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ROOTS 2011 WORKSHOP

Abstracts

Joensuu, Finland,13–14 December 2011

Marja Roitto, Tarja Lehto, Sirkka Sutinen, Leena Finér and
Tapani Repo (eds.)

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Abstract

The ROOTS 2011 workshop will be organized in Joensuu on the 13th -14th December, jointly by Metla, Joensuu Research Unit and the University of Eastern Finland, School of Forest Sciences. The workshop aims to provide an update to current root research in Finland. The previous root seminar was held in Joensuu 13 years ago. Meanwhile quite a lot of water has passed in the Pielisjoki river, and much new knowledge has accumulated concerning growth and function of roots to be discussed. The current meeting brings together 40 scientists working in the field of root research. The topics of the presentations deal with innovative methodological developments, studies on responses of roots to environmental stresses and root biomass and dynamics in different environments. This Working Paper includes the abstracts of 21 oral presentations and 8 posters. We hope that the workshop will serve as a way for networking between senior and junior researchers, and would provide a forum for fruitful discussions concerning the current hot topics in root research.

Keywords

Abiotic stress, biomass, biotic stress, climate change, growth, methods, mycorrhiza, root

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Other information

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Program

Tuesday Dec. 13, 2011

13:00	Opening Taneli Kolström *Metla* & Tarja Lehto *University of Eastern Finland*

Methods

Chair Krista Lõhmus

13:10	Heljä-Sisko Helmisaari, *University of Helsinki*: Belowground processes in forests - methods to estimate fine root turnover
13:40	Shambhu Sah, *University of Helsinki*: Use of carbon and nitrogen isotopes in root research
14:00	Raija Laiho, *University of Helsinki*: Application of infrared spectroscopy for assessing the mass proportions of different plant species in root biomass samples
14:20	Raimo Silvennoinen, *University of Eastern Finland*: Electrical impedance of tree roots
14:40	Coffee

Biomass and growth

Chair Heljä-Sisko Helmisaari

15:10	Leena Finér, *Metla*: Fine root biomass, production and turnover in forest ecosystems in relation to stand and environmental characteristics
15:40	Ivika Ostonen, *University of Tarto*: Fine root foraging strategies in Norway spruce, silver birch and Scots pine forests across a European climate gradient
16:00	Tuomo Kalliokoski, *Metla*: The effect of tree architecture on conduit diameter and frequency from small distal roots to branch tips in *Betula pendula, Picea abies* and *Pinus sylvestris*
16:20	Break
16:30	Tiina Badorek, *Metla*: Root production and decomposition on forestry-drained peatland
16:50	Timo Domisch, *Metla*: Effect of tree species on fine root biomass and production - Presentation of FunDivEurope

Biotic stress

17:10-17:40	Mikhail Kozlov, *University of Turku*: Sources of variation in plant responses to belowground insect herbivory: a meta-analysis
18:00	Posters, dinner in Metla-house

Wednesday Dec. 14, 2011

Abiotic stress

Chair Timo Domisch

09:00	Raimo Sutinen, *Geological Survey of Finland*: Root-zone soil temperature through boreal gradient (60º–69ºN) in Finland
09:30	Tapani Repo, *Metla*: Effects of soil frost on root growth and longevity
09:50	Jaana Leppälammi-Kujansuu, *University of Helsinki*: Effects of long-term temperature and nutrient manipulation on Norway spruce fine roots, mycorrhizal root tips and mycelia production
10:10	Break
10:20	Sirkka Sutinen, *Metla*: Watering frozen soil reduces root growth in Scots pine saplings
10:50	Marja Roitto, *Metla*: Soil frost, flood and Scots pine saplings
11:10	Ai-fang Wang, *Metla*: Impacts of winter and spring waterlogging on the forest trees in Finland
11:30	Lunch

Mycorrhizas

Chair Tapani Repo

12:30	Annamari Markkola, *University of Oulu*: Host carbon resources affect ECM fungal communities
13:00	Anna Korhonen, *Metla*: Frost hardiness of mycorrhizal and non-mycorrhizal Scots pine (*Pinus sylvestris* L.) roots
13:20	Sannakajsa Velmala, *Metla*: Fine root characteristics of Norway spruce in relation to growth and ectomycorrhizal diversity
13:40	Jussi Heinonsalo, *University of Helsinki*: Enzyme activities in non-mycorrhizal vs. endophytic and ectomycorrhizal Scots pine root tips
14:00	Irmeli Vuorinen, *Metla*: Developing commercial scale propagation methods for mycorrhizal fungi
14:20	Concluding remarks: Elina Vapaavuori, *Metla*
14:30	Coffee

Oral presentations

Belowground processes in forests – methods to estimate fine root turnover

Heljä-Sisko Helmisaari

University of Helsinki, Dept. of Forest Sciences, P.O.Box 27, FI-00014 University of Helsinki, Finland

The ability to quantify the amount of carbon plants allocate to fine roots (and their mycorrhizas) and its below-ground residence time is a major missing link in efforts to quantify and describe forest carbon cycles (Joslin et al. 2006). Quantification of the role of roots in carbon cycling requires estimating root biomass, turnover rate, and carbon concentrations. More data is available on the fine root biomass (e.g. Finér et al. 2007, 2009; Helmisaari et al. 2007, 2009), whereas root turnover rates and their relationship to soil environmental factors still remains poorly known for most species and sites.

Estimates of root turnover rate or longevity have been obtained through e.g. sequential coring, measuring root growth into root-free ingrowth cores, minirhizotrones allowing in situ observations of root growth and mortality, or isotopic methods. Fine root turnover rate estimation has been hampered by the fact that it cannot be directly measured in the field, and all methods involve disturbance of some kind. Despite of all the difficulties, an important task for the root research community is to gain a better understanding of the variation in fine root turnover rates, and the factors affecting them, including methods for measuring root turnover. This is possible only through continuing empirical and experimental research.

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Use of carbon and nitrogen isotopes in root research

Shambhu P. Sah

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Assessment of root carbon quantity and longevity is extremely important for carbon and nutrient cycles. The carbon and nutrient inputs into forest soil in root litter may be several times larger than the inputs from aboveground litter Thus, there is wide consensus in the scientific community that roots of trees and understorey vegetation play an important role in the carbon and nutrient dynamics of forest soils but quantitatively, not enough is known about their contribution to the carbon and nutrient budgets. Estimates of root turnover and longevity have been obtained through various methods, from traditional sequential coring to modern mini-rhizotron method, but no method has been considered enough to measure root longevity precisely. The most recent methods of using stable isotopes and radiocarbon has been has been reported to be more precise and reliable.

