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Models of litterfall production for Scots pine (*Pinus sylvestris* L.) in Finland using stand, site and climate factors

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Abstract

The aim of this study was to identify the most significant site, stand and climate factors affecting needle (LF_{needle}) and total (LF_{total}) above-ground litterfall production and to develop multiple linear regression (MLR) models that can be used to reliably predict litterfall production in the boreal zone using readily available variables. Unlike most other litterfall production studies, we use climate data for the actual sites and annual litterfall values. A data set including 34 Scots pine stands located throughout Finland was compiled. The data for some stands covered a period of more than 30 years. The age of the stands ranged from 35 to >200 years and all were growing on upland, mineral soil sites. Stand mean annual LF_{needle} ranged from 22 g m^{-2} (northern Finland) to 157 g m^{-2} (southern Finland); corresponding values for LF_{total} were 32 and 230 g m^{-2}. Annual LF_{needle} production accounted between 49 and 75% of stand LF_{total} production and explained 88% of the variation in LF_{total} over all stands. There was considerable annual variation in litterfall production also within the same stand. The coefficient of variation in LF_{needle} in each stand ranged from 4 to 58% (mean = 19%) and from 3 to 39% (mean = 22%) for LF_{total}. Both LF_{needle} and LF_{total} were highly significantly ($p < 0.01$) and strongly correlated (Spearman) with latitude, stand basal area, effective temperature sum (ETS) of the current year and even higher with that of the previous year, and the previous years' July temperature. LF_{needle} had a weak negative, although significant ($p < 0.05$) correlation with stand age, but age was not significant for LF_{total}. MLR models using latitude and stand basal area (also dominant tree height in the case of LF_{needle}) as predictive variables accounted for 82% of the variance in both LF_{needle} and LF_{total}. The standard error of the estimate (SE_{est}) was 12.6 g m^{-2} for LF_{needle} and 23.3 g m^{-2} for LF_{total}. Latitude effectively described the climate at each stand but ignored the considerable within-stand variation in annual litterfall production. Using the annual values for the climate variables instead of latitude, 70% or more of the variation in both LF_{needle} and LF_{total} in MLR models could be explained. The models are useful tools for predicting annual litterfall in mature Scots pine stands for use in soil organic and carbon models.

Keywords: Litterfall; Multiple linear regression; Boreal forests; Biomass

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1. Introduction

Canopy litterfall represents the major above-ground pathway by which carbon and nutrients are returned to the forest floor (Cole and Rapp, 1981). On an annual basis, needle litterfall accounts for the main part (ca. 70%) of the total litterfall in Scots pine stands (Mälkönen, 1974; Flower-Ellis, 1985; Finér, 1996) and correlations between needle and total litterfall have been found to be highly significant (Berg et al., 1999; Berg and Meentemeyer, 2001).

In many studies, the annual litterfall flux has been found to correlate with factors describing the characteristics of the stand and climate. Albrektson (1988) found that the amount of above-ground needle litterfall in Scots pine stands increased with increasing site quality and decreased with increasing stand age and latitude. Differences in litterfall production of Scots pine related to stand age were clearly shown also in the study by Flower-Ellis (1985). Stand age is an indirect measure of stand biomass and latitude is an indirect measure of climate, with both temperature and precipitation generally decreasing northwards in the boreal zone. In a compilation of Swedish Scots pine litterfall data, including that of Albrektson (1988) and Flower-Ellis (1985), Breymeyer et al. (1996) found that latitude, site index and basal area together explained 73% of annual needle litterfall and 77% of total above-ground litterfall. Berg et al. (1999) were able to explain about 78% of the variation in Scots pine needle litterfall on a European scale using combinations of latitude, basal area, site index and age as independent variables, with no one factor dominating.

Annual litterfall varies considerably (Flower-Ellis, 1985; Finér, 1996; Hennessey et al., 1992), which can be expected to be related weather conditions differing from year to year. There is also a clear seasonal pattern in litterfall. Scots pine needle litterfall production in the Nordic countries typically peaks during September (Viro, 1955; Mälkönen, 1974; Flower-Ellis, 1985; Finér, 1996) associated with needle senescence, and is the lowest during early summer (Mälkönen et al., 2000). Besides the effect of weather conditions in the current year, weather conditions during previous years can also affect current litterfall production (Kouki and Hokkanen, 1992).

Berg and Meentemeyer (2001) presented regression models explaining litterfall production with climate factors such as average annual temperature, average July temperature, total annual precipitation, potential and actual evapotranspiration, and the soil moisture deficit. For needle litterfall production in pine stands (mainly Scots pine) at the European scale, they obtained the best (highest R^2) model using actual evapotranspiration and stand age as independent variables. However, in the study by Berg and Meentemeyer (2001), as in many other studies, average annual litterfall production and long-term mean values for the climate factors have been used to derive relationships, thus ignoring the large annual variability in litterfall production and weather conditions. Moreover, climate variables applied have been for the nearest weather station and not for the stand.

The aim of this study was to identify the most significant site, stand and climate factors affecting needle and total above-ground litterfall production and to develop multiple linear regression models that can be used to reliably predict Scots pine litterfall production at any site using readily available data. Unlike most other litterfall production studies, we use annual climate data for the sites and annual litterfall values. The need for such specific models has been motivated by the central role played by litterfall production in driving soil organic (carbon) models for boreal forests (Liski et al., 1998).

2. Material and methods

2.1. Study stands

Data on above-ground total and needle litterfall were collected from 34 Scots pine stands growing on a range of upland, forest site types located throughout Finland (Fig. 1).

The stands were pure or almost pure Scots pine stands and the volumetric proportion of other species, mainly Norway spruce and downy birch and silver birch, was <7%, with the exception of stand number 53 (18%). The percentages of the stands on barren, dry, dryish and fresh site types were 3, 29, 53 and 5, respectively. Stand age ranged from 35 to well over 200 years, and stand stem volume ranged from 46 to 315 $m^3\ ha^{-1}$ (Table 1).

Stand characteristics were measured using standard silvicultural mensuration methods and stand stem