Forest Condition Monitoring in Finland – National report

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Significance of litter production of forest stands and ground vegetation in the formation of organic matter and storage of carbon in boreal coniferous forests

By Sari Hilli

Summary

In the boreal forests, tree stands, mosses and dwarf shrubs produce the majority of the litterfall, which becomes a component of humus as it decomposes. In this study, we determined the composition of the litter layer in 6 Norway spruce and 6 Scots pine forests and examined the significance of the composition of litter in the formation of humus layer in the forests located in the northern and southern boreal vegetation zones.

In general, the amount of semi-decomposed dwarf shrub and moss litter was higher in the litter layer of pine forests than in spruce forests. Moreover, the role of dwarf shrubs in the formation of forest soil organic matter (SOM) was much greater in the north, and the carbon (C) production of mosses even exceeded that of tree litter in the Hylocomium-Myrtillus type spruce forests in Northern Finland.

Northern and southern forests showed no significant differences in the decomposition rates of needle, moss or bilberry leaf litter, though needle litter decomposed slightly more rapidly in the latter stages of the decomposition in the south. Among the litter types studied, bilberry leaf litter had the highest concentration of water-extractable C and nitrogen, and it decomposed clearly more rapidly than needle or moss litter in the early stages of the decomposition.

The C composition of tree and dwarf shrub litter differed significantly from the C composition of moss litter. The significance of the litter layer to the total SOM in forests and as storage of various C compounds is much greater in the northern boreal zone than in the south. In general, more C accumulated in SOM in spruce forests than in pine forests.

Introduction

Litterfall produced by plants is the main source of organic matter for forest soil. Litter decomposition and the formation of humus are processes that are dependent on vegetation and the quality and quantity of its litter production (e.g. Coûteaux et al. 1995). Litterfall that is not readily degradable has been observed to affect the formation of organic matter in particular (Högberg et al. 2003). Litterfall produced by certain plants may be fully degradable and thus will not turn into highly decomposed organic matter, i.e. humus (Kang et al. 2009).

Furthermore, the structure and activity of the decomposing microbial community affect the properties and formation of humus (Grayston & Prescott 2005). In the course of the litter decomposition process, the microbial community, and fungi species in particular, transform in line with the carbon compounds available (Sinsabaugh 2005, Korkama-Rajala et al. 2008).

According to previous studies, climate and site factors and the chemical properties of a specific litter type affect its decomposition rate on both global and regional levels (e.g. Aerts 1997, Liski et al. 2003). The temperatures in the boreal coniferous forest zone are expected to increase over the next 50 years as a result of the climate change (Carter et al. 2005). Longer and warmer growing seasons may increase primary production, and enhance the decomposition rate of litterfall. Previous studies have suggested that decomposition rates may be enhanced by global warming to a greater extent than primary production (Schimel et al. 1994).

The vegetation composition characteristic of boreal coniferous forests comprises a tree layer, an understorey of dwarf shrubs, and a ground layer of mosses and lichens. Tree litter, its quantity and chemical properties, and the impact it has on the forest ecosystems' ecological processes, such as decomposition, formation of humus, and nutrient cycling, have been studied extensively (e. g. Ukonmaanaho et al. 2008). On the contrary, only in recent years have studies been conducted on the ecological significance of ground vegetation to boreal forest ecosystems (Nilsson & Wardle 2005, Kolari et al. 2006). In previous studies, moss litter has been observed to decompose slowly and to accelerate the decomposition rate of other litter types through its ability to maintain a sufficient moisture level (Wardle et al. 2003). On the other hand, mosses have been found to potentially impede litter decomposition rates, because they buffer soil against temperature changes by increasing surface insulation (Oechel & Van Cleve 1986). Bilberry (*Vaccinium myrtillu*), the most common dwarf shrub species found in boreal forests, produces leaf litter that contains high concentrations of nitrogen (N) and decomposes more rapidly than the litter produced by lingonberry (*Vaccinium vitis-idaea*) and black crowberry (*Empetrum nigrum*; Nilsson & Wardle 2005). Black crowberry litter in turn has been found to produce large quantities of polyphenolic compounds, thus impeding decomposition (Wardle et al. 2003).