In the present paper we discuss the implications of isotopes of C (^{13}C, ^{14}C) and N (^{15}N) in the root researches. Stable isotopes are ones that are not radioactive. Natural abundance observations of stable isotopes of N can provide insight into biogeochemistry. There are two stable isotopes of N: ^{14}N and ^{15}N. The natural abundance of stable isotope levels is not an absolute value, but is reported as delta (δ), in parts per thousand or per mil (‰) relative to a known standard material (for instance, atmospheric N_2 for nitrogen). Natural abundance of N isotope helps in studying several field-based ecological processes including root ecology without disturbing their substrates/systems, which is not possible by traditional methods. In the present paper, it is discussed how the stable isotope analysis can be used for studying the root-fungi relationship (mycorrhizal and saprotrophic), role of fungi in plant N uptake, plant N sources, and soil-plant N cycling.

For Carbon there are two stable isotopes (^{12}C and ^{13}C) and one radiocarbon (^{14}C). Unlike stable isotopes, radiocarbon is constantly created and destroyed. The above-ground nuclear tests that occurred between 1955 and 1963 dramatically increased the amount of ^{14}C in the atmosphere and subsequently in the biosphere; after the tests ended the atmospheric concentration of the isotope began to decrease. One side effect of the change in atmospheric ^{14}C is that this enables the determination of the age of an individual. This method only works for individuals born after 1943. ^{14}C may be used as an Indicator of age of living organisms during bomb period, cycling rates of carbon in vegetation and soils, source pools to carbon fluxes. In the present paper, we explain how the bomb radiocarbon isotopes provide a new method that does not have many of the disadvantages of earlier methods on fine root turnover or longevity assessment. In addition, the reliability of this method is also described in more details. Furthermore it is also outlined how the mycorrhizal origin in roots and soils can be determined by ^{14}C method.

Application of infrared spectroscopy for assessing the mass proportions of different plant species in root biomass samples

Raija Laiho, Noora Ilola, Piia Launiainen and Petra Straková

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Species-level information on fine root biomass and production is still very limited. This is partly due to practical constraints for visual identification. Infrared spectroscopy (IRS) has been adopted as a popular tool for characterising the composition of different organic materials (e.g., Bouchard et al. 2003, Vávřová et al. 2008). Recently, applications for identifying roots of different plant species in root misture have also been reported (e.g., Roumet et al. 2006, Picon-Cochard et al. 2009, Lei & Bauhus 2010). IRS is a fast and easy method to study chemically complex samples. IR spectra can be utilized either for directly interpreting the absorbance intensities at different wave lengths, or, as is more commonly done in ecological applications, for building so called calibration models based on calibration data consisting of samples with known composition; these models may then be used to predict the composition of unknown samples. We have tested the applicability of IRS for estimating the mass proportions of several common forest and peatland species, both arboreal (8 species) and herbaceous (9 species), in root mixtures. For peat soils, we also tested the possibility to predict the mass proportions directly in soil samples (i.e. without separating the roots).

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Electrical impedance of tree roots

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New study methods are needed for assessing growth and physiological activity of roots. One potential method is based on the electrical impedance (EI) properties of roots. In this method root with a growing substrate is set in an electric field between electrodes, one set into the stem and another into the growing substrate. When an electric field of different frequencies is applied to the system, current is assumed to pass from stem through the root system into the soil along different routes depending on the frequency. According to the frequency response of complex impedance, an electrical circuit model is formulated that considers stem, root and soil.

The method was tested in an experiment with Scots pine (*Pinus sylvestris* L.) seedlings raised in perlite with and without inoculation of the root system with fungi (*Hebeloma* and *Suillus luteus*). The aim was to find out if the impedance method could be used for detecting root damage and if the mycorrhizal formation would have an expression in the electrical impedance parameters. For the study, part of the seedlings was artificially cold acclimated and part was raised in long day and high temperature throughout the study. The seedlings were tested for the cold tolerance of their roots at the end of the experiment by exposing them to freezing temperatures. The electrical impedance spectra of roots were measured over the frequency range from 5 Hz to 100 kHz. A new approach in the data analysis was used that was based on normalization and classification of the impedance spectra. Both the frost exposure and fungal inoculation affected electrical impedance of roots.

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Fine root biomass, production and turnover in forest ecosystems in relation to stand and environmental characteristics

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The production and turnover of fine roots (diameter ≤ 2 mm) contributes significantly to carbon cycling in forest ecosystems. We compiled an global database covering fine root biomass (FRB) from 512 stands and in addition fine root production (FRP) from 186 stands from literature and estimated FRB, FRP and fine root turnover (FRT) for boreal, temperate and tropical forests, and the relationships between FRB, FRP or FRT and environmental variables and stand variables (Finér et al. 2011ab). Total FRB for all plants was 419 g m^{-2}, 486 g m^{-2} and 465 g m^{-2} for boreal, temperate and tropical forests, respectively. The FRB of the understorey vegetation accounted for 20–31% of the total FRB. Total FRP was 311, 428 and 596 g m^{-2} a^{-1} in the boreal, temperate and tropical forests, respectively, and the corresponding annual FRT rates were 0.77, 1.21 and 1.44, respectively. The mean FRP of trees for the temperate and boreal forests combined was 306 g m^{-2} a^{-1} and the annual FRT was 1.31.

The results indicate that the mean basal area of the forest stand can explain 49% of the total FRB and 79% of the FRB of trees at the tree level. FRB was the most significant factor explaining the variation in FRP, and more so at the tree level than at the stand level, explaining 53% of the variation in FRP for trees at the tree level. The results indicate that the variation in FRB and FRP on a global scale can be explained to a higher degree if we focus on tree roots separately from the roots of the understorey vegetation and on FRB or FRP at the tree level instead of FRB or FRP at the stand level or on FRT.

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Fine root foraging strategies in Norway spruce, silver birch and Scots pine forests across a European climate gradient

Ivika Ostonen[1], Heljä-Sisko Helmisaari[2], Werner Borken[3], Elena Vanguelova[4], Douglas Godbold[5], Leho Tedersoo[1,6], Marika Truu[1], Jaak Truu[1], Jane Frey[1], Kestutis Arnolaitis[7], Mats Varik[8], Veiko Uri[8], Antti-Jussi Lindroos[9], Pekka Nöjd[9], Päivi Merilä[10], Mikko Kukkola[9], Endla Asi[11], Krista Lõhmus[1]

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Fine root acclimation to different environmental conditions is crucial for growth and sustainability of forest trees. Relatively small changes in fine root standing biomass (FRB), morphology or mycorrhizal symbiosis may result in a large change in forest carbon, nutrient and water cycles. We elucidated the changes in fine root traits and associated ectomycorrhizal (EcM) fungi in 12 Norway spruce, 13 silver birch and Scots pine stands across a climatic and N deposition gradient from subarctic-boreal to temperate regions in Europe (69°N–48°N). We analyzed the standing FRB and the ectomycorrhizal root tip biomass (EcMB, g m^{-2}) simultaneously with measurements of the EcM root morphological traits (e.g. mean root length, root tissue density (RTD), N% in EcM roots) and frequency of dominating EcM fungi in different stands in relation to climate, soil and site characteristics. Bacterial species diversity was additionally determined for birch stands by DGGE.

