Minutes from an SNS network (N 2010-9) workshop

Long-term effects of intensified harvesting for bioenergy - what can we learn from established experiments?

Drøbak, Norway, 10-12. August 2010

Participants

Name	*Institute*
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Kjersti Holt Hanssen	The Norwegian Forest and Landscape Institute
Sofie Hellsten	IVL Swedish Environmental Research Institute
Ulf Sikström	Skogforsk, Sweden
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Tuesday 10/8 2010 – Country presentations

Nicholas and Karsten welcomed the participants and in his introduction Karsten emphasized the importance of knowledge on long term experiments.

Questions and comments

- Brian: The Nordic countries, Canada and USA should coordinate their activities within this field, as this may be a key for cooperation. He expressed the hope that a well coordinated cooperation could lead to funding.

Gustaf Egnell, SLU, Sweden, emphasized that Sweden has quite a lot of information on the topic, but that most of it has been done by PhD-students. This means that the information is small-scale and scattered, with large amounts of data only being available on people's personal hard disks. The compilation of data from old/all experiments is an ongoing process in Sweden, and it is far from finished. He underlined the importance of analyzing all the data together

A new major research program "Future Forests" (www.futureforest.se) focusing on sustainable management of forests under increased demand and uncertainty started in Sweden in 2009.Together with this two new research forests have been established and they will be heavily exploited. Presently, background measurements are being made. Landscape level data will be obtained from this study.

The project has been grated 40 mill SEK for the first 4 years and will hopefully continue for 8 years.
A Nordic database, NOLTFOX (www.noltfox.com) gives very rough information about which long-term experiments that exist. The database contains information on a large amount of experiments, but it is not complete.

Another site that contains information about long-term studies is www.silvaboreal.com. In this database there are 87 research plots dealing with slash removal. The database has existed for 4-5 years, and it is still being elaborated. The database is hosted by SLU and contact persons are given at the web page. The database is in Swedish only.

A number of available experiments were mentioned:

- Björkroths trial with whole-tree harvesting at the final felling. The experiments include 4 sites, 3 treatments, and 4 replications. It was established in 1977-78.
- The SNS series with whole-tree harvest in the first thinning. The results have been published by (Jacobson *et al.*, 2000) and is on the way to published again including the last 10 years response.
- Kardell's trial which was established 1978-79. It includes whole-tree and stump harvest at the final felling in pine and spruce stands. There are 9 location, 4 treatments, but no replications. The data are only available on paper.
- The so-called GG trials that include thinning form, strength, and fertilization. They were established in 1966-1983 and results are recently published in Studia Forestalia Suecica (http://www-umea.slu.se/bibum/studia/).
- Sune Linder's and Johan Bergh's interval-experiments (Bolags-experiments) about how often fertilizers should be applied? Experiments with balanced nutrient supply are established at 15 sites. The experiments do not include any harvesting treatments.

Questions and comments:

- We need tree physiological knowledge: what is in the trees in not the same amount as what they need.
- Karsten: what is the level of synthesis already done? Gustaf: Statistical analyses and publication is the next step.
- Brian: Canada also has the problem with lack of results at landscape level, but they have tried to do something where there is a cluster of experiments and in that way attack the problem.
- Gustaf: Data from old ruined research plots. Nicholas: Data are also obtainable from old reports. Gustaf: But old reports often just include plotted data.

Ulf Sikström, Skogforsk, Sweden addressed long-term field experiments managed by Skogforsk. These are mainly randomized block experiments, but include also catchment studies. During the last 50 years, about 300 experiments related to biomass removal and nutrient addition have been established. The nutrient addition includes different fertilizers (N, P, K), lime and biofuel ash. Today, c. 120 of the experiments are active. Data from many of the old abandoned experiments still exist. Only two catchments studies are running; one of them includes wood ash treatment. Skogforsk are responsible for WTH experiments that includes WTH in both thinnings and final felling, and experiments that include wood ash addition in both clear-fellings and closed stands. Various parameters have been measured.

- Results from the Nordic series of WTH thinning experiments have been published (Jacobson *et al.*, 2000).
- There are 7 sites with experiments on WTH in Norway spruce final felling.
- There are 18 sites with wood ash experiments on mineral soils, where forest yield has been measured. Of these, 15 are in closed forest stands. Usually the doses are about 3 tonnes per ha.
- A current SNS project will provide a meta-analysis of data from wood-ash and liming experiments on mineral soils. The hypothesis is that the ash/lime affects the N availability in the soil and causes changes in tree growth. The effect depends on the productivity of the site, reduced stem growth on low-productive soils, and increased growth on high-productive soils. In the intermediate sites, no effect is expected.
- Experiments include also wood ash added on peatland with the purpose of testing various doses. Measurements on tree growth, greenhouse gas emissions and water chemistry are included.
- There are a large number of N-fertilization experiments. For example, predictive functions for tree growth responses have been developed, based on data from 230 sites (Petterson, 1994).

Reference:
Pettersson, F. 1994. Predictive functions for impact of nitrogen fertilization on growth over five years. The Forestry Research Institute of Sweden, Report No. 3. Uppsala. 56 pp. ISSN 1103-6648.

