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Dynamics of organic matter accumulation and decomposition in the surface soil of forestry-drained peatland sites in Finland

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ABSTRACT

We studied organic matter accumulation dynamics in peatland surface soil, using the root collar depth of tree-ring aged Scots pine seedlings for dating the base level of quantitative soil samples. The data consisted of 222 samples collected from 47 forestry-drained and four undrained locations. At the drained sites, the data indicated an average dry biomass accumulation of about 4 kg m^{-2} in samples representing the past 30 years. Despite great variance in the data, the results clearly indicate decreasing *per annum* accumulation values with increasing sample age, thus implying rapid decomposition of the fresh litter. Derived from the age-mass relationship we can estimate that about 95% of 1 year's litter input will be decomposed during 30 years. High decomposition rate of the litter suggests that drained peatland forest soils do not act as a carbon sink. The average detritus accumulation values were somewhat higher on the undrained control sites than on the drained sites. Among the forestry-drained sites, the average accumulation was significantly lower in sites with timber volumes exceeding 200 m^3 ha^{-1}, as compared with sites with timber volumes <100 m^3 ha^{-1}, suggesting a connection between tree stock and litter decomposition rate.

1. Introduction

Forestry drained peatlands account for 54 000 km^2 of peatlands in Finland, and their timber stock is 24% of the total growing stock of 2.28×10^9 m^3 of Finnish forests (Finnish Forest Research Institute, 2011). Peatland forests and forestry thus constitutes a significant element in the national carbon (C) budget (Sarkkola, 2007). The dynamics and balances of soil C in drained boreal peatlands are not fully understood, and there is much controversy in the existing data (Laiho, 2006). Some studies have addressed the C dynamics of drained peatland soils by soil respiration measurements (e.g. Byrne and Farrell, 2005; von Arnold et al., 2005a,b; Minkkinen et al., 2007; Mäkiranta et al., 2007; Ojanen et al., 2010). The total respiration measurements include CO_2 production from living roots and decomposition of both litter and older peat, whereas in heterotrophic respiration the contributions of living roots and fresh litter are excluded (Alm et al., 2007). Soil respiration data alone is not sufficient; to achieve a C balance estimate for the soil, one must also assess by other methods the gross input of C into the soil (Laiho, 2006). Litter production of trees can be estimated relatively reliably (Muukkonen, 2004; Muukkonen and Lehtonen, 2004). On the other hand, production of mosses at drained sites is poorly known, and estimates of the root litter production are highly uncertain, as are decomposition rates of litter in varying conditions (Laiho, 2006; Laiho et al., 2008; Strakova, 2010).

Direct measurement of litter accumulation in the surface peat provides an alternative approach to study C dynamics in peat soils. The main problem with the method is the need for an exact dating for the recent peat deposits (ranging in age from a few years to some decades). Radiometric methods based on multiple samples taken stratigraphically from a peat sequence ("wiggle matching") could potentially provide exact ages for recent peat. In practice, unknown and varying accumulation rate of the peat sequence may obscure matching of the age measurement samples with the ^{14}C calibration curve, resulting in poor age resolution. Moreover, the expenses of a study employing radiometric methods with multiple sampling will grow high (Turetsky et al., 2004). A simple solution is provided by seedlings of woody perennial plants, germinating at the soil surface, and dating the subsequent burial depth of that level. The pine root collar method (Lindholm, 1989; Tolonen and Turunen, 1996; Ohlson and Økland, 1998; Schulze et al., 2002) provides accurate dating for superficial peat strata thus allowing modeling of the post-depositional decomposition process and potentially enables determination of the true rate of C accumulation at the site (Gunnarsson et al., 2008). In this study, we collected surface peat samples associated with individual Scots pine (*Pinus silvestris*) seedlings from different types of drained peatland forests to obtain quantitative data for litter dynamics.

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The goal of this study was to produce estimates on dry litter accumulation of surface soils in different types of drained peatlands and to demonstrate the applicability of the method for studying the dynamics of C incorporation in the surface peat on forestry-drained peatlands.

2. Material and methods

The main body of samples, representing ditch-drained peat soils, was collected from former Geological Survey of Finland (GTK) peat inventory coring sites, which we visited in 2009 for re-investigation of the full peat mass inventory (Simola et al., in press). The samples, consisting of individual pine seedlings with the associated surface soil, were collected at 47 sites, situated in five regions in Finland (Fig. 1). Most of the sites were ditched for forestry improvement in the 1970s, a few in the early 1980s. The peat thickness at the sites was on average 190 cm (range 60–220 cm). Climatically the regions are fairly similar, although region 3 is slightly cooler and moister than the other ones (Table 1). The elevations of the sites vary between 120 and 200 m asl.

The study sites represent a range of original mire types and trophy levels between ombrotrophic and eutrophic sites (see Table 2). At the sites, the forests consisted mainly of Scots pine (*P. silvestris*), birches (*Betula* spp.) and spruce (*Picea abies*) in varying proportions. Scattered rowan (*Sorbus aucuparia*), gray alder (*Alnus incana*), great sallow (*Salix caprea*) and aspen (*Populus tremula*) were also found in many of the sites.

Timber volumes at the study sites (estimated with a relascope) vary between <10 and 280 $m^3 ha^{-1}$ (Table 2). The tree cover of the sites seemed to have developed with little human interference after the drainage. Except for thinning of the forest at a few of the sites, there were no signs of wood cutting.