Latitude and N deposition explained the greatest proportion of variation in Norway spruce fine root traits. EcMB per stand basal area (BA) increased exponentially with latitude in Norway spruce stands (Ostonen et al., 2011). EcM roots are significantly longer and with higher RTD and lower N concentration in northern stands for all tree species. The total variation of EcM root morphological characteristics decreased in following order: birch > spruce > pine. There was clear difference in dominating colonizing EcM fungi in root tips between northern and southern spruce, birch and pine forests. For Norway spruce forests in boreal zone, we predict approximately 50% decrease in EcMB per stand BA with an increase of 2°C annual mean temperature (Ostonen et al., 2011). Different fine root foraging strategies in boreal and temperate forests highlight the importance of complex studies on respective regulatory mechanisms in changing climate.

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The effect of tree architecture on conduit diameter and frequency from small distal roots to branch tips in *Betula pendula, Picea abies and Pinus sylvestris*

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We studied the effect of tree architecture on xylem anatomy in three *Betula pendula* Roth., three *Picea abie*s (L.) H. Karst. and three *Pinus sylvestris* L. trees (age of trees ca. 35 years). The xylem anatomy and the architectural organization of the tree together determine the efficiency with which water and solutes can be conveyed from roots to shoots, and further to leaves. In studied species, conduits tapered and their frequency increased from roots (≥ 2 mm) to stem, from stem to branches, and further to leaf petioles in *B. pendula*. Xylem anatomy of lateral and main branches differed from each other both below- and aboveground in all the studied species. Conduit diameter increased and frequency decresed from the pith to the bark in shoots, whereas no clear pattern was observed in roots. Increase in individual leaf area corresponded the increase in conduit diameter and frequency in the leaf petioles of *B. pendula*. One scaling theory predicts an increase in conduit size with distance from stem apex with a specific minimum value 1/6 of the scaling parameter in order to minimize the energy dissipated in fluid flow (WBE-model, West et al. 1999), while other one asserts that to maximize hydraulic conductance with a given investment, trees should have a constant relationship between the volume flow rate and the sum of the conduit radius cubed (Murray's law, Murray 1926). Against the predictions of WBE-model, the scaling parameter values changed from one tree compartment to another, and no constant conductivity ratio, constant conduit tapering, or unchanged total number of conduits on tree-level were observed. Murray's law applied quite well to the shoots, while in the roots the observed relationship between relative conduit tapering and the conductivity ratio clearly deviated from the predicted one in each species, especially in *P. sylvestris*. The results support the theory that trees adjust both their macro- and microstructure to maximise their water transport efficiency, but also to prevent embolism and ensure mechanical safety.

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Root production and decomposition on forestry-drained peatlands

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We investigated the dynamics of fine roots and coarse root systems (CRS) by measuring their production and decomposition rates and carbon contents in different stages of decomposition in two forestry-drained peatland sites. Our aim was to study the poorly known role of the fine roots and coarse root systems in the drained peatland carbon cycle. Regarding fine roots, our hypothesis were: i) fine root turn-over rate is greater in drained peatland than on upland pine sites, ii) fine root production and turn-over rates increase when nutrient content increases, iii) fine root decomposition is slower on the nutrient poor site. Regarding coarse root systems, our hypotheses were: i) the decomposition of coarse root systems is very slow in peat even in drained sites, ii) coarse root systems form an important part of the whole peatland carbon pool and act as a long-term C sink after harvesting the aboveground tree biomass.

Both study sites were in southern Finland. Kalevansuo was a nutrient poor dwarf shrub pine bog and Lettosuo was a nutrient rich pine-birch fen with a spruce understorey. For the fine root production study we installed root ingrowth cores (depth 0–50 cm) a subset of which will be annually recovered for biomass weighing during a four-year monitoring period. Live fine root biomass (0–20 cm) by different plant groups was separately sampled and assumed to show no interannual variation. Fineroot turn-over rate will be determined as the ratio of annual production to biomass. Decomposition of pine, spruce and birch fine roots is studied by using the litterbag method.

For decomposition dynamics of CRS we excavated Scots pine stumps and roots (diameter down to one cm) of both live trees and those of trees that had been cut earlier. We tested different biomass models against the measured dry mass of living stumps and roots andmodeled the coarse root biomass using tree inventory data. The old stumps were analyzed with dendrochronological methods and with radiocarbon dating to determine the time of death. Mass loss for each excavated old root system were then calculated as the difference of measured necromass and modelled biomass of a similar live tree.

Preliminary results show that in both sites fine roots grow mainly on the layers 0–10 and 10–20 cm. In Kalevansuo the root growth was ca. 75 g m^{-2} a^{-1} and 68% of the whole root biomass was in this layer. In Lettosuo the annual growth of this layer was ca. 165 g $m^{-2}a^{-1}$. This was 83% of the whole root biomass. The decomposition rates of coarse root systems was markedly low.

Effect of tree species on fine root biomass and production — Presentation of FunDivEurope

Timo Domisch and Leena Finér

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The "FunDivEurope — Functional significance of forest biodiversity in Europe"-project is an EU-funded project within the European Union Seventh Framework Programme, running from 2010 to 2014 (www.fundiveurope.eu). It is coordinated at Freiburg University, and 25 organisations from 14 countries are participating. The main objective of the project is to quantify the effects of forest biodiversity on ecosystem functioning and services in major European forest types in six European bioclimatic regions, of which the boreal forest is one. An important part of the project was the establishment of study plots in mature forests of deciduous and coniferous tree species composition reaching from monocultures to mixed species stands. Diverse mixed forests can induce niche partitioning between species resulting in higher biomass and productivity compared to single tree species forests (Erskine et al. 2006). Most of the studies into the diversity effects on biomass and productivity have focussed on the above-ground parts of grassland ecosystems, and much less is known about the diversity effects on forests, and on below-ground parts of the ecosystems (Brassard et al. 2011). In forest ecosystems, the root systems, especially fine roots play a significant role in carbon and nutrient cycling and allocation, since up to 60% of the biomass production by forest trees are allocated below-ground (Helmisaari et al. 2002). Metla is responsible for determining fine root biomass and production from the plots of the six study sites across Europe. We hypothesise that fine root biomass and production is higher in mixed forests compared to forests of single tree species due to a more effective utilisation of soil resources in mixed forests. The species composition within the individual tree root samples will be determined using near-infrared spectroscopy (NIRS, Lei & Bauhus 2010). For calibrating the NIRS method, additional root samples are taken from plant individuals in a way that all species occurring on the plots are sampled. The NIRS models are then used to predict the tree species composition in the tree root samples.

