these inputs are not quantified on these sites as they are time consuming measurements. The two sites differ greatly in the amount of ground vegetation and probably in production and build-up of litter – most likely due to differences in stand structure as well as decomposition rate (clay vs. sand).

Holger Lange presented the models that will be used for the simulation studies on the two sites. Romul is the more detailed model and Yasso07 the simpler model. The following discussion focused on the experience available for the Yasso07 model. Studies around the world indicate that Yasso07 tends to give low C stocks in areas with high precipitation (where measured C stocks can be high). But not only precipitation determines the moisture availability at a site, also topography, evaporation etc).

We should not ignore the fact that C stocks are poorly estimated at certain sites – even though estimated C change may be realistic. Model development to capture the processes giving high C stocks is necessary and identification of causes of why simulated stocks are low is important. The plan for

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[7] ICP Forest: the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests operating under the UNECE Convention on Long-range Transboundary Air Pollution.

[8] SFT: Statens Forurensningstilsyn, Statlig program for forurensningsovervåking; Overvåking av langtransportert forurenset luft og nedbør.

Yasso07 model development (at SYKE) is to use more C stock data in the next parameterization. In the longer term Yasso07 will have a new structure and include processes thought to better represent a variety of soil development processes. Paludification (slow peat formations) is not represented in Yasso07. Swiss study at steep mountain forest site showed that none of several models could estimate measured C stock or dynamics; example that some sites may be particularly problematic and such an exercise is very difficult.

### By the end of day 1 some comments and recommendations were:

Two test sites is not much and for soil C measurements there is a danger that it is not enough. C input to the soil from mycorrhizae is expected to be large in boreal forests (ref. to recent Swedish publication in Science (Clemmensen et al. 2013); 50-70%). Be aware that soil C dynamics is a result of many biological processes of which you in your measurements (the two sites) only have few represented. In fact you need knowledge on the whole system. Data on the biological processes are crucial – i.e. all the biological controllers over time (litter input/turnover, stand history). Be aware also that the selected stands are plantations and may not show similar C dynamics as that found in a more typical Norwegian forest (i.e. not-plantations). Look at Swedish repeated soil measurements (forest soil inventory). Particularly for the region close to the Swedish border (Fylke Hedmark) these are likely to be useful in validation. Get as much information from the data as possible (trends) but expect that uncertainty may be large. Important to represent stand history in simulations. We have to satisfy several aims: i) our scientific ambition, ii) ministry expectations, and iii) UN reviewers of the GHG inventory. Use current study for as much as it is worth but be open to also use studies testing model processes on relevant sites / situations that may not necessarily be in Norway. As far as possible – be ready to publish results in international journal as this is often a good basis for a positive review.

On day 2 the focus was on the national level estimate of forest soil C change. Important issues and recommendations were:

While several Yasso07 parameter sets have been published the safest is to use the one from the Graphical User Interface. Do not use recently published parameters from Finnish validation study (are specific to study results in Finland). Large differences observed between measured and simulated stocks (even though with a changed parameter set the simulated stocks will be larger). Such large differences are worrying; may be related to drainage status of the soils sampled. Appears to be differences between soil C stock in Norway (high) and Sweden (comparable to Yasso07 estimates). A comparison of measured C stocks near the Norwegian/Swedish border will be necessary and useful. Differences could be caused also by management practices and sampling methodology. Soil types may also differ. General approach of using Yasso07 in a spatially explicit manner is good. Litter estimates and measured soil C stock from Norway will be used in next Yasso07 parameterization.

# Appendix 5

Minutes from the reference group seminar held October 24th, 2013, Ås.

Project: Changes of carbon in forest soil – reference data for selected field sites and validation of process models for use by the UNFCC and the Kyoto Protocol reporting. 2. and final reference group seminar.