Questions and comments:

- Gustaf: There will be a large amount of ash available from 2011, because it will be prohibited to deposit it. An option is to use it for forest road construction.
- Karsten: Is there an effect of time after fertilization? Gustaf: It is too short to consider only 5 years. Effects should be studied at least for 10 years. The Finnish liming experiments are up to 40 years old, and they have sometimes been re-treated. Ulf: The occurrence of boron deficiency is one drawback in relation to liming experiments on some sites. Karsten: Have the effects of temperature or latitude been studied? Ulf: They are correlated, but site index was the strongest predictive variable in a preliminary study of the joint Nordic data (ash and lime exps.). Karsten: I would expect the opposite trend for Denmark: negative effects of wood ash fertilization on richer sites, as ash can initiate decomposition. Gustaf: N is immobilized by decomposers in Northern Sweden. It has happened that trees were killed due to boron deficiency after liming.
- Ulf: It is important not only to compile the data, but also to look at the quality. Gustaf: It can be a problem that there are no replications, but data should only be left out, if there the drawbacks are very obvious.
- Karsten: Is there an effect on N-fertilisation responses of stand age? Ulf: The effect do depend on stand age or stand development stage, e.g. young Scots pine trees show a weak response in height growth which is not the case for Norway spruce. It is more profitable to fertilize old stands.
- Effects of pre-harvest N-fertilization (next generation effects): Brian: If fertilization can carry on into the next generation, then it would be logical that removal of N can also persist to the next generation. Ulf: N-fertilization gives only a temporary effect. Karsten: If P is the limiting nutrient, then the stand will react differently to addition of N. Effects of P addition have not been seen in the boreal-nemoral areas, but they might occur in temperate regions.

On very fertile sites in southern Finland, effects of joint NP fertilization have been shown, but not P alone.

- Brian: There exists a Canadian paper on fertilization effect in the next generation (Footen P.W. *et al.*, 2009). N fixation takes place in the slash, but coarse woody debris might not be important as a source of N, but maybe as a habitat for micro-organisms. The question is if we need the carbon base for N-fixers, which we will not have if we just remove the slash and fertilize.
- Gustaf: Carl-Olof Tamm started experiments with N addition back in 1971. The heaviest loads have been given up now as they induced boron deficiency. These plots show that micro-biology communities are quickly restored to their former status, and that there are no long-term effects on the soil in terms of microbiology.

Nicholas Clarke, Norwegian Forest and Landscape Institute (NFLI), Norway, told that a large part of the energy production in Norway is already from renewable sources, being based on hydropower, but that fossil fuels should be replaced by biofuels. One of the most obvious solutions is to harvest the forest residues. Activities in Norway include:

- New integrated experiments that were set up at Gaupen (eastern Norway). Two treatments are included: 1) residues piled and removed, with measurements being made both inside the piles and outside (from where residues had been removed to build the piles), and 2) residues spread evenly over the whole plot. The trees were harvested in March 2009 and the piles removed in September. The removal treatments are close to the current practice, i.e. about 63% of the residues are removed, on average. In 2010, a new similar experiment was started at Voss (western Norway). This site has a different climate compared to eastern Norway. In western Norway there is more precipitation and a milder climate. Unusually for the forests in western Norway, the stand at Voss is a "natural" Norway spruce stand about 140 years old. The stand at Gaupen is also a "natural" spruce forest.
- GreenWood: About harvesting and road building in steep terrain. One aim is to quantify the soil erosion.
- Bioenergy Innovation Centre (CenBio), which also deals with agricultural bioenergy. The idea is to address several issues in context: biological, technical etc issues.
- Bioenergy Promotion Project. Interreg project on sustainable bioenergy production. Policy-relevant reports have been published.

Questions and comments:
Karsten: How did you deal with the effects of slopes in the integrated experiments, as the effects of removals will probably depend on the slope? Nicholas: The blocks are paired to ensure that slopes are "equal" among treatments.

Kjersti Holt Hanssen, NFLI, Norway, presented an overview of the Norwegian long-term experiments:

- Skog og Landskap has a database which contains all Norwegian long-term experiments (www.skogforsk.no/feltforsok/). The database also includes graphical presentation of the results.
- There exist two experimental series with WTH. One series with 4 plots is part of the Nordic SNS series. The other series has 8 sites with WTH experiments: 4 sites with Norway spruce, and 4 sites with Scots pine. For this series, growth reductions have been shown throughout the measured period (0-30 years). The richest pine site, however, showed slightly better

growth after whole-tree harvesting. However, plots are too few and the range of site indices within each species is too small to conclude about whether site index matters. Growth reductions are significant for Norway spruce, but not for Scots pine. Even after one season it was possible to see growth reductions. This may indicate that some other effect than nutrient availability is also present – perhaps soil temperature or moisture.

- Thus, the growth reduction appeared immediately after the thinning and was still there after 25 years. Manuscript on these results is being prepared.
- Several fertilization and liming experiments exist.