Results and discussion

Litterfall produced by plants is the main source of SOM in forests. Each plant species has a different impact on the formation of humus. In the boreal coniferous forest zone, tree stands, mosses and dwarf shrubs produce the majority of the litterfall on the forest floor, which becomes a component of humus as it decomposes. Forest stand litter production (Ukonmaanaho et al. 2008) and the proportion of tree litter from the total quantity of litterfall in the litter layer was greater in the sample plots of the southern boreal zone than in the northern zone (Fig. 1). The tree litter accumulated in the surface layer (L) of the forests in Southern Finland contained far more twigs and cones than the L layer of the forests in Northern Finland (Fig. 2), whereas the relative share of needles from the total amount of tree litter was greater in the sample plots located in Northern Finland (Fig. 2).

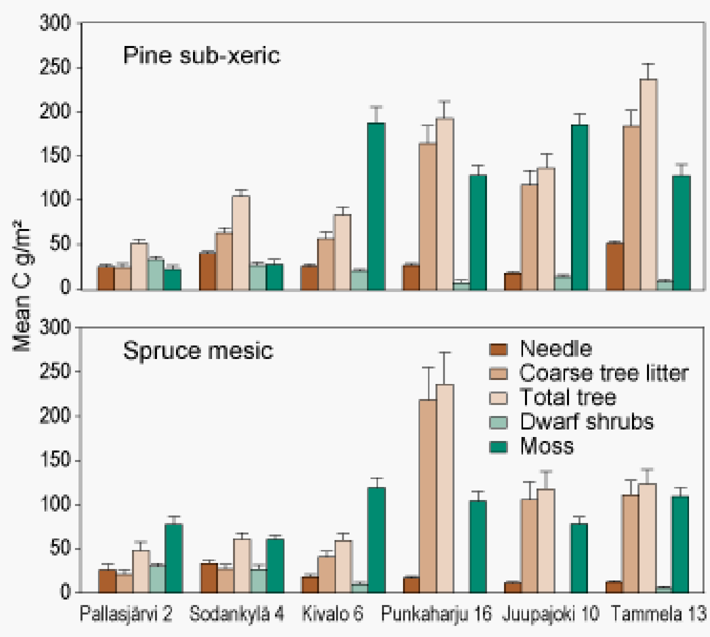

Figure 1. Carbon stocks in main litter fractions of L layers of boreal coniferous forests. The error bar = standard error of the mean.

Larger quantities of semi-decomposed dwarf shrub and moss litter were found in the litter layer of pine forests in comparison to spruce forests, apart from the two northernmost sample plots (Fig. 1). This is largely due to the higher proportion of evergreen dwarf shrubs among the shrub species of pine forests. The litter produced by evergreen dwarf shrubs has a lower decomposition rate than bilberry or lingonberry litter. Stendahl et al. (2010) have shown with their simulations that ground vegetation plays a more significant role in the litter production of pine forests than spruce forests. The quantity of moss litter in the pine forests of Northern Lapland (Pallasjärvi and Sodankylä) reduces significantly due to the increased proportion of dwarf shrubs and lichens among the plant species and their subsequent greater role in the production of litter. This can be seen in the accumulation of organic matter and its total organic carbon content (Fig. 1). The role of dwarf shrubs in the formation of forest soil organic matter and as a source of carbon is much greater in the north, because sparse forest stand does not prevent light from reaching the ground, thus allowing the formation of a dense layer of dwarf shrubs. The carbon production of mosses exceeds the amount of carbon produced by tree litter in the Hylocomium-Myrtillus type (HMT) forests of Northern Finland (Fig. 1).