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Sources of variation in plant responses to belowground insect herbivory: a meta-analysis

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Although the importance of studying root-feeding herbivores for understanding the dynamics of plant communities in both natural and managed ecosystems was underscored in a number of narrative reviews (Brown & Gange 1990; Blossey & Hunt-Joshi 2003), the phrase ‘out of sight out of mind’ reflects the past attitude of many ecologists (except for those studying agricultural pests) to belowground herbivory (Hunter 2001). However, the situation changed quite recently; considerable growth in the number of publications on root herbivory and the remarkable diversity of the accumulated information inspired us to quantitatively explore the variation in the outcomes of individual studies (Zvereva & Kozlov 2012). We conducted a meta-analysis of 85 experimental studies reporting the effects of root-feeding insect herbivores (36 species) on plants (75 species). On average, belowground herbivory led to a 36.3% loss of root biomass, which was accompanied by a reduction in aboveground growth (16.3%), photosynthesis (11.7%) and reproduction (15.5%). The effects of root herbivory on aboveground plant characteristics were significant in agricultural studies and studies where root herbivores were used to control invasive plants, but not in studies of natural systems. Experiments conducted in controlled environments yielded larger effects on plants than field experiments, and infestation experiments resulted in more severe effects than removal studies employing natural levels of herbivory. Simulated root herbivory led to greater aboveground growth reductions than similar root loss imposed by insect feeding. External root chewers caused stronger detrimental effects than sap feeders or root borers; specialist herbivores imposed milder adverse effects on plants than generalists. Woody plants suffered from root herbivory more than herbaceous plants, although root loss was similar in these two groups. Evergreen woody plants responded to root herbivory more strongly than deciduous woody plants, and grasses suffered from root herbivory more than herbs. Drought, poor nutrient supply, among-plant competition and aboveground herbivory increased the adverse effects of root damage on plants in an additive manner. In general, plant tolerance to root herbivores is lower than tolerance to defoliating aboveground herbivores.

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Root-zone temperature through 60.5°N–68.9°N in Finland

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Root-zone (<30 cm) soil temperature (ST) and water content (SWC) were automatically monitored at 19 stations through the boreal gradient (60.5–68.9°) in Finland. It was found that the length of the growing season waried from 195 days (using +3.2 C° treshold) at Nurmijärvi station (60.5°N) to 123 days at Sammaltunturi forest station (68°N). At Peera (palsa) station (68.9°N) the ST did not exceed the +3.2 C° treshold value. Mean annual air temperature was 5.6°–7.1°C through 60.5 °N (Nurmijärvi) and 62.9 °N (Ylistaro) stations, whereas it was from +2.8 to +1.2°C through 64.9 °N (Suomussalmi) and 66.3°N (Kuusamo) stations as well as from +0.9 to -0.9°C through 67.6 °N (Naruska) and 68.9°N (Peera) stations.

The seasonal mean ST (using +3.2 C° treshold) on elevation gradient from 370–394 m (forest) to 470–480 m a.s.l. (treeline) was 11.1–11.3°C for forest and 10.6–10.8°C for treeline. Hence our ST's are higher than worldwide treeline ST's of 6–7°C given by Körner and Paulsen (2004). Also the length of the growing season, 118–130 days, was longer than that, 102–106 days, given by Körner and Paulsen (2004) for subarctic-boreal treelines. In winter ST seldom falls below -1.5°C if snowpack (>30 cm) present. Snowmelt infiltration ocurred rather unimpeded such that SWC was at its maximum more than a month before ST reached 0°C.

Temporal stability of spatial patterns (time stability) of SWC applied through the boreal gradient such that SWC for all stations, analyzed with Spearman's rank correlation coefficients, showed significant time stability (r^s=0.93–0.99). This indicates that SWC is not governed by e.g. shorter growing season or lower summer temperature, but rather is associated with soil physical properties and winter precipitation, i.e. the presence of snowpack, as well.

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Effects of soil frost on root growth and longevity

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Soil frost is common in northern hemisphere. The depth of soil frost is much dependent on snow cover which is predicted to change with climate warming. Accordingly soil frost is probable to change in future, the direction dependent on occurrence of wintertime frosts in relation to snow cover. In our previous study in about 50-years old stand of Norway spruce (Picea abies L. Karst) in eastern Finland, soil frost and especially its prolonged thawing in spring and summer affected physiology and morphology of needles and buds as well as trunk diameter growth pattern. In the present study we used the same experiment with an aim to assess the effects of the soil frost treatments on biomass, growth and longevity of fine roots. Treatments were: i) Control (CTRL) with natural snow accumulation and melting. ii) OPEN with snow removed during winter. iii) FROST that was the same as OPEN but the soil surface was insulated in late winter to delay soil thawing. The treatments were repeated in two winters 2005/06 and 2006/07 with three replicate plots for each treatment. Fine root biomass (diameter <2mm) was assessed by soil coring in July and October 2007. Twentyseven minirhizotron tubes (3 tubes/plot) were installed into the soil at a mean angle of 30° in autumn 2005. Maximum imaging depth was on an average 33 cm. Root growth and survival time was assessed by imaging at about one month intervals from May to October in four years between 2006–09. Survival function and median short root survival time was calculated according to Kaplan-Meier statistics and compared between treatments with Cox regression. No difference was found in the fine root biomass between treatments. According to the pooled data of all soil layers median short root survival time ranged from ~~724~~ to ~~753~~ days. No difference was found between treatments in the survival time in the upper soil layers. At the depth of 15–25cm the median survival time was significantly longer in CTRL than OPEN and FROST. There was less formation of new short roots in FROST as compared with CTRL and OPEN between May and August in 2007. There seemed to be some compensatory growth, i.e. more new short roots, in FROST than CTRL and OPEN in 2008 and 2009.

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Effects of long-term temperature and nutrient manipulation on Norway spruce fine roots, mycorrhizal root tips and mycelia production

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We examined the responses of Norway spruce fine roots and ectomycorrhizal (EcM) mycelia in northern Sweden after 14 years of soil warming and/or 22 years of liquid fertilization. Fine root biomass and necromass, EcM root tip biomass, morphology and number, as well as mycelial production were determined from soil cores and mesh bags.