Questions and comments:

- Brian: Concerning induced N deficiency and the speed with which N is circulated from the slash: Andrew Weatherall recorded N14 in the needles of living trees 3 months after adding N14 enriched slash (Brian).
- Gustaf: Be aware of the autocorrelation when analyzing data: basal area growth in one period depends on the basal area resulting from previous effects.

Karsten Raulund-Rasmussen, ***Morten Ingerslev*** and ***Inge Stupak***, Forest & Landscape Denmark, presented the few Danish experiments which include intensive harvesting treatments: 1) WTH in thinnings on two sites, and 2) WTH in final felling on two sites (presented by Inge). The species is, in all cases, Norway spruce. The WTH thinning experiments show only weak effects which differ among sites and with time after harvesting. The WTH final felling experiments show a pronounced effect (decrease in growth) after 25 years for one site, while no effect on forest floor C and growth was found for the other site.

Morten gave a presentation on the questions: “To what extent can ash application ensure sustainability?” and “What are the criteria for sustainability?”. With regard to different sustainability criteria, he concluded that if the criteria were:

- perfect nutrient balance (compensating the nutrient export, ensuring that all exported nutrients are returned), then ash application must be regarded as not being sustainable, as the input and output often will show a deficit.
- adding some of the nutrients that were exported (partly compensating the nutrient export), then ash application can be regarded as being sustainable.
- ensuring of fertile soils in the long term perspective, then ash application may be regarded as being sustainable, most likely on nutrient poor soils.
- improving tree nutrition in the long term perspective compared to no compensatory fertilization, then ash application possibly can be regarded as being sustainable, most likely on nutrient poor soils.
- making sensible use of the ashes compared to waste dumping, then ash application possibly can regarded as being sustainable, however, the contents of ecotoxic components and reactivity should be considered before general conclusions can be drawn.
- bringing back the forest ecosystem to the stage before harvesting or to a stage where harvesting had not been carried out, then ash application most likely can be regarded as not being sustainable, as new and different situation may be introduced by the application.

Fertilisation experiments and experiences were presented by Karsten, who gave an overview of the historical reasons to fertilise in Denmark; until the 1940’ties the focus was on stand establishment.

It switched to increased growth until about 1980, when the motivation changed to vitalisation fertilisation. Since about 2000, focus of discussions has been on compensation of nutrient removals after intensive harvesting. Experiments support that synergetic effects can be obtained when fertilising with both N and P, and that the fertiliser response depends on soil fertility; soils of low fertility responds more positively than sites of high fertility. He concluded that fertilisation can be a way to produce more biomass in plantations.

Questions and comments:

- Gustaf: In wood ash fertilization, should we be happy with elevation of a few elements in the top soil layer or what do we wish to obtain? Should focus be on wood production or water quality? Morten: We wish to secure compensation of nutrient removals in the long term. Gustaf: it is important to secure a balanced nutrient supply and not introduce new imbalances. This emphasises the importance of applying the 'right' ashes on the right locations.
- Discussion on the nutrient balance approach and what it can be used for. Gustaf: site adapted recycling is preferable. Wood ash should not blindly be put anywhere WTH has taken place.
- Karsten: We should not fertilize in old stands, but in younger stands. Old stands are very good at recycling nutrients while this is not the case for younger stands. If we can identify a positive response to fertilization, we can probably also have negative responses to intensified harvesting. There may, however, be practical problems with spreading fertilizer in young stands.
- Karsten: Fertilization is politically incorrect as it is associated with eutrophication of the water bodies. Sludge is also available in huge amounts from animal farming. Optimizing fertilization for increased growth without increasing leaching should be possible.

Heljä-Sisko Helmisaari, METLA, Finland introduced by presenting the Finnish target for use of wood chip in energy production: 13.5 mill tons by 2010 (potential 16 mill tons). A large part of the potential is being harvested in agreement with Tapio guidelines. The potentials are concentrated in central Finland, where also stump heaps can be seen everywhere from the roads. Some Finnish activities were presented:

- The 'common Nordic experiments' include for Scots pine: 14 experiments in total, 8 of these are in Finland; for Norway spruce: 8 experiments in total, 6 of these in Finland. The 'common Nordic experiments' include both harvesting strategies (WTH and Stems only) combined with fertilization. Generally, increased biomass export leads to decreased growth (most significant for Norway spruce). Fertilization compensated the growth decrease in WTH. New results are available from Smolander et al. (2008) and (2010), Helmisaari et al. (in prep.), Tamminen et al. (in prep.), Luiro et al. (2009).
- A new manuscript is being elaborated with results from the Finnish WTH thinning experiments (Helmisaari et al., in prep.). The Finnish SNS experiments also have treatment with extra residues. All treatments have 3 replicates. The second thinning was performed in the same manner as the first one. There are almost significant differences in needle concentrations between treatments. Growth responses are more interesting as the response is more pronounced than for needle concentrations. In the future it will be attempted to explain different response with nutrient budgets. Some Scots pine stands were thinned only once (three experiments). There were almost no differences found between treatments. Some Scots pine stands were treated twice and they continued to show a negative effect on growth.