At the study sites we drilled five cylindrical soil samples, each adjacent to a pine seedling, by means of a steel cylinder with a sharpened edge and inner diameter of 12.5 cm. On a few sites it was not possible to find the intended number of pine seedlings, so a total of 222 tree-ring dated surface peat samples were included in this study. An additional set of 20 samples of surface peat and pine seedlings were taken from four pristine, treeless ombrotrophic mire sites situated in region 1. The samples were taken within a radius of about 20–30 m from the coring points of GTK. From each soil cylinder, the top layer above the root collar depth of the adjacent pine seedling was packed into plastic bags and taken as a quantitative sample into the laboratory (Lindholm, 1989; Ohlson and Økland, 1998). Litter, small shrubs and living mosses were included in the samples. The pine seedling was taken along, for subsequent tree-ring age determination of the surface sample. In laboratory, dry masses of the samples were determined after drying at +105 °C.

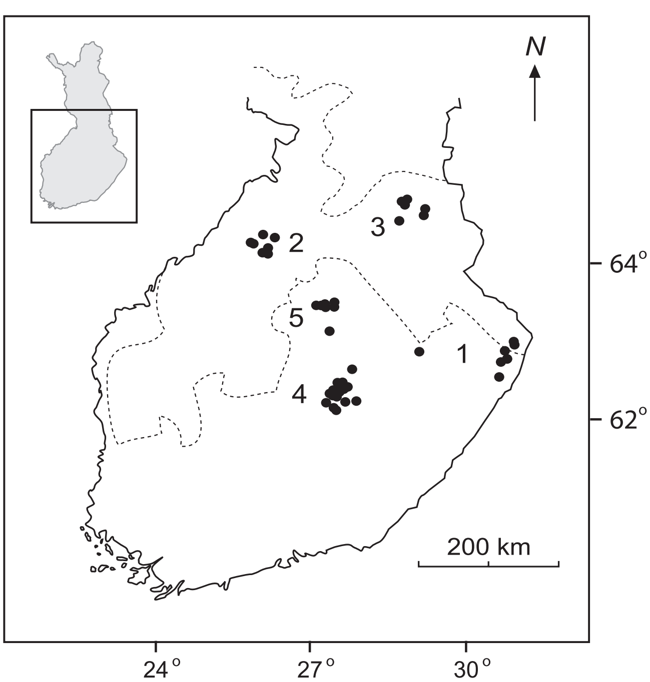

Fig. 1. Study locations in five areas in Finland.

Table 1
Some climatic parameters of the regions.

Region	Temp. (°C$_1$)	Precipitation$_2$	*P.*-E.mm$_3$	*T.* sum$_4$
1	2–2.9	630–650	<0 to −20	1000–1100
2	2.3	560	0 to −20	1000–1100
3	1.2	580–620	+20–+60	900–1000
4	3	650	0 to −20	1000–1100
5	2.9	620	0 to −20	1000–1100

(1) Mean temperature of the year (period 1971–2000); (2) mean precipitation mm $year^{-1}$; (3) difference between precipitation and evaporation on cultivated areas from snow melt to the end of July (period 1931–1960); and (4) effective temperature sum during the growing season (period 1931–1960)

The basal age of each of the surface soil samples is the dendrochronologically determined age at root collar level of the pine seedling that was taken adjacent of the soil sample. The dry mass of the soil sample (g 100 cm^{-2}) divided with its basal age gives a yearly average mass accumulation value. Assuming 50% of C content for the dry mass (Minkkinen and Laine, 1998), the yearly average mass accumulation values were converted to recent apparent rate of carbon accumulation (RERCA) (Tolonen and Turunen, 1996). Most of our observations fall into the age range 5–30 years, which thus is the practical time frame for analyzing the decay process. We have fitted a simple exponential decay model for the data (Yu et al., 2001).

Concerning C dynamics of the surface soil, the basic limitation of the method is that the root collar depth only reveals positive or zero accumulation values, and the results only apply to the material deposited above the root collar levels of the seedlings. Thus, significant mass balance changes may take place deeper down and remain unaccounted for by this method. Such changes may involve decomposition, but also mass accumulation by deep roots.

For statistical comparisons of different subsets of the data, one-way ANOVA with Tukey HSD test was used.

3. Results

Most of the samples (83%) contained living mosses at the surface, mainly *Sphagnum* spp., while 17% of them were solely litter covered.

We measured the precise height of the sampled top section of the peat cores from only a representative subset of the samples (taking the measure is not necessary in the routine slicing at the root-collar depth). The mean sample height, including the living moss layer, was 7.3 cm (s.d. = 5.1, range 0–22 cm, n = 50). The dry bulk density of the samples ranged from 10 to 170 g L^{-1} (mean 58 g L^{-1}, s.d. = 41), while in all samples thicker than 7 cm the bulk density values were between 10 and 45 g L^{-1}.

The mean age of the collected surface peat cores of the drained sites was 14 years (s.d. = 7.6, range 3–43 year). The corresponding average dry mass accumulation of the cores was 207 g m^{-2} $year^{-1}$ (s.d. = 111, range 0–440 g), or 104 g C m^{-2} $year^{-1}$ (RERCA). The average dry mass accumulation rate of the undrained sites was 290 g m^{-2} $year^{-1}$ (s.d. = 80, range 160–410, mean age 17 year),