Participants: Lars Vesterdal, Per-Arild Aarrestad, Jari Liski, Ingeborg Callesen, Line Tau-Strand, Holger Lange, O. Janne Kjønaas, Jogeir Stockland, Aaron Smith, Signe Kyndig Borgen, Rasmus Astrup, Tonje Økland, Silje Skår, Jørn-Frode Nordbakken, Lise Dalsgaard.

Minutes are based on notes and comments from: Jogeir Stokland, Aaron Smith, Lise Dalsgaard, Signe K. Borgen, O. Janne Kjønaas and focus on issues emerging during the discussions as the slides from the presentations (see Agenda) are available as pdf.

### Part 1: Forest soil C dynamics, results from experimental sites - presentation summary

Vegetation studies focused on the site in Nordmoen (Skiptvet dense and with very sparce ground vegetation). Too early to present relationships between cover% and biomass.

SOC data not fully analyzed. Only significant trend with time appears to be a significant decrease with time in SOC in organic layer under birch in Nordmoen and due to the decrease, the SOC stock in 2012 is lower under birch than under spruce and pine.

Model studies indicated that Yasso07 overestimates SOC stocks in Nordmoen by a factor of ca. 2 compared to measured SOC. In Skiptvet Yasso07 estimate of SOC stocks was close to measured stocks. At both sites Yasso07 predicted an initial decrease in SOC followed by a continuous increase with time (Skiptvet and birch Nordmoen) or a continuous increase with time only (pine and spruce Nordmoen). While an initial decrease in SOC may agree with the measured stock, a consistent increase late in the time series is not supported by measurements. Romul reproduced SOC stocks in Nordmoen spruce with a moderate increase in SOC over the course of the time series but this was not supported by measurements. For Nordmoen pine and birch and for Skiptvet, Romul reproduced the SOC stocks at the beginning of the time series but had very steep increases in SOC stocks with time not supported by measurements. Calibration parameters (k8 (=humus layer mineralization parameter), d) were in some cases set at (or even beyond?) their recommended limit.

### Discussion: part 1 - measured SOC stocks and changes

The very low measured SOC in Nordmoen (ca. 3 kg C/m2) may indicate that this site is an outlier. Despite the fact that measurements do not cover the entire soil profile. The nearby “chronosequence site” may give a more realistic and representative C stock (re-measurement of these sites could be valuable). Soil data from the two sites indicate that they are comparable in mineral soil horizons. Low SOC could be related to slash removal prior to stand establishment for the current tree species trial and/or intense historical use of wood in the area (glass production). For the time during the tree species trial the Nordmoen site was fenced to avoid heavy browsing (ie. low SOC probably not related to browsing). The decrease in SOC (forest floor) in Nordmoen (birch) likely represents a transition from spruce to birch – not a general feature of birch stands.

### Discussion: part 1 - measurements vs. model

When including soil C down to 1 m depth (ie, relying on supplementary data), the Yasso07 runs for Nordmoen (indicating a SOC stock of 7-9 kg C / m2; spruce) may fit very well. The repeated soil sampling is based on layers sampled for acid rain research initiated in 1974, where the soil profile was not sampled continuously. The soil pool in 2012 was sampled continuously down to 33 cm mineral soil giving a total pool of 5 kg C m-2. The nearby "chronosequence-site" at Nordmoen showed SOC down to 1 m soil depth (found from soil sampling) of between 8.7 and 13.3 kg C m-1, and the comparable 30 yr stand in the chronosequence contained 9 kg C m-2. At Skiptvet, where the soil was sampled continuously down to 30 cm, Yasso presumably (?) underestimates the SOC pool as Yasso model SOC down to 1 m soil depth. A way to estimate the amount of deep soil C would be to use the NFI database (ICP level 1 soil profile database) to find SOC stocks in the deeper mineral soil from soil profiles of comparable soil type. If biomass needs to be updated and this has effect on litter input then simulated stocks will change accordingly. Preliminary data presented needs to be checked.