The Norway spruce stands that were thinned twice showed a constant negative trend with regard to growth. The most northern experiment (Scots pine) in northern Finland (Lapland) responds positively to WTH. The question is why?

- There were generally significant differences in basal area and volume increment. An attempt was made to make a predictive model. For Norway spruce there was an almost significant trend with amounts removed and site index; more negative effects were found for increased removed amounts, while less negative effects were found for fertile sites. No conclusions could be made for Scots pine. Removing and adding double residues gave opposite results of the same magnitude.
- On the sites with the largest increment decreases, there is also a decrease in the mineralization rate (four of the six Norway spruce stands). For diterpenes there was a lower release in WTH plots.
- For WTH final felling experiments there were no significant effects 22 years after removal of logging residues: Scots pine (heavy scarification). In the near future, soil samples from 2008 will be analysed and new measurements will be made. A new WTH final felling experiment was established in a WTH thinning experiment. Leaching, field vegetation under piles etc will be measured.
- New modeling studies are being performed with Russian growth model modified for Finnish conditions. The aim is to optimize the economic-ecological timber-bioenergy production.
- Individual tree experiments have been established, where logging residues are placed around the seedlings.
- A list of involved persons and current projects was given, some of them being: Hannu Ilvesniemi (fertilization wood ash and nitrogen), Pekka Tamminen (Logging residues…), Earo Kubin (Logging residue and stump removal and planting), Heljä-Sisko (stratified sampling in holes, heaps and unaffected soil).
- Experiments exist on nutrient release from decomposing stumps. These show that carbon is released, but not nitrogen.

Questions and comments:

- The two Norwegian Norway spruce stands in the SNS trials were thinned only once, so it is difficult to draw conclusions from these.
- Gustaf: The positive growth response in the WTH thinning trial in northern Finland could perhaps have something to do with temperature.
- Swedish stump harvesting experiments are being analyzed and published
- Brian: Roots on seedlings are moving along stump coarse roots.
- Kjersti: What are the practical recommendations for stump harvesting in Finland? Heljä-Sisko: There are restrictions in wet areas. At least 25 stumps per hectare should be left. Previously removal of stumps in pine was not recommended, but now it is accepted, because there are no data to say that there will be negative responses. The Tapio guidelines are revised almost every second year. It is also recommended to use a rough delimbing in thinnings.
- Heljä-Sisko: Forest owners decide what should be left in the forest and they do not want to give away the residues.
- Heljä-Sisko: Wood ash combined with N gives a positive effect on growth and this shows that the effect on growth increment appear to be a long-term effect, probably due to the long-term liming effect on the mineralisation of N (Anna Saarsalmi). It is difficult to separate effects of giving many nutrients with the ashes from the effects of applying a

liming agent. It is important that we take into account the long-term perspective if we want to make sound research based on the mechanisms.

- Karsten: We need to understand the mechanisms that interact during and after ash application, hence we need to make sound science that elucidates the chemical interaction of ash formation <-> ash hardening <-> ash properties <-> soil conditions <-> nutrient availability <-> nutrient uptake <-> tree growth.

Brian Titus, Canadian Forest Research, Canada, presented the situation in North America and gave an overview of the North American field trials. These field trials are being measured right now, and several persons are involved.

Currently WTH recommendations differ among Provinces. WTH is performed for economic reasons (stem at road side) and energy wood is a by-product of that. Nova Scotia wants to go back to stem harvesting only, but only Ontario is doing some science on this. There is an operational inertia to shift back to stem only harvesting.

The current types of energy wood in Canada are saw mill and pulp mill waste, trees from stand rehabilitation (young stagnant or dead stands), thinning (fire risk reduction), salvage of dead trees (insects, disease etc.), short-rotation plantations (mostly poplar, new), and logging residues which are often already at the road side. In Canada, 2 million ha per year are affected by wildfire, and 6 mill ha per yr are killed by forest pests. About 51 Tg yr^{-1} and 20 Tg yr^{-1} comes from harvesting residues. Different estimates exist of the available amounts in Canada: 11 mill, 19-32 mill tonnes/yr, 76-92 mill tonnes/yr. Probably the available amount is 20-40 mill tonnes yr^{-1} = 6 % of the energy consumption. Canada's forests are not in the Kyoto agreement as they it will be a source of carbon for the next 25 years.

Various environmental issues are addressed in the North American field trials:

- Soil degradation
- C cycling (what to cut and what to leave,
    - Renewable C time-frame: renewability over the life cycle of the stand (Manomet 2010), "our grandparents paid for it".
    - Growth intercept increases with post harvest site C
    - Limiting factors….
- Hydrology and water quality (Jeziorski)
- Biodiversity

Canadian results and activities:

- Canadian trials are mostly established on mesic sites, while now we would have targeted the poor sites. (Overview: BC: 12 sites. ON: 18+1 sites. QC: 3 sites, Black spruce, jack pine, Edatopic 1980 is the oldest exp., Maritimes: 6 sites (Mahendrappa), NL: 3 sites. There is a total of 43 sites, see also meta-database). Most of them set up in late 80s until mid 90s and most of the treatments are operational. No formal system has been established to secure data, so it is difficult to get the data.
- The results show reduced Ca in soil after WTH. Results for soil N are not equal to those for foliage N (Thiffault et al. 2006). WTH reduces leaching because of a better regeneration (Thiffault et al. 2006). WTH leads to reduced foliar Calcium on poorer soils in QC (Thiffault et al. 2006). Vector analyses were not performed as they are only good for

seedlings (cf. Vic Timmer). Fast growing species are able to release more cations due to weathering (Belanger et al. 2004).

