

Biomass distribution in a young Scots pine stand

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The standing biomass of a young Scots pine stand was measured at the SMEAR II experimental station in Hyytiälä, southern Finland. The stem volume was found to be $119 \text{ m}^3 \text{ ha}^{-1}$, corresponding to $41\,450 \text{ kg ha}^{-1}$ in stem biomass. The needle biomass was 5100 kg ha^{-1} and was constituted mainly by the two youngest needle age classes. The branch biomass was 9040 kg ha^{-1} and the root biomass $12\,520 \text{ kg ha}^{-1}$. The height of the first living branches was found to vary from 2.2 to 6.9 m, whereas the variation in tree height was between 4.1 and 14 m. The needle surface area was $3.9 \text{ m}^2 \text{ m}^{-2}$ and the root length and surface area were 4180 m m^{-2} and $8.8 \text{ m}^2 \text{ m}^{-2}$, respectively. More than half of the total fine root surface area was found in the upper 10 cm of the soil.

Introduction

Boreal forests are an important storage of carbohydrates and their role in the global carbon balance is significant. In the literature, the amount of stem volume is well documented (e.g. Koivisto 1959, Ilvessalo and Ilvessalo 1975, Vuokila 1980), but less information is available on other parts of trees such as needles, branches and roots (Mälkönen, 1974, Hakkila 1979, Marklund 1988, Vanninen *et al.* 1996).

In the analysis of the interactions between single trees in the stand, spatial distribution of single trees is an important factor (Ceulemans 1997). The interaction between the environment and the trees is greatly affected by the amount and distribution of the roots and needles within the stand. Light adsorption and the effects of gaseous phase compounds and atmospheric par-

ticles are very much dependent on vertical needle distribution and needle surface area. Also transpiration, canopy interception, and soil water balance depend on needle distribution in the stands.

Roots form the contact area between trees and soil. The distribution of the roots is horizontally heterogeneous and has strong vertical gradients (Pietikäinen *et al.* 1999). Most of the biomass is located in the coarse roots, but the main part of the root surface area is found in the fine roots ($\varnothing < 2 \text{ mm}$) and mycorrhiza attached to them.

The tree stand is one of the major carbon reservoirs in the boreal coniferous ecosystems. In this study we present the distribution of tree biomass separately to needles, branches, stems and roots in a young Scots pine stand. The results can be used in estimations of carbon accumula-

tion into a stand and as a basis for model calculations of stand growth and structure.

Material and methods

The studied site is located at Hyytiälä Forestry Field station in southern Finland (61°51'N, 24°17'E) and is a part of the intensively studied Forest Ecology and Atmospheric Physics Research station SMEAR II. The experimental setup and the measurements carried out at the station are described in detail in Vesala *et al.* (1998).

Pine seed was sown after prescribed burning and scarification in 1962 on podzolized glacial till soil. At present, the ground vegetation is evenly distributed consisting mainly of *Vaccinium vitis-idea*, *Vaccinium myrtillus* and *Calluna vulgaris*. The mosses are mainly *Dicranum* and *Pleurozium* species. The detailed soil properties of the site are presented in Ilvesniemi and Pumpanen (1997).

At the beginning of the experiment, the location of each tree was determined. The trees were numbered and the stem diameter at breast height (1.3 m, DBH) as well as tree height and the height of the lowest living branches was measured in 1996. The height measurement was repeated on selected sample trees in 1998 and the diameter at breast height has been recorded annually. The determination was done at a marked height from two different directions. The stem volume of trees in the stand was calculated from the DBH measurements according to Laasasenaho (1982).

The needle biomass of 9 selected sample trees was estimated with a sample branch method. The sample tree selection was based on DBH distribution of all trees in the stand. The stem of the sample trees was divided into one-meter long sections, and the diameter of all branches, both near the stem and beside the first living needles, was measured. From each section 1 to 6 sample branches were taken; the total number of sample branches was 128. The needles and branches were separated by age class, dried in the oven at 60 °C for 24 h, and weighed. The sampling was carried out in the autumn, after shedding of the oldest needle age class,

giving a minimum estimate of the needle biomass.