Total fine root biomass and necromass were highest in the fertilized plots, following similar trends in above-ground biomass response. In this northern, nutrient-poor site, fertilization improved the overall nutrient availability and stand productivity, both above- and below-ground. Warming increased the fine root biomass, live/dead ratio and the number of EcM root tips in the mineral soil. Greater fine root biomass in the mineral soil also meant more EcM tips, although the EcM tip frequency on fine roots was not affected by fertilization or warming. The higher specific root length of EcM tips indicated an increased need for nutrients caused by warmer soil and longer growing season. Better nutrient supply and warmer soil temperature provide a potential to increase the flow of carbon to the soil via increased fine root biomass, but the carbon balance also depends on production and decomposition.

Watering frozen soil reduces root growth in Scots pine saplings

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Climate scenarios for the boreal areas predict increased precipitation that falls as rain rather than snow, in addition to higher wintertime temperatures. It is not well known how the rain, i.e. increased liquid water in the frozen soils, and its freezing affects conifer trees during winter and early spring. This phenomenon was studied with 4-year-old Scots pine (*Pinus sylvestris* L.) saplings in a growth chamber experiment, which comprised pre-growth (G1), dormancy (D) and second growth periods (G2). The treatments were as follows: Trt1) watering twice, 21 and 14 days before soil thawing and once on the day of the beginning of soil thawing, Trt2) watering started on the day of the beginning of soil thawing, and Trt3) and Trt4) watering started 7 and 14 days after soil thawing. Once started, watering continued regularly in all treatments during G2 period. Fine root (diameter < 1.0 mm) growth, assessed with the minirhizotron method, was strongly reduced in Trt1 where frozen soil was watered three times. In Trt2 the frozen soil was watered only once and consequently root damage was milder than in Trt1. Total root biomass was reduced and morphological characteristics of the roots (length, surface area, volume, number of root tips) showed reduction at the end of the experiment in Trt1. These detrimental effects probably were caused by the mechanical damage due to the ice formation in the frozen soil after watering. Recovery of the root growth was not noted after one growing season in Trt1 suggesting that the repeated ice formation after watering into the frozen soil damaged not only the finest roots but also caused breakage of larger fine roots.

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Flooding, soil frost and Scots pine saplings

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Water-logging of trees reduces root formation, branching and growth of existing roots and increases root mortality. However, due the low demand for oxygen by roots in winter, it is thought that dormant trees tolerate hypoxic soil conditions better than trees in the active growing phase. Scots pine is among the plant species with low flooding tolerance (Glenz 2006). The aim of this study was to evaluate the effects of flooding and soil frost on the fine root (diameter < 2mm) biomass and morphology in pine saplings. The four-year-old pine saplings were transplanted into root containers in dasotrons (RTR48, Conviron, Winnipeg, Canada). Forest mineral soil with a thin organic layer was used as a growth medium in the containers. The experiment had three seasons, i.e 12-week pre-growth (G1), 13-week dormancy (D) and 12-week second growth periods (G2). In FLOOD, water table was rised to soil surface with lake water for six weeks. In FROST, soil temperature was decreased to -2°C, but in NONFROST soil was kept without frost (+2°C). Total fine root biomass did not differ between the treatments. However, the soil temperature in winter affected root responses to flooding, especially in the uppermost organic soil layer at the end of the G2. In that layer, FROST+FLOOD led to increased fine root length, specific root length and number of root tips as compared to other treatments. The results show that flooding during winter was not detrimental for the growth or recovery of fine roots in the following growing season.

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Effects of waterlogging in winter on the physiology and growth of Scots pine and Norway spruce seedlings

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There are a few studies on the effects of waterlogging on trees in winter. It is believed that the effects on roots would not be significant due to lower root respiration in winter than in summer. However, global climate change is predicted to increase precipitation and snow melt frequency and to reduce snowfall during the winter in northern regions. Tree species have different reactions to waterlogging, and knowledge about this could be used in afforestation in flood susceptible regions. We aimed to study the difference of the response between Norway spruce and Scots pine to winter waterlogging. One-year-old dormant Norway spruce and Scots pine were subjected to two treatments: No flood in dormancy phase + no flood in growth phase (Control) and flood in dormancy phase + no flood in growth phase (Flood). In the one-month dormancy phase, air temperature was 2°C, relative humidity 90%, photoperiod 6/18h (day/night) and photosynthetic photon flux density (PAR) 200µmols^{-1}m^{-2}. The conditions in the growth phase (six weeks) were: air temperature 22/15°C (day/night), relative humidity 70/80% (day/night), photoperiod 18/6h (day/night) and PAR 400µmols^{-1}m^{-2}. Control seedlings were irrigated as needed. Flood seedlings were kept in a container with a water table at the soil surface of the pots. Soil in the pots consisted of peat and quartz sand. Physiological and growth parameters were measured at the end of the dormancy phase and during the following growing season. No significant differences were found between Control and Flood in total biomass increment or biomass of needles, stems, roots of either species during the growth phase. Flood reduced the root volume of spruce ($P<0.05$) and pine ($P<0.10$), but not root length, root surface area and number of root tips. The water potential of Norway spruce needles was significantly higher in Flood than Control in the end of dormancy phase and in the early growth phase ($P<0.05$). There was no difference between the treatments in water potential of pine needles. Flood reduced Ca, K, Zn ($P<0.05$) and Mg ($P=0.052$) content of Norway spruce needles (during the growing season). In conclusion, flood in winter did not change the biomass, but changed the nutrient balance and water balance of Norway spruce in the following growing season.

Host carbon resources affect ECM fungal communities

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Reduced carbon availability in forest trees e.g. due to herbivory or shading, has earlier been suggested to cause an overall reduction in ectomycorrhizal (ECM) fungal colonization on host roots. Recent work of our research group has provided contrasting results. Carbon limitation in woody hosts resulted in altered composition of ECM fungal communities rather than reduced colonization. A relative decrease in mycorrhizal morphotypes with abundantly external fungal mycelia (potential high C demand) and an increase in morphotypes with low amount of external mycelia (potential low C demand) under constrained C availability of the host were also found. These community changes seem to be connected with the current C flux belowground, and, consequently, be reversibile in a long term after foliage loss. Moreover, several studies report decreases in fungal sporocarp production and changes in ECM community at the root level under high N availability, especially in coniferous forests. These changes are often pronounced in those ECM species producing abundantly and/or large sporocarps and high C demanding mycorrhizal morphotypes, such as Cortinarius spp. and Suillus variegatus with abundant external mycelia. High nitrogen availability directs host carbon resources towards shoot growth especially in low light conditions or during compensation growth after foliage loss, as plants generally invest in those parts acquiring the limiting resources. This may provide a mechanism to constrain C allocation to mycorrhizal symbionts in the roots, under both low C and high N conditions. Future challenges include determining the actual C costs of different ECM fungal guilds and species. This is crucial in order to evaluate ECM symbiosis costs for the host tree, and to study regulation of symbiosis.