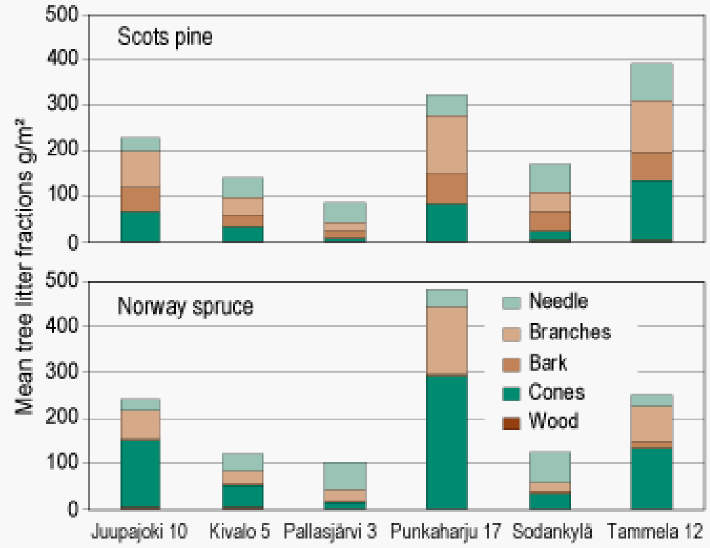

Figure 2. Tree litter composition (fractions) of L layers of boreal coniferous forests.

Significance of litter in the accumulation of carbon and organic matter

Northern and southern boreal forest zones showed no statistically significant differences in the decomposition rates of needle, moss or bilberry leaf , although needle litter did decompose slightly more rapidly in the latter stages of the decomposition process in the southern boreal zone (Fig. 3, Hilli et al. 2010). Among the litter types studied, bilberry leaf litter had the highest concentration of water-extractable carbon (WEC) and N, and it decomposed clearly more rapidly than needle or moss litter and in the early stages of the decomposition process (Hilli et al. 2010). Previous studies have found that under very similar climate and soil conditions, there are differences in the decomposition rates of plant-derived litter types (e.g. Wardle et al 2003). Litterfall with high concentrations of N or WEC has a higher decomposition rate than litterfall that contains low concentrations of N and water-soluble extractives (WSE) and high concentrations of lignin or other acid-insoluble residue (AIR) (Tian et al. 2000, Wardle et al. 2003).

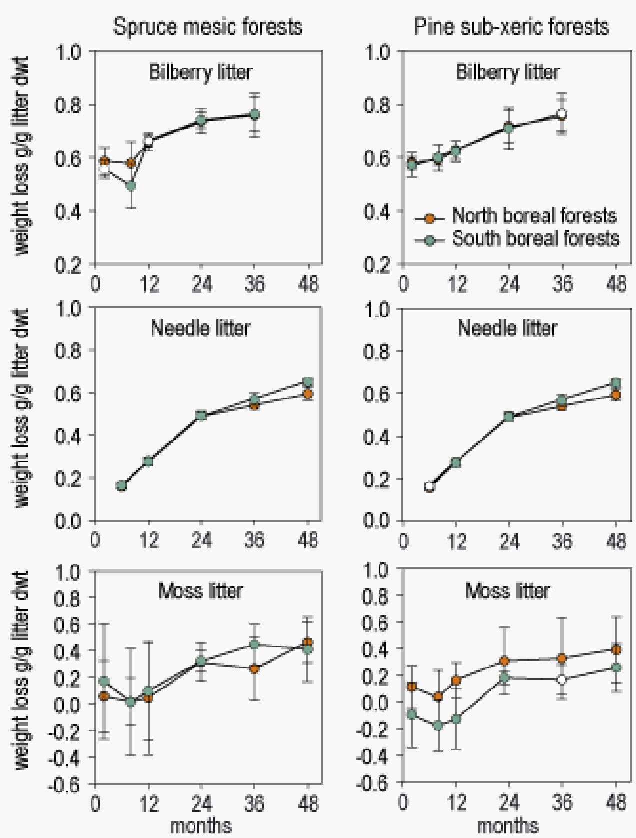

Figure 3. Mass loss of bilberry leaf, needle and moss litter during decomposition in the spruce and pine forests of Northern and Southern Finland. Source: Hilli et al. 2010.