A regression model, using branch diameter in estimation of needle and branch biomass, was established separately for the six topmost whorls and the lower part of the crown. This model was applied to calculate the total needle and branch biomass of the sample trees. In order to estimate the needle and branch biomass of the stand, a regression model between the stem cross-sectional area (SCA) at breast height and the needle or the branch biomass of the sample trees was determined. This model was applied to all the trees of the catchment, and the surface area of the catchment was used to obtain the biomass per hectare values.

To avoid digging in the study area, five sample trees for root biomass determination were selected from a similar stand within a 50 m distance from the catchment. Roots attached to the stump were dug up, divided into stump, > 20 mm, 10–20 mm, 5–10 mm, 2–5 mm and < 2 mm diameter size fractions, air dried and weighed. An unknown proportion of roots < 2 mm could only be sampled with this method. A regression equation was established between the total root biomass and diameter at breast height, and this equation was used to obtain the total root biomass in the stand.

For the estimation of the needle surface area, 30 sample branches were selected to represent different heights in canopy. Twenty sample needles representing the needles of corresponding age class were taken randomly from each branch, and the mass and length of each needle was measured. The all-sided surface area of the needle was calculated from needle length, by applying an empirical equation

$$a_1 l + a_2 (l)^2 \quad (1)$$

where a_1 and a_2 are parameters (2.1 and 0.045, respectively) and l , needle length in mm (Ross *et al.* 1986). From these measurements, a coefficient expressing the ratio between the needle biomass and the needle surface area was calculated and the total needle area in the stand was obtained by multiplying the needle biomass of the stand by this coefficient.

Fine root (< 2 mm) length was estimated from 50 cm deep soil core samples (diam. 4.6 cm)

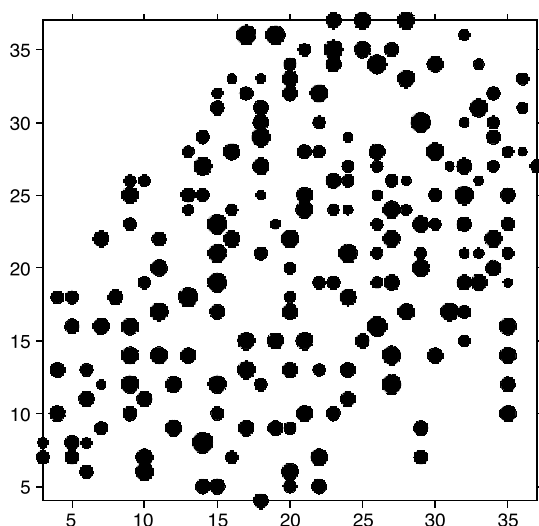


Fig. 1. Map of the mini-catchment studied and the stem spatial distribution within the stand in 1996. The size of the dot is proportional to stem diameter measured at breast height (range 4–19 cm).

taken systematically from the site. The cores were separated in humus, eluvial, upper and lower illuvial and ground soil layers, washed free from soil and spread on overhead sheets for scanning. The digitalized images were calculated for root length and diameter with the WinRhizo V 3.2 (Regent Instruments Inc., Canada) program.

Results and discussion

The spatial distribution of the trees at the mini-catchment is reasonably even (Fig. 1), although the depth of the soil varies from base rock covered only with lichens to 1.8-m deep soil at the lowest part of the catchment. No correlation was found between soil depth and the tree diameter at breast height.