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Frost hardiness of mycorrhizal and non-mycorrhizal Scots pine roots

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Survival of mycorrhizal associations at below-zero temperatures is not known well. Two separate studies on frost hardiness (FH) of Scots pine will be presented here. In **Exp. 1**) the objective was to study the FH of mycorrhizal (*Hebeloma sp.* (ECM)) and non-mycorrhizal (NM) roots of Scots pine (*Pinus sylvestris* L.) without and with artificial cold hardening treatment. We hypothesised that mycorrhizal roots are more frost tolerant than non-mycorrhizal ones after the hardening treatment. The objective of **Exp. 2**) was to compare the FH of roots and needles of mycorrhizal (*Hebeloma sp.* (ECM)) and non-mycorrhizal (NM) Scots pine seedlings with two fertilisation treatments, without and with artificial cold hardening. The hypothesis was that after hardening treatment, roots would benefit of the mycorrhizal treatment especially when the nutrient availability is low.

ECM and NM Scots pine seedlings were cultivated in growth chambers in four blocks for 17 and 16 weeks in Exp. 1 and 2, respectively. After four (Exp. 1) or three (Exp. 2) weeks, half of the seedlings were inoculated with the fungus *Hebeloma sp*. (ECM) and the rest were left without the inoculation (NM). In Exp. 1, seedlings had time to grow for nine weeks before cold hardening. In Exp. 2, after the first six weeks, there were two fertilization treatments: low (LF) and high (HF) (N content 40 mgl^{-1} and 80 mgl^{-1}, respectively) fertilization level for three weeks. Subsequently, the hardening treatment (SDLT) was applied to half of the seedlings in a growth chamber with short photoperiod and low temperature for four weeks. The FH of the roots was assessed using controlled freezing tests and the electrolyte leakage method. Dry weights and nutrient analyses of the roots, stems, and needles were assessed. In both experiments, the setup was randomized block design with four blocks.

No significant difference was found in **Exp. 1**) in the FH of ECM and NM roots with hardening and without hardening. In **Exp. 2**) the ECM roots were slightly more frost hardy than the NM roots. The interaction between mycorrhizal and hardening treatment was close to significant i.e. roots of the ECM seedlings were more frost hardy than the NM seedlings in LDHT but not in SDLT. The interaction between mycorrhizal and fertilization treatment was close to significant i.e. the FH of the ECM and NM roots did not differ at the HF but the ECM roots were more frost hardy than NM ones at the LF. More studies are needed about the frost hardiness of different mycorrhizal fungi and different tree species and their functioning at below zero temperatures.

Fine root characteristics of Norway spruce in relation to growth and ectomycorrhizal diversity

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The development and morphology of short roots is known to be closely related to forest site conditions and soil structure. At poor sites, Norway spruce trees maintain sufficient mineral nutrition by increasing the number of short roots and active root area. Short roots form the interface between the symbiotic ectomycorrhizal (ECM) fungi and host tree, and ensure constant nutrient and water flow to the host. Many studies report of an increase in short root density after infection by ECM fungi, but the results are often contradictory and the effect depends largely on the host species and genotype. Root density is also suggested to select for ECM species with exploration strategies that are best matched to root spacing, and therefore root density of the host tree may affect the symbiotic interactions in forest soil.

Our recent greenhouse experiment, with Norway spruce cuttings representing tree breeding material from Southern Finland, showed that the short root density is a moderately heritable trait. We found a strong genetic host tree effect on the root system characteristics, but no linear correlation between root tip density and ECM richness or root biomass. In another experiment conducted with slow- and fast-growing seed families of Norway spruce, we found that young seedlings from slowly growing origins had higher mean short root density than seedlings from fast growing origins. Our presentation will summarize the results on the relationships between ECM diversity, short root density and growth rate of Norway spruce in regulated nursery conditions.

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Enzyme activities in non-mycorrhizal vs. endophytic and ectomycorrhizal Scots pine root tips

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Courty et al. (2005) and Pritsch et al. (2011) have developed a method for measuring enzyme activities directly from individual ectomycorrhizal root tips. Eight different enzymes have been chosen for the assay and they can be used as indicators for enzyme activities related to C, N and P cycling in forest soil. The method has been widely used in the last years and new insight has been gained in the functional diversity of ectomycorrhizal fungi. In the presentation, the method will be explained in detail.

In our study, we inoculated Scots pine seedlings in axenic conditions with 17 different fungal species, all originally isolated from Scots pine ectomycorrhiza. The species were ectomycorrhizal (3), common root endophytes (5), decay fungi (5) or with unknown status (4). The enzyme activities of the inoculated root tips were analysed and compared to non-inoculated control seedlings. The functional role of different root-associated fungi will be discussed.

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Developing commercial scale propagation methods for ectomycorrhizal fungi

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We have isolated several strains of ectomycorrhizal (ECM) fungi from well growing Norway spruce wildings in the field. Nursery seedlings of Norway spruce were inoculated with these fungal strains and their growth was monitored for 3–4 years after outplanting. Several fungal strains proved to enhance the growth of seedlings in the first years. (Pennanen et al., 2003)

Our present studies aim to develop a commercial scale method for production of ECM fungal inoculum applicable in nursery conditions in order to improve the ECM colonization status of Norway spruce seedlings. We have chosen eight growth enhancing fungal strains (*Amphinema sp., Cenococcum geophilum, Hebeloma sp., Laccaria sp., Meliniomyces bicolor., Paxillus involutus, Piloderma byssinum and Tylospora asterophora*) for further studies. We have developed a growth medium for solid substrate cultivation process that is economical and optimally promotes growth of the selected fungal strains.

The fungal cultures were formulated to sprayable suspension, which was spread to inoculate 1–2 month-old-seedlings. In the end of the growing season, the growth and vitality of the seedlings was monitored and their mycorrhizal status was confirmed by microscopical examination of the root systems. Next spring seedlings were outplanted and their growth was monitored in the end of each growing season. So far the results implicate that the inoculation method is not effective enough and thus needs optimizing. We also need to find a solution how to improve the shelf life of the mycorrhizal inoculum.