- Old Canadian trials (Kranabetter et al. 2006, Fleming et al. 2006) show that microclimate is more important for growth than nutrients. Temperature and frost damage are the most important microclimatic factors. Generally, there were no differences between WTH and Stem only harvesting, except in Nova Scotia. Here it showed up that hares, hiding from eagles, were eating the seedlings!
- Modeling results suggest a loss of growth after WTH (Perakis et al. 2006, see also Bhatti et al. 1998 for Ca and N coupling. Generally, WTH leads to a growth loss.
- A literature review was made, focusing on total stem height versus post harvest year.
- Compensatory fertilization is not addressed in the trials. Fertilization is not permitted in ON. There are no trials with different levels of slash removal.
- The first WTH thinning trial is not running anymore.
- Long-Term Soil Productivity (LTSP) trials: over 50 sites. Run by MB Scots in the USA. The LTSP trials show different effects in the different climatic regions. They were set out to research limits (cf. Sune Linder) and not current practices. One result from these trials: compaction of soil can be positive on coarse textured soils. A point is that soil compaction is something to think about, e.g. in stump harvesting. LTSP summary: Limiting factors for productivity vary. Initially microclimate, competition are important, thereafter nutrition.
- Overview of LTSP trials:
    - Traditional WTH vs. Stem only: Un-replicated, one replicate per site, multiple replicates per site. Sites: mesic (BC), site productivity gradient (NL), nutrient x moisture (ON).
    - Legacy trials, paired monitoring plots, operational, cover site types quickly, but smaller number of treatments,
    - Mini plots (new in 2010),
    - Wildlife + site productivity (in planning): 10 ha large plots for wild-life, productivity less. 30 m tree response plots at one end, with replicates, difficult to replicate on-site because of the area needed. Biodiversity people will be invited.
    - Operations + biology (in planning) Logistic trials require 6 weeks of operations (in planning).
    - Case study area (new in 2009). Landscape around cluster of traditional field trials.
    - retrospective studies in QC (Thiffault)
    - Ash studies
    - Etc, see ppt presentation
- LTSP studies are of different complexity, and different temporal and spatial scales. Objectives are to explain what is behind the complexity.
    - Stage of stand development or harvesting objective
    - Biomass component
    - Crop species
    - Compensatory and other treatments
    - Confounding…
    - Etc, see ppt presentation.
- Results in relation to wildlife are that residues can be used as corridors for animals, cf. also Taumey Mahendrappa's experiments with hares.
- The Future Forest Initiative tries to make people do regeneration immediately after beetle attacks.

Wednesday 11/8 2010 – Excursion

Handouts from Long-term experiments at Bergermoen and Nordmoen and New integrated experiments at Gaupen are available from Annex I

Thursday 12/8 2010 - Discussions

Thursday's discussions were structured around questions. Each question was introduced by one of the participants:

What controls site-specific effects?
Introduction by Kjersti.

- N availability is the most important factor affecting forest growth. Any doubts?
- There are negative effects of WTH in the Nordic countries. Are these effects different from effects in North America? Probably effects are the same.
- Why does the effect last so long? Heljä-Sisko: It is logical as long as the residues are decomposing, which would be about 20-25 years. The effects fade out more quickly on nitrogen rich sites.
- Why does spruce tend to show more negative effects? Is it simply about the amount of slash taken out, or, in relation to thinnings, does pine retranslocate nutrients better or is it due to its lower nutrient need generally? Green needles are not litter, they have more available N. In litter, N is only located in the structural tissue, and is less available.
- What happens on nutrient poor sites vs. nutrient rich sites? In spruce the effects depend on site index, but not in pine.
- Why are there plots showing effects already after 1-3 years? Could the fresh needles on the forest floor explain the quick effects? Does different harvesting practice give different responses, cf. bundling practices in Finland that remove more needles than current practices in Norway and DK?
- Brian: What does N fixation mean? There is evidence that lodgepole pine can fix N.

What can the nutrient balance approach be used for?
Introduction by Sofie Hellsten, IVL Swedish Environmental Research Institute: Nutrient balances can be applied for nutrient compensation recommendations. Nutrient balances can be calculated at different scales/levels (e.g. site level and regional level) and applying different methodologies (e.g. input-output mass balances, weathering minus harvesting or comparing net losses of base cations with the soil pool of exchangeable base cations). Nutrient balances at site level assess the effect at that particular site and are likely associated with smaller uncertainties (applying site specific data) compared with regional calculations. On the other hand, nutrient balances at regional level provide the "general pattern", as it is difficult to compare results of site specific nutrient budget calculations when different input data are applied (depending on data availability at the different sites).