### Discussion: part 1 - model behavior

The two chosen models, Yasso07 and Romul, represent a spectrum – a "simple" and a "complicated" model in terms of input requirement and user defined parameterization.

None of the models had good fits with the measured SOC for the two sites. While Romul in some cases came closer to the stock levels (first few data points; given as starting points) it also tended (in some situations) to exponentially climb toward very high SOC. Yasso07 predictions more realistic dynamics (less flexible) but perhaps different in scale related to measured soil C on these two sites (depending on assumptions for the SOC that was not included in measurements). Which model is the "better" is not possible to determine from data on only two sites. The relevant issue is that we need to use the study to learn how models react to input over time and may offer insight into processes in addition to what is measured. Identify the most critical part of the model.

### Discussion: part 1 - simulation strategy and spin-up

As Yasso07 treats the decomposition and input of branches, coarse roots and deadwood (in the GHG reporting) as well as non-woody litter it is necessary to be careful to include dead branches and large-dimension dead wood in the measurements in the same manner as they are represented in Yasso07. Standing dead biomass is not included as part of the soil in the reporting (it is DOM, and not in SOC measurements on these two sites). Dead wood should therefore not be considered part of the soil in our case.

Coarse-woody litter was included in the spinup for Yasso07 in these two sites and in the "imitated" spruce rotation (presimulation) prior to the current ca. 40 year old stand. But for the simulation starting at year 0 in the current stand coarse woody litter from mortality was not included. This was an attempt to make simulation stocks as comparable to measured SOC stocks as possible (i.e. simulated stocks should not include standing or lying dead trees).

Yasso07 is usually initiated by a spin-up to equilibrium primarily to partition the C into different pools (AWENH, chemical pools) at the beginning of the simulation. Initial values can be set by the user based on fx a known (measured) SOC stock, but spinup typically provide better partitioning into the different chemical pools than pure guessing. Input used for spin-up represents site-history. It is important to be aware how well the historical data is matching the actual site input data being used. Mismatch here will result in rather sharp increase/decrease of C levels relative to spinup values (regardless of the expected representativeness for the region or site of the spin-up/historical data). Effects of steady state litter input on simulations have been published.

### Discussion: part 1 - recommendations, ideas and consideration for next steps

Yasso07 is calibrated from a large group of sites, and is not very site specific. The combination of low measured SOC and high litter input (Nordmoen) seems unlikely (an input of 250 g m-2 yr-1 and soil C of approx. 4 kg is a very unlikely combination) – based on NFI-simulations maybe the likeliness of such a combination can be quantified.

Use litter from NFI at the start, then measured litter data from actual site based on measured biomass. The change in C pool is too large, which is connected to litter input Investigate how these sites are different to the NFI data.

It is not straightforward to use the two sites to support/build national method (Yasso07, NFI) – consider: if we make model fit measurements – would this application be relevant on a country scale? To force models to fit measurements may not give much information.

Contrast the two sites with information on a country scale – are simulation inputs and/or measured SOC similar or exceptionally different?

On the two sites – used as a study platform: how steep a trend (both directions) is possible while still staying within the error bars of measured SOC? What assumptions in litter input for the spinup are required to reach the measured change in SOC?

Uncertainty analysis is good. But separate the uncertainty into different contributions or sources of uncertainty. AWEN chemical litter composition is the smallest cause of likely uncertainties in the model. Different components of uncertainty needs to be presented. The presented uncertainty for the sites only cover only model parameter uncertainty – not litter amount.

SOC measurements are difficult and may be unreliable – how large is the uncertainty – how large would the uncertainty be if the measurements would not be able to pick up a trend in SOC? Important to understand how the measurements relate to the trend. Including the errors.