The distribution of stems into diameter size classes at breast height (Fig. 2) was typical of young Scots pine stands at the time of canopy closure. Most of the stems were found in the medium size classes, but the distribution was also slightly bimodal. This grouping can be connected to the competition between single trees and as a result of the competition, separation to suppressed and dominant trees (Ford

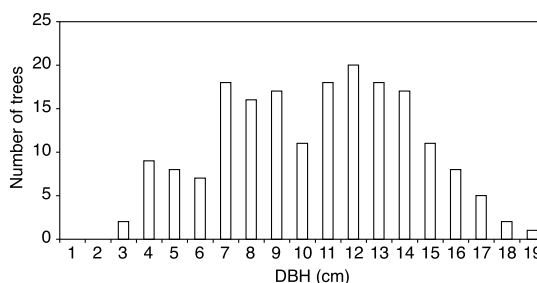


Fig. 2. The distribution of the Scots pine stems in DBH size classes. Class interval is 1 cm.

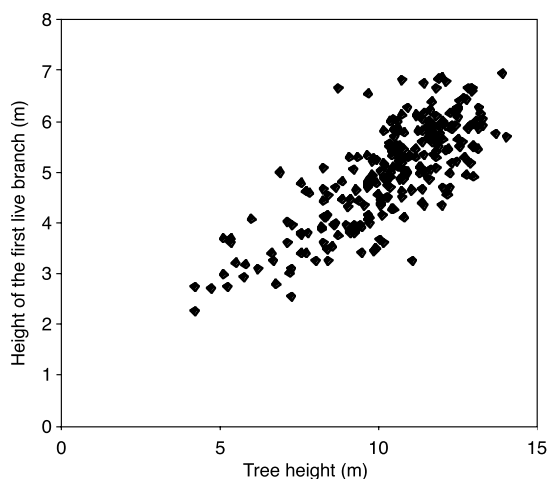


Fig. 3. Correlation between tree height and the height of the first live branch measured from the soil surface.

1975). Visual observation of the stand supports this conclusion.

The height of the first live branches was dependent on tree height (Fig. 3), but the length of the live crown was smallest in shortest trees. This is also a clear indication of competition between individual trees, eventually leading to self-thinning of the stand (Nikinmaa 1992).

If the stem volume is expressed in biomass units using the measured average density of 0.34 kg dm^{-3} for stem wood, it can be calculated that at the time of sampling the biomass storage in stem wood was $41\,450 \text{ kg ha}^{-1}$ and expressed in units of accumulated carbon, $20\,725 \text{ kg ha}^{-1}$ (Table 1).

The needle biomass followed the variation in branch diameter (Fig. 4a and b). Also the branch biomass could be explained by the branch diameter (data not shown). The connection between

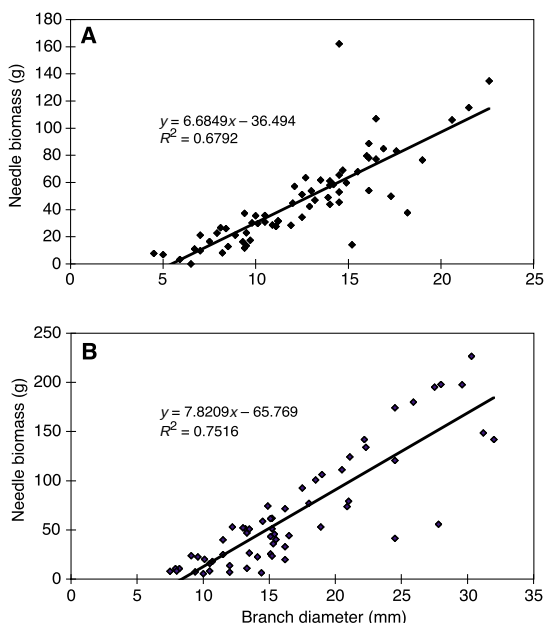


Fig. 4. Correlation between branch diameter and needle biomass. — **A:** six topmost whorls; — **B:** the lower part of the crown.

stem cross-sectional area at breast height and the total needle and branch biomass was close (Figs. 5 and 6). From the stem discs it could be seen that the heartwood formation in the stems at breast height was negligible and thus most of the stem was still conducting water. The estimated amounts of needle and branch biomass were 5100 and 9040 kg ha⁻¹, respectively (Table 1). The branch cross sectional area and needle biomass ratio seems to be in the same range as presented by Nikinmaa *et al.* (1996), and the stem cross-sectional area to needle mass ratio somewhat lower than that presented by Mäkelä *et al.* (1995).