The carbon compositions of tree and dwarf shrub litter were significantly different from the C composition of moss litter (Fig. 4). Mosses contained clearly more cellulose (acid-soluble fraction, AS) and had much lower concentrations of WSE, non-polar extractives (NPE) and AIR than tree and dwarf shrub litter. According to measurements conducted using the TOC method, the WSE fraction of moss litter contained much lower concentrations of phenols, sugars and WEC than those of tree or moss litter (Fig. 5a–c). On the other hand, mosses contained higher concentrations of water-extractable N (Fig. 5d). Mass loss in the C fractions of litter varied according to the type and decomposition rate of litter, but the differences between northern and southern boreal zones were small when comparing the fractions of a single litter type (Hilli et al. 2010). The decomposition rate of moss litter was clearly lower than the rates of tree or dwarf shrub litter, and there were fewer relative changes in the carbon fractions.

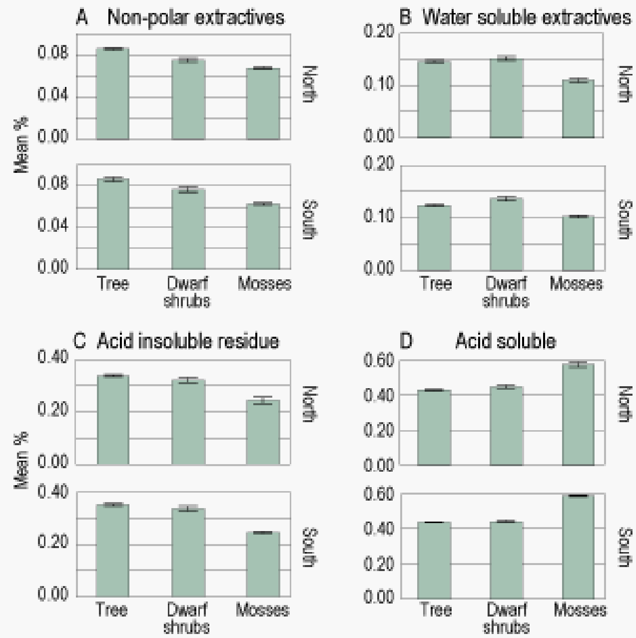

Figure 4. Carbon fractions (NPE, WSE, AS and AIR) of tree, dwarf shrub and moss litter in the sample lots of Northern and Southern Finland.

Although the decomposition rates of various litter types did not vary between the northern and southern boreal forest zones, the significance of the litter layer to the total SOM in forests and the storage of various carbon compounds is much greater in the northern boreal zone (Hilli et al. 2008a, b). Especially in northern boreal pine forests, the litter layer contains much larger WEC stocks compared to those in the south, as well as a significant proportion of the total carbon content of the organic horizons (Hilli et al. 2008a, b). More soil C accumulation occurred in spruce forests than pine forests, although there was no variation in the decomposition rate of litter between these two types of coniferous forest (Hilli et al. 2010). Considerably more variation was found in the comparison between spruce and pine forests located in the northern boreal zone than in the comparison between the two types of forest in the southern boreal zone (Hilli et al. 2008a, b). The simulations of Stendahl et al. (2010) have shown that under the same environmental conditions, the spruce forest soil accumulates 22% more carbon than pine forest soil. However, the difference in favour of spruce forests decreased with the increase in temperature (Stendahl et al. 2010). On the basis of the present study, temperature or other site factors do not have a direct influence on the accumulation of organic matter, but instead influence it indirectly through the vegetation and its litter input.