### Part 2: Country scale - presentation summary

Overall evaluation of the Norwegian forest soil data database (ICP level 1) indicates that it is reliable (be aware of separate document describing details of the database). Error may be high on individual profiles and vary among soil types, depth etc. Compared to Swedish soil inventory (data available from C. Ortiz) a higher frequency was found in the Norwegian data base of hydromophic soils. These are different profile sampling strategies in Norwegian and Swedish data. - Norwegian data are based on continuous sampling down to rock or 1 m soil depth.

Country scale Yasso07 estimates of SOC stock (NFI plots) are still low after changing parameter set and initialization method (presimulation with extrapolated data 1960-1990). Presimulation (or back casting) had variable effects depending on tree species and site index presumably related to inclusion of harvest residues in early inventory years.

### Discussion part 2 - back-casting / presimulation

The back-casting to the 1960-ies for individual plots represent novel and very valuable data. New back-casted series should be compared to old NFI data on biomass/volume if possible (is planned). There are many advantages of site specific calculations and the information is very useful irrespective of model used. Double check the average of individual measurements/variables from strata of the back-casted data with corresponding averages from strata derived from the actual NFI data measured at the same time. If you find a good match here, that will further strengthen the value of the back-cased data. (Fx. an entry in 2005 which was back casted from 2010 NFI observations should be compared to actual NFI registration in 2005 from the relevant NFI plots / strata).

### Some final recommendations

Consider site specific study an examplification of the NFI approach.

Is the litter+SOC combination at two sites likely when compared to the country scale data? Test the suitability and validity of the approach through litter and decomposition. Maintain the division of litter but fit the litter input level to get level of soil C, and evaluate how litter input over the experiment need to develop to reflect the soil C stock. - Can get the initial value correct, but the trend wrong. Base evaluation on litter measurements on site. Use the two sites as a platform for sensitivity analysis: 1) change litter input levels, 2) keep litter input levels, but might be higher decomposition rates. Play around with turnover rate that might change with age. Do not tune the models to fit, but use them for sensitivity analysis for the two sites, that then will be linked to the national level. Try to use spinup to calibrate output to go through 1st measurement point. What is necessary to reproduce measurements, is this realistic input values? Work on explanations WHY fits are not good, explain the differences by use of the modeling exercise from the two experiments. Build argumentation that while stocks may not hit the spot, changes can still be ok. Work with other reporting groups using Yasso07 to build argumentation.

On national level, find the most essential conditions where Yasso07 works and where it does not work (set up simulated vs. measured stocks; probably median stock is better than mean). Predictions from country scale Yasso07 should be studied more closely and in relation to many categories (fx. Soil type, vegetation type, drainage….). The best correspondence can be expected in well drained conditions. Find best possible humidity indicator in country level data. Can reproduce drainage classes by vegetation classes and topography.

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NIBIO
NORSK INSTITUTT FOR
BIOØKONOMI

Norsk institutt for bioøkonomi (NIBIO) ble opprettet 1. juli 2015 som en fusjon av Bioforsk, Norsk institutt for landbruksøkonomisk forskning (NILF) og Norsk institutt for skog og landskap.

Bioøkonomi baserer seg på utnyttelse og forvaltning av biologiske ressurser fra jord og hav, fremfor en fossil økonomi som er basert på kull, olje og gass. NIBIO skal være nasjonalt ledende for utvikling av kunnskap om bioøkonomi.

Gjennom forskning og kunnskapsproduksjon skal instituttet bidra til matsikkerhet, bærekraftig ressursforvaltning, innovasjon og verdiskaping innenfor verdikjedene for mat, skog og andre biobaserte næringer. Instituttet skal levere forskning, forvaltningsstøtte og kunnskap til anvendelse i nasjonal beredskap, forvaltning, næringsliv og samfunnet for øvrig.

NIBIO er eid av Landbruks- og matdepartementet som et forvaltningsorgan med særskilte fullmakter og eget styre. Hovedkontoret er på Ås. Instituttet har flere regionale enheter og et avdelingskontor i Oslo.

Forsidefoto: Arne Stuanes

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