Table 1. The measured stand properties at the SMEAR II mini-catchment.

Average height (m)	10.2
Dominant height (m)	13.3
SCA (m ² ha ⁻¹)	22.1
Stem volume (m ³ ha ⁻¹)	119
Needle biomass (kg ha ⁻¹)	5 100
Branch biomass (kg ha ⁻¹)	9 040
Root biomass (kg ha ⁻¹)	12 520
Stem biomass (kg ha ⁻¹)	41 450
Total biomass (kg ha ⁻¹)	68 100

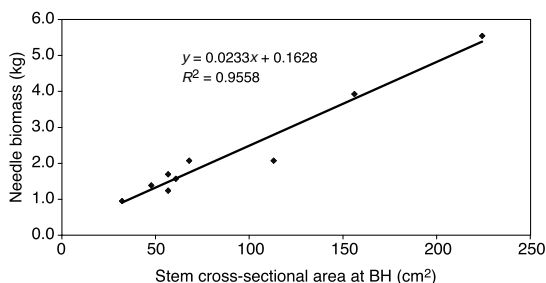


Fig. 5. The correlation between the stem cross sectional area at breast height and the total needle biomass of the sample tree.

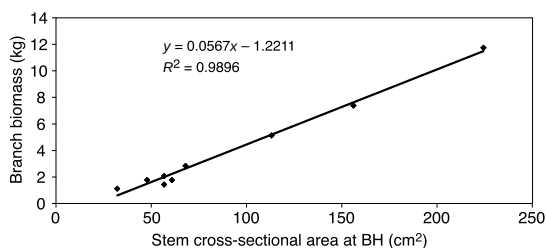


Fig. 6. The correlation between the stem cross sectional area at breast height and the total branch biomass of the sample tree.

The average ratio of needle surface area to needle mass was 7.65 m² kg⁻¹. As the needle biomass was 5100 kg ha⁻¹, it can be estimated that the average all-sided leaf area was 3.9 m² m⁻².

The number of live whorls ranged between 10 and 12, except in one tree where it was 8 whorls. There were three living needle age classes with only occasional needles in the fourth age class. To describe the average shape of the crown, the vertical distribution of needle and branch biomass and branch length in an average tree of the stand was calculated based on the sample tree measurements. The needle biomass distribution (Fig. 7A) is more top oriented than that of branches (Fig. 7B). The longest branches can be found in the lowest part of the living canopy (Fig. 7C).

Root biomass

The root biomass estimate was 12 520 kg ha⁻¹ (Table 1). A major proportion of the root biomass is located in the stump and in the > 20 mm fraction of the roots. For the calculation of the

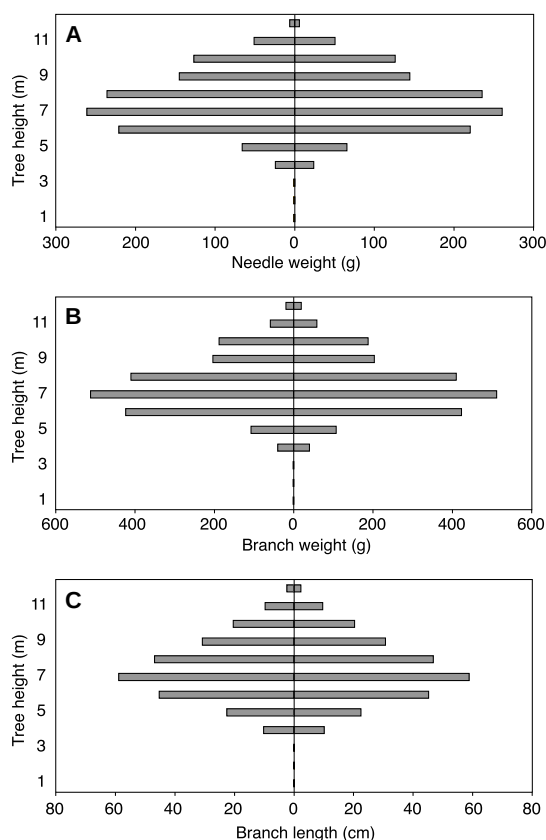


Fig. 7. The vertical distribution of needle biomass (A), branch biomass (B) and branch length (C) in an average tree of the stand based on sample tree measurements.