Nutrient balances are associated with uncertainties in deposition, weathering, leaching, N fixation and nutrient removal at harvesting. Furthermore, input-output mass balances may be inadequate to show the qualitative changes in the availability of an element, affecting its uptake and further (i.e. lack of dynamics). Recommendations for nutrient compensation should therefore be based on a

combination of results from nutrient budgets, experiments (on intensive harvesting effects and fertilisation) and dynamic modelling.

- Site level versus regional level budgets; regional level budgets are associated with higher uncertainty, e.g. from the inputs variables. It is a question which inputs/outputs that are the most uncertain? Deposition is maybe most certain. For Sweden, deposition is estimated based on modeling with the MATCH model, and/or measurements from 70 stations
- Karsten: Nutrient budgets must be interpreted together with other information, e.g. from long-term experiments.
- Gustaf: We must make uncertainty analyses when setting up budgets. What is worst case and best case?
- Brian: Canada is collecting all nutrient data in a database now, to try to set up nutrient budgets.
- Heljä-Sisko: Finland is calculating nutrient budgets for experimental sites so that they can be connected to the observed effects.
- Deposition is not compensation, because it falls everywhere.
- Is it good to remove "excess" N? It is still difficult to know.
- What is the contribution of different input/outputs to the overall balance? Generally, for base cations it is probably weathering, for P harvesting, and N deposition.
- Simple balances can be set up: weathering (PROFILE) minus harvesting. How reliable are weathering estimates made by models? Karsten: Accumulation of acidity (in the lower soil layers - C horizon) is an indicator of inadequate weathering.
- Another way to present things is by the rate of depletion. How quickly will the available nutrients be removed, i.e. "how many rotations are left"?
- Gustaf: pH is higher on the control plots compared to WTH plots, but it levels out over time. Karsten: if it is pH in the organic layer, it is not related to weathering. It is interesting if changes are in the C-horizon. Brian: How soon would you be able to see differences in the C horizon? Karsten: Not very fast, and acidity is only an indicator of insufficient weathering.

Conclusion: Nutrient budgets can be applied e.g. at site level, regional level, and for catchment areas. They can be applied in different forms, e.g. weathering minus harvesting, or rate of depletion. However, we should not just rely on nutrient budgets. Also other information should be considered when judging the site vulnerability to intensive harvesting.

What is recycling of wood ash good for?
Introduction by Morten

- We should not use the term "ash recycling", but ash application or nutrient cycling.
- Presentation of different sustainability criteria: 1) Perfect nutrient balance: not sustainable, 2) Adding some of the nutrients: sustainable, 3) Ensure fertile soils – long-term perspective: maybe sustainable, 4) Improve tree nutrition – long-term perspective: maybe sustainable, 5) Make sensible use of the ashes (waste management): probably sustainable, 6) Bringing the forest back to at the stage before harvesting: probably not sustainable.
- Gustaf: What positive effects can we get in the short term (that should also a criterion)?
- Gustaf: In most places, hopefully new energy solutions will show up, so that wood ash recycling is not needed in the long term. Karsten: I do not think we should rely on that.

- Karsten: Reactive ash can be a problem. A larger amount of elements will leach. How can we ensure that the elements are available and available where they should be?
- Morten: It is a problem that there is currently no connection between addition and effects. We do not know that if we take *this ash* in *these amounts*, then it will give *these effects* in the forest.
- Ash addition will not happen in Norway as it does not pay. Large deposit fees make the situation different in Sweden and Denmark. Karsten: If ash addition is not economic, then we should perform research to make it economic. Kjersti: Several experiments show negative effects of ash on poor sites. Karsten: …but we should also know why. Morten: Future EU legislation will probably not allow dumping of ash.
- Heljä-Sisko: Anna Saarsalmi's results show that the effect of N is better when given together with wood ash. Gustaf: The effect may be due to the higher basal area. N easily takes off if added together with ash. Flakaliden and Asa show different results for N given together with other elements. Sometimes there were no additional effects, sometimes there were. Other results from Anna Saarsalmi: Adding wood ash only gave a smaller positive effect after 11-15 years. Ploughed plots show no effect of wood ash addition at the time of regeneration. Positive effects were recorded at unploughed sites: ploughing probably overruled the wood ash effect as both stimulate mineralisation.
- Brian: maybe rather make a uniform fertiliser to crack the theoretical questions. Ash is so variable.

Does the soil provide an answer?