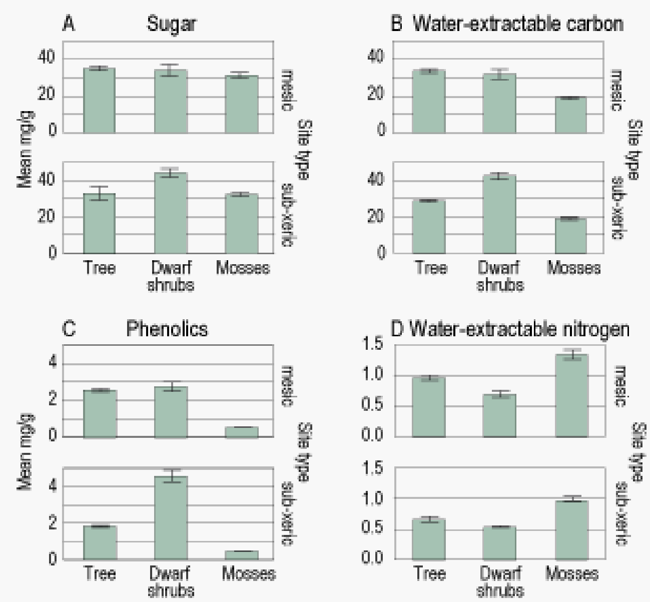

Figure 5. Sugar, WEC, phenol and WEN concentrations of tree, dwarf shrub and moss litter in the L layers of spruce and pine forests

Clear changes in the plant community structure of the understorey and forest floor of coniferous forests may cause significant changes to the quantity and quality of litter, which in turn has a direct impact on soil C accumulation

(Hättenschwiler & Gasser 2005). Because the changes in the litter layer's microbial community structure and decomposer community occur on account of changes in the plant community (Allison et al. 2009), the changes in the species composition and activities of the decomposer community have an indirect impact on the accumulation of organic matter. In particular, changes to the amount of mosses and their litter input combined with tree litter have a significant impact on the amount of organic matter accumulated and, through it, an impact on the carbon stocks of boreal coniferous forest soils.

Material and methods

Three sites including Scots pine and Norway spruce plots located within the northern boreal vegetation zone (Pallasjärvi nrs. 2 and 3, Sodankylä and Kivalo nrs. 5 and 6) and three sites within the southern boreal vegetation zone (Tammela nrs. 12 and 13, Juupajoki nrs. 10 and 11 and Punkaharju nrs. 16 and 17) were selected for the purpose of studying the impact of climate and soil factors and vegetation on the decomposition and formation of organic matter. Vegetation coverage analyses were conducted before taking the soil samples. The decomposition and accumulation of organic matter to forest soil were analysed through decomposition experiments (Hilli et al. 2010), and by taking samples of naturally formed layers of organic matter that were in various stages of decomposition (Hilli et al. 2008a). In total, 28 soil samples measuring 30 x 30 cm^2 were removed from the forest floor of each sample plot and then separated into three individual samples: the litter layer (L), the fermentation layer (F), and the humus layer (H). The litter layer was further characterised into the following fractions: 1) needle litter, 2) coarse tree litter, 3) dwarf shrub litter, 4) moss litter, 5) lichen litter, and 6) litter produced by herbs and grasses.

Chemical analyses

In order to understand the ecology of accumulating C substrates, we characterised the soil organic matter according to Ryan et al. (1990) into the following fractions: non-polar extractives, chloroform soluble (NPE, waxes, fatty acids, oils), water-soluble extractives (WSE, e.g. sugars and phenolics), acid-soluble fraction (AS, e.g. cellulose), and acid-insoluble residue (AIR) (lignin, tannin and cutin) (Ryan et al. 1990, Preston et al. 1997).

In order to characterise the WSE fraction in detail, the water-extractable phenolic concentration was determined by the Folin-Ciocalteu method (Suominen et al. 2003) and the concentration of soluble sugars by the method presented by Wood and Bhat (1988). Water-extractable carbon (WEC) was analysed using a carbon analyser (Shimadzu TOC-5000A) and water-extractable N by flow injection analysis (FIA 5012) after oxidation of N to NO_3-N with alkaline potassium persulphate (Williams et al. 1995).

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