total biomass of the stand, it will thus be sufficient to estimate the coarsest root fraction. The proportion of the root biomass of the stand biomass was in the same order of magnitude as presented by Marklund 1988 (Table 2).

The total root length based on the soil core

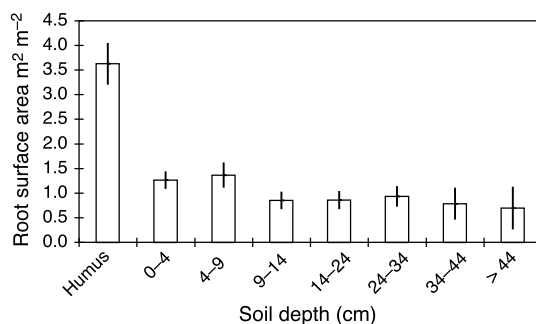


Fig. 8. The surface area of roots in different soil horizons. The total surface area of the < 2 mm roots in the stand was 8.8 m² m⁻².

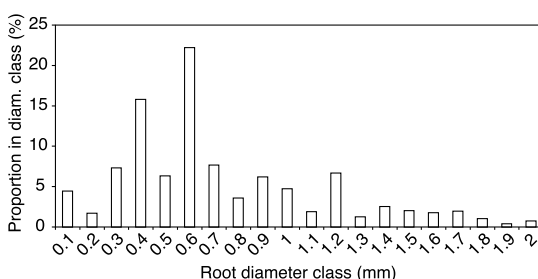


Fig. 9. The distribution of the measured roots in different root diameter classes (0.1 mm classes).

samples was found to be 4180 m ha⁻¹. The surface area of the roots was 8.8 m² m⁻² and the roots were superficially distributed (Fig. 8). The largest proportion of the fine root surface area was found in diameter classes between 0.3–0.7 mm (Fig. 9). The biomass of fine roots was 3930 kg ha⁻¹, which is a somewhat higher value than those presented by Makkonen (1993), Pietikäinen *et al.* (1999) and Vanninen and Mäkelä (1999).

Table 2. The distribution of the root biomass (g) into different root diameter size fractions. All root sample trees are presented separately on separate lines in the table. The stump includes the stem-like part below the highest root attached to stem and the parts of the coarsest roots at the immediate vicinity of the stump. The classification of the roots into diameter classes was done mainly by eye, but the borderline cases were checked by measurements.

< 2 mm	2–5 mm	5–10 mm	10–20 mm	> 20 mm	Stump	Total	Total with stump
12	25	95	200	830	1 670	1 160	2 800
9	48	186	220	1 820	2 230	2 280	4 500
52	146	401	650	2 970	6 350	4 220	10 600
21	117	196	360	1 840	4 660	2 530	7 200
50	201	428	460	11 640	7 880	12 780	20 700