Intoduction by Karsten

- What have we learned so far: Sites respond differently to very intensive harvesting. There are robust and sensitive sites, see hypothesis slide, but many soils are intermediate. A postulate is that all soils are sensitive in the long-term.
- Gustaf: Do we have enough knowledge about soil today for prediction? Karsten: yes, and we can add to the existing knowledge on site index based on growth measurements.
- There are various impacts of very intensive harvesting on soil properties: Removing nutrients, acidification, compaction, decrease in soil organic matter, and influence on functional biodiversity. If we should try to explain the observed effects, we need indicators, e.g. for the forest floor: pH, C/N, amount (thickness, N amount), P content or other elements; and for the mineral soil: total N content, pH. Other indicators are available and total nutrient pools in the soil.
- Soil nutrient pools can be estimated by consecutive acidic extractions ("weatherability capacity"). Nordic-Baltic results (Callesen and Raulund-Rasmussen in prep) showed that for P and Ca, there are no sources in the soil for weathering in the long-term. Figure 3.6. from (Röser *et al.*, 2008): if you are out of the box, you are on the safe side. Soils have other important indicators than texture: mineralogy, but maybe texture together with pH can be used as good indicators.
- Gustaf: We are often dealing with N problems and this method is not suitable for this, but maybe it is suitable for more southern sites. Karsten: we should also include N factors, see slide about nitrogen. In the north, the soil formation is due to the climate (temperature, sometimes humidity), in the south it is due to geology.

Does a decrease in soil organic matter answer the question?

Introduction by Nicholas.

- The amount of forest floor organic matter changes during stand development. These results are consistent with Norwegian results (distributed during the field trip).
- Organic matter in the mineral soil layer also changes, negatively or positively. It could be an artefact of the analysis; when roots decompose, they are more likely to go through the sieves. Fewer roots are included from the first samples during the sieving (2 mm sieving). There will also be more roots when the ground vegetation starts to cover the site.
- Gustaf: Does most of the produced carbon stay in the stand (litter and fine root turnover)? Is the harvested carbon only a small part?
- Brian: The pulse is important. It is a functional question. An additional increase in carbon of 200 kg C per ha per yr^{-1} has been shown.
  Modelling with Yasso results in better growth without harvesting and slash. There is no big difference between harvested with or without GROT.
  Karsten: Differences would probably be even bigger in the long-term. Cf. Staffan's graph: WTH + fertilization: Is the negative effect due to the removed organic matter? Gustaf:

Should we go for a metadatabase, or do we already have one?
Introduction by Gustaf.

Type of initial database.
It was expressed that we should not go for a database with all data as it is bound to fail. It would be better to follow the North American approach and make a meta-database (Brian presented the template for the LTSP. It is a meta-database with basic data and contact information.). Maybe the North American database can be extended to the Nordic countries. It was discussed that the compilation of data should be a pragmatic process as you never get perfection.

Sofie mentioned that a Centre for Advanced Research on Ecosystem Services (CAR-ES) is also collecting data for a meta-database with N and P fertilization experiments. Perhaps this could be coordinated.

Second step
A second step will be to search for the right data for performing meta-analyses. It is important to look at the variables that are most commonly measured. Brian told that what has been done in relation to the LTSP experiments was to divide the trials into groups with different patterns. Currently the 10 year analysis is being performed. Gustaf mentioned that simple and rough pre-tests of a given hypothesis provide indications if further examination should be carried out. It is a good manner to explore and select the important explaining variables.

It could be an option just to add Scandinavian data to the Canadian database. Rob Flemming and Andy Scott would like to make analyses across the ocean.

An interesting example of a meta-analysis is that of Antti Wall (Biomass & Bioenergy, in press).

Copyright and cooperation
Gustaf pointed out that there may be problems with getting data, due to copyright issues. He emphasized that it is important to make signed agreements with people about the use of data, and

that people should be informed about the use of their data. Some participants pointed out that they preferred to publish their data before submitting them to a joint database.

Brian told that in the LTSP network, it is an offer that people can submit their data in any form and Canadian technicians will enter them into the spreadsheets (something should be produced by 31st of March). He offered the other participants to submit their data. The only people seeing the data are technicians and the person doing the analysis.

Funding for meta-analyses and new experiments and cooperation
We can compile a simple meta-database for the Nordic countries, or make a list of existing experiments, but funding is needed to collect the actual data and perform meta-analyses. It may be difficult to find common funding immediately, but it is possible to be prepared for the cooperation by having the same protocols etc. If basic funding is available, it is also possible to establish the experiments, perform treatments etc and later apply for funding to do further measurements and data analysis.

Data quality check
It was commented that in the future, it will be useful to perform ring tests to check the comparability of data.

Possibilities to meet
It was mentioned that the workshops of IEA Bioenergy Task 43 could be a possibility to meet in the future. BIOGEOMON is another possibility as are the conferences of the American Soil Science Society.

How to continue?

Reporting
Reporting of the workshop should be completed in the beginning of 2011. The report should include

- a synthesis of the presentations and discussion from the workshop
- pdfs of presentations given

Applying for funding
The following possibilities were mentioned:

- A new CAR-ES could be a platform for the work.
- SamNordisk Skogsforskning or Nordic Energy Research,
- Interreg for the Nordic-Baltic Region or North Sea
- EU R&D (FP7 and FP8 - limited amounts of funding can be used for transatlantic cooperation)
- WWF
- Nato (in terms of energy security)
- National agencies (Energimyndigheten, Varmeforsk, EUDP).

Optional steps that can be taken

- Meta-analyses can be performed immediately following the Canadian offer and process. Parties that are interested can submit their data.