Among the eight tested fungi, an ascomycete *Meliniomyces bicolor* has best endured the different stages of commercial production. According to previous studies, this fungal strain possesses antagonistic properties against the common forest pathogen *Heterobasidion parviporum and H. annosum* (Pennanen et al., abstract 2008; Hyder et al., manuscript). Therefore, we are investigating the potential of the liquid inoculum of this fungus to protect host seedlings against *Heterobasidion annosum* root rot after outplanting. Furthermore, ECM inoculation with several fungal strains was tested for its potential to enhance rooting of Norway spruce cuttings intended to be used in tree breeding. The results were encouraging since one of the fungal strains seemed to improve rooting frequency of the cuttings.

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Posters

Fungal colonization of an understory grass *Deschampsia flexuosa* in relation to tree presence in a primary successional site

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Forest trees, understory plants, mycorrhizal fungal symbionts and interactions between all these parties are essential elements in forest regeneration and for maintenance of forest ecosystems. The present study asks how root fungal colonization of understory grass *Deschampsia flexuosa* is affected by tree removal in a primary succesional site. The study was conducted in Hailuoto on the Bothnian Bay coast in Northern Finland which has been subjected to primary succession due to post -glacial isostatic land uplift. The coast is characterized by the flat land and sandy soil with dry and poor nutrient conditions. Study site is a deflation basin dominated by sparsely located mature Scots pine trees. The understory vegetation is also sparse, consisting mainly of *Empetrum nigrum ssp. hermaphroditum, Vaccinium* spp. and lichens. Some Scots pine seedlings were also present. The tree-removal experiment was conducted at the study site in 2008. Samples of *D. flexuosa* roots and shoot parts were collected from twenty-four plots in 2010, in twelve of which individual Scots pine trees were cut,and in another twelve were left uncut. The root fungal colonization of *D. flexuosa* was assessed and studied in relation to vegetation variables and C/N status of shoot green parts. The microscopy study on root fungal colonization percentage shows that the absence of tree does not affect arbuscular mycorrhizal colonization but increases root dark septate endophytic (DSE) fungal hyphal colonisation in *D. flexuosa.* Increased DSE colonization is likely related to site openness or availability of dead root material. The results on fungal colonizations in relation to shoot C/N and understory vegetation variables will be presented.

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Integrated effects of elevated ozone and temperature on growth and carbon partitioning in silver birch (*Betula pendula*)

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There is substantial and growing evidence that northern ecosystems are already experiencing a climate change. In the near future, anthropogenic influence on climate and thereby on northern forests is expected to accelerate even further. According to the climate change scenarios, the mean global surface temperatures will continue to rise during this century, and simultaneously forests will be exposed to damaging ozone stress. Both increasing ozone and temperature alone exert multiple effects on forest trees, but the combined effects of these climate change factors cannot be predicted on the basis of single exposures.

In summer 2007 and 2008, four silver birch genotypes (gt12, gt14, gt15 and gt25) growing in submerged pots were exposed to elevated ozone and elevated temperature alone and in combination in an open-air exposure field in Kuopio, central Finland. After the second exposure season (2008), increased temperature was able to increase silver birch above- and below-ground growth and soil respiration rates. However, some of these variables showed that temperature effect was modified by tree genotype and prevailing O_3 level. For instance, soil respiration was increased in T and O_3+T treatments in gt14, but in other genotypes O_3 either partly (gt12) or totally nullified (gt25) temperature effects on soil respiration, or acted synergistically with temperature (gt15). O_3 caused stem growth reductions was clearest in the fastest-growing gt14 and gt25, whereas mycorrhizal root growth and sporocarp production increased under O_3 in all genotypes. Labelling experiment showed that temperature increased tree total biomass and hence ^{13}C fixation in the foliage and roots, and also label return was highest under elevated temperature. O_3 on the other hand seemed to change tree ^{13}C allocation, as it decreased foliar ^{13}C excess amount simultaneously increasing ^{13}C excess found from the soil beneath the trees. Present results suggest that warming has potential to increase silver birch tree growth and hence C accumulation in tree biomass, but final magnitude of this C sink strength is partly counteracted by temperature-induced increase in soil respiration rates. Silver birch populations' response to climate change will also largely depend on their genotype composition.

Impacts of harvesting stumps and logging residues on mycorrhizal fungal communities of spruce (*Picea abies*) saplings

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In recent years, energy wood harvesting has increased rapidly, although the impacts of removal of logging residues and stumps on forest regeneration and fungal communities of trees are largely unknown. Our aim is to quantify contributions of energy wood harvesting to composition of soil microbial community, especially ectomycorrhizal fungi in spruce (*Picea abies*) sapling roots. The focus is on fungal diversity, its possible changes due to altered inoculum potential of surrounding environment and further impacts on spruce sapling growth.

Nursery seedlings of Norway spruce were planted in 2008 in four treatments: 1) clear-cut + patch mounding, 2) clear-cut + 70% logging residue removal + patch mounding, 3) clear-cut + 70% logging residue removal + stump removal (25 stumps/ha left) + patch mounding, and 4) un-cut control forest. The experiment was established in three different locations; one in south, one in central and one in north Finland. Sampling was done in September 2011. Results of spruce sapling height and growth during last growth season are shown. Mycorrhizal communities of spruce root samples will be studied by 454 pyrosequencing with Roche GS Junior at the Department of Biology, University of Oulu. Use of 454-pyrosequencing has increased rapidly in microbial community studies. Pyrosequencing enables simultaneous multi-species sequencing from environmental samples and provides solutions for many problems in microbial ecology research (i.e. large amount of unknown taxa and problems in identification). For fungal identification to species or genus level, the obtained sequences will be compared with open databases (e.g. GenBank and UNITE) using the BLAST tool.

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Community structure of wood-inhabiting fungi in relation to substrate quality of decaying Norway spruces

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Dead wood and wood-decaying fungi have a major importance in boreal forest ecosystems in the context of biodiversity, global CO_2 dynamics, nutrient cycling and forest regeneration. White-, brown-, and soft-rot fungi are the major functional groups in decaying wood, but also ectomycorrhizal fungi can utilize organic nutrient forms through the production of extracellular enzymes, potentially leading to competition of woody habitats among saprotrophic and ectomycorrhizal fungi. Currently information about succession and habitat preferences of wood-inhabiting fungi in boreal forests is mainly based on polypore fruiting bodies and our view of wood-inhabiting community is thus limited.

We investigated succession of fungal communities inhabiting dead fallen logs in natural Norway spruce dominated forests in Southern Finland. Altogether, 543 spruce logs from 5 sites were sampled and measured. Diversity and composition of wood-inhabiting fungi were analyzed by direct DNA extraction and PCR-DGGE profiling coupled with Sanger sequencing. Also physico-chemical properties of logs were determined.