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References

- Ceulemans R. 1997. Direct Impacts of CO₂ and temperature on physiological processes in trees. In: Mohren G.M.J., Kramer K. & Sabaté K. (eds.), *Impacts of global change on tree physiology and forest ecosystems*. Kluwer Academic Publishers, pp. 3–14.
- Ford D. 1975. Competition and stand structure in some even-aged plant monocultures. *Journal of Ecology* 63: 311–333.
- Hakkila P. 1979. *Utilization of residual forest biomass*. In: Wood science. Springer Verlag, Berlin, 568 pp.
- Ilvesniemi H. & Pumpanen J. 1997. Soil. In: Haataja J. & Vesala T. (eds.), *Smear II, Station for Measuring Forest Ecosystem–Atmosphere Relation*. University of Helsinki Department of Forest Ecology publications 17, pp. 30–37.
- Ilvessalo Y. & Ilvessalo M. 1975. Suomen metsätyypit metsiköiden luontainen kehitys- ja puuntuotokyvyn valossa. *Acta Forestalia Fennica* 108: 1–101.
- Koivisto P. 1959. Kasvu- ja tuottotaulukoita. *Comm. Inst. For. Fenn.* 51.8: 16–17.
- Laasasenaho J. 1982. Taper curve and volume functions for pine, spruce and birch. *Comm. Inst. For. Fenn.* 108: 1–74.
- Mäkelä A., Virtanen K. & Nikinmaa E. 1995. The effects of ring width, stem position and stand density on the relationship between foliage biomass and sapwood area in Scots pine (*Pinus sylvestris*). *Can. J. For. Res.* 25: 970–977.
- Makkonen K. 1993. Seasonal variation in fine root biomass in a Scots pine (*Pinus sylvestris* L.) stand. In: Tuomisto J. & Ruuskanen J. (eds.), *Proceedings of First Finnish Conference of Environmental Sciences*. Kuopio, October 8–9, 1993, 'Environmental research in Finland today'. Finnish Society for Environmental Sciences, pp. 82–85.
- Marklund G. L. 1988. Biomassfunktioner för tall, gran och björk i Sverige. *Institutionen för skogstaxering. Rapport 45*. Sveriges lantbruksuniversitet.
- Nikinmaa E. 1992. Analysis of the growth of Scots pine. Matching structure with function. *Acta For. Fenn.* 235: 1–68.
- Nikinmaa E., Kaipainen L., Mäkinen M., Ross J. & Sasonova T. 1996. Geographical variation in the regularities of woody structure and water transport. In: Hari P., Ross J. & Mecke M. (eds.), *Production process of Scots pine; Geographical variation and models*. Final report of the cooperation project "Growth of Scots pine stand" of the Academy of Finland and the Science Academy of Russia. Department of Forest Ecology, University of Helsinki, pp. 49–78.
- Persson H. Factors affecting fine root dynamics of trees. *Suo* 43: 163–172.
- Pietikäinen J., Vajärvi E., Ilvesniemi H., Frize H. & Westman C.J. 1999. Carbon storage of microbes and roots and flux of CO₂ in boreal coniferous forest soil. *Canadian Journal of Forest Research* 29: 1197–1203.
- Ross J., Kellomäki S., Oker-Blom, P., Ross V. & Vilikainen L. 1986. Architecture of Scots pine crown: phytometrical characteristics of needles and shoots. *Silva Fennica* 20: 291–105.
- Vanninen P., Ylitalo H., Sievänen R., & Mäkelä A. 1996. Effects of age and site quality on the distribution of biomass in Scots pine (*Pinus sylvestris* L.). *Trees* 10: 231–238.
- Vanninen P. & Mäkelä A. 1999. Fine root biomass of Scots pine stands differing in age and soil fertility is southern Finland. *Tree physiology* 19: 823–830.
- Vesala T., Haataja J., Aalto, P., Altimir N., Buzorius G., Garam E., Hämeri K., Ilvesniemi H., Jokinen V., Keronen P., Lahti T., Markkanen T., Mäkelä J.M., Nikinmaa E., Palmroth S., Palva L., Pohja T., Pumpanen J., Rannik U., Siivola E., Ylitalo H., Hari P. & Kulmala M. 1998. Long-term field measurements of atmosphere-surface interactions in boreal forest combining forest ecology, micrometeorology, aerosol physics and atmospheric chemistry. *Trends in Heat, Mass & Momentum Transfer* 4: 17–35.
- Vuokila Y. 1980. *Metsänkasvatuksen menetelmät*. WSOY. Porvoo.

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