- It could be attempted to establish new experiments with coordinated designs, treatments etc., including experiments with e.g. poplar. In Denmark fertilisation experiments might be converted to WTH experiments.

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Annex I Handouts for the excersion to long-term Whole-Tree Harvesting experiments at Bergermoen and Nordmoen, new intergrated experiment at Gaupen

Insert Kjersti pdf here

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REGULAR ARTICLE

Dissolved organic carbon concentrations in four Norway spruce stands of different ages

Nicholas Clarke · Yijie Wu · Line Tau Strand

Table 1 Stand data

	Time period	Approximate stand age (years)			
		10	30	60	120
Number of trees[a] (/ha)		N/A	2381	899	431
Mean *T* below canopy (°C)	2001	3.9	3.2	3.7	3.7
	2002	4.0	3.7	4.2	4.1
Mean *T* in O horizon (°C)	2001	4.7	3.6	4.6	3.9
	2002	5.0	4.1	4.9	4.4
Mean *T* at 15 cm depth in the mineral soil (°C)	2001	4.7	3.6	5.7	4.2
	2002	5.1	3.8	7.1	4.6
Mean throughfall (mm/day)	30.05.01–06.11.01	3.0	2.4	2.3	2.4
	28.05.02–29.10.02	2.4	2.1	1.8	2.0
Mean above-ground tree litterfall (g/m^2/day)	22.05.01–29.05.02	0.07	0.93	1.7	1.7
Thickness of O horizon (cm)		3.7	3.0	4.4	5.6
Mean C in O horizon[b] (kg C/m^2)		2.7	2.3	3.5	5.2
Standard error C in O horizon (kg C/m^2)		0.3	0.3	0.2	1.3
Mean C in mineral soil[b] (0–100 cm) (kg C/m^2)		6.2	6.4	6.8	6.2
Standard error C in mineral soil (0–100 cm) (kg C/m^2)		0.3	0.4	0.4	0.7
C in tree biomass[a] (kg C/m^2)		N/A	7.5	12	13
C in fine roots in O horizon[a] (kg C/m^2)		0.03	0.09	0.05	0.04
C in fine roots, 0–60 cm[a] (kg C/m^2)		0.17	0.32	0.19	0.26

C in tree biomass was calculated using allometric equations. Fine roots of Norway spruce were obtained by soil coring.

N/A: not available

[a] Data from Kjønaas et al. (2002).

[b] Average of three subplots.

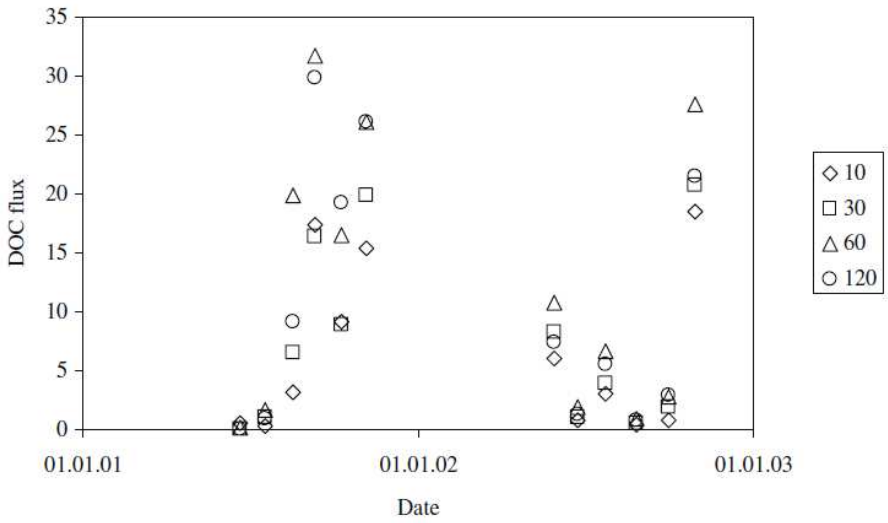

Fig. 2 Time series for estimated DOC fluxes (mg/m^2/day) at the base of the O horizon

Table 5 Repeated measures ANOVA results: F and p values for effects of stand, year, season, and their interactions on DOC fluxes

Ecosystem level	Effect	*df*	*F*	*p*	
Bulk precipitation	Year	1	1.0	0.36	
	Season	1	0.13	0.73	
	Year × season	1	2.9	0.16	
Throughfall	Stand	3	7.6	0.00	10=30< 60=120
	Year	1	9.1	0.01	2001<2002
	Season	1	6.8	0.01	Autumn< summer
	Stand × year	3	0.50	0.68	
	Stand × season	3	2.6	0.07	
	Year × season	1	0.015	0.90	
	Stand × year × season	3	0.15	0.93	
Base of O horizon	Stand	3	2.6	0.07	
	Year	1	52	0.00	2001>2002
	Season	1	104	0.00	Summer< autumn
	Stand × year	3	3.9	0.02	
	Stand × season	3	1.5	0.25	
	Year × season	1	18	0.00	
	Stand × year × season	3	0.49	0.69	

df: degrees of freedom