We observed succession in wood-inhabiting fungi along wood decomposition. Logs properties affecting species composition were decay stage, density, C/N ratio, lignin content, moisture, diameter, volume and distance to soil. Fungal diversity was highest in the most decayed substrates. Ascomycetes typically colonized recently fallen wood, whereas basidiomycete white- and brown-rot fungi were most frequently found during intermediate decay stages. Interestingly, ectomycorrhizal fungi were first detected in moderately decayed logs, after which they increased to eventually become the dominant functional group. This raises a question about the saprotrophic lifestyle of some ectomycorrhizal fungi.

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Functionality of mycorrhizas in Norway spruce seedlings with differences in inherent growth rate

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Ectomycorrhizal fungi (ECM) have a pivotal role for growth and performance of trees in the boreal forests, which are poor in soil nutrient contents. ECM fungi significantly increase uptake of dissolved nutrients and water, as they can render nutrients available from complex coumpounds that are inaccessible for a host tree. Nutrient uptake capacities of ECM species differ, but less is known about the effect of host trees on the functionality of ECM fungi. Moreover, relationship between host growth performance and ECM functionality is not known.

We investigated how enzyme activities vary between common ECM species in Norway spruce and how host genetic background affects on them. Six Norway spruce families known to be fast and slow growing were selected for the experiment. Seedlings were inoculated with three ECM fungal species: *Piloderma* sp., *Wilcoxina* sp. and *Tylospora asterophora*. Part of the seedlings were left un-inoculated. After one-year-growth the seedlings were harvested and ECM root tips were subjected to a microplate multiple enzymatic assay (Pritch et al. 2011). Investigated enzymes were leucine aminopeptidase, βxylosidase, βglucuronidase, cellobiohydrolase, N-acetylglucosaminidase, βglucosidase, acid phosphatase and laccase.

Preliminary results showed variation in ECM enzyme activities between host families, whereas growth performance groups did not seem to affect differently on their ECM fungi. Highly different enzyme activity levels were noted between ECM fungal species. Findings indicate that composition of ECM species may affect nutrient acquisition of host trees and thereby contribute to their vitality and growth.

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Fine roots of aspen clones in high salt and petroleum hydrocarbon pollution

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The quality of polluted soil can much be improved and the environmental risks reduced by use of phytoremediation. Harmful hydrocarbon compounds can be degraded through the activity of plant and its associated microbes. We previously showed that PAHs increase aromatic ring-cleavage gene diversity in rhizosphere of birch (Sipilä et al. 2008, Yrjälä et al. 2010a) and the rhizosphere of aspen harbors *Burkholderia* bacteria able to degrade aromatics (Yrjälä et al. 2010b). The results are promising for successful remediation of polluted soils with woody plants. The aim of our studies is to elucidate the response of the plant and the associated bacteria to oil pollution and high salt. In a long term greenhouse experiment the effects of petroleum hydrocarbons and high salt on aspen seedling clones and on bacterial populations were studied. The root morphological plasticity of four selected aspen clones was studied. In the long term experiment with soil from an accidental oil spill, the abundance of catabolic ring-cleavage genes was elevated in the rhizopsphere. Stress effects on root morphology were detected, but one of the clones differed in that it hardly responded to the treatments. The height growth of trees correlated positively with specific root length and area. It can be concluded that certain bacteria populations are clearly favored by oil pollution, especially in the rhizosphere. The aspen seedlings may generally try to increase fine root length and surface area in response to oil but with clear exceptions.

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Shifts in understory vegetation, soil biology and fungal communities along moth outbreak gradients in the subarctic

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In the subarctic mountain birch forests outbreaks of foliage feeding autumnal moth *Epirrita autumnata* appear in ten-year intervals (Nuorteva 1963). During these outbreaks death of individual trees is common, but sometimes large areas are afforested due to the larval consumption of all the foliage during several years (Kallio & Lehtonen 1973, Ruohomäki et al. 2000). Recently, also another moth species, winter moth *Operophtera brumata*, has dispersed to the area and caused forest damages; this dispersal is potentially associated to the climate warming (Jepsen et al. 2008). Despite obvious impacts of moth outbreak in the ecosystem, detailed studies on vegetational shifts and putative changes in soil and fungal variables in relation to moth damage are rare. We carried out a monitoring project in Utsjoki, N-Finland in 2008–2010 and aimed to find out how vegetation, soil parameters and fungal communities change along replicated moth feeding gradients consisting of three levels: control, one year of severe foliar damage, and 4 years of severe foliar damage. We found coverage of *Deschampsia flexuosa* to increase and *Empetrum nigrum* to decrease. Soil fungi: bacteria ratio and soil C/N were decreased and enchytraeid numbers increased. Ectomycorrhizal fungal fruitbody numbers were decreased and saprotrophic fruitbody numbers increased. Fungal symbiont communities of *D. flexuosa* root and shoots also changed. Ectomycorrhizal community associated with mountain birch roots will be studied using 454 pyrosequencing. We conclude that moth outbreak causes marked shifts in the mountain birch ecosystems soon after the damage.

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Root hydraulic conductance as an indicator of frost damage in roots of Norway spruce seedlings

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During the winter storage, nursery seedlings are exposed to frost temperatures. Due to the lack of proper methods, it is difficult to assess if winter storage has declined the vitality of roots. Currently used methods, like root growth potential, are time consuming. Therefore, their applicability in the nurseries is limited. We aimed to study i) how root hydraulic conductance of two-years old Norway spruce (*Picea abies* L. Karst) seedlings changes after exposure to frost, and ii) weather this method could be used for assessing root damage of the seedlings. The seedlings were cold-stored at the FinForelia Tuusniemi nursery over winter. The seedlings were in a quiescent phase (i.e. no bud burst occurred), and moved outside in July shortly before exposing them to temperatures +5, -2, -6, -9 and -12°C in controlled tests. The tests (8 seedlings/temperature) were long enough for roots to reach the target temperature. Root hydraulic conductance was measured with the High Pressure Flow Meter (HPFM) after root ball was thawed and warmed to room temperature. The measurement is based on driving water into the root system through the cut stem at approximately 15 mm above root collar by gradually increasing pressure. Hydraulic conductance is defined as the ratio of volume flow of water and the applied pressure.

Root hydraulic conductance increased from 2 to 10 mg s^{-1} MPa^{-1} by decreasing the exposure temperature from +5 to -12°C respectively. This refers to frost damage in the root system. We concluded that HPFM might be an applicable method in assessing root damage in controlled freezing tests. Further studies are needed to compare the changes in hydraulic conductance with other methods. HPFM is a potential tool that could be used in the nurseries for scoring root damage after winter storage.

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