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Biomass functions for mountain birch in the Vuoskojärvi Integrated Monitoring area

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Simple linear regression models for estimating the oven-dry stem, living and dead branch, and leaf components of above-ground biomass for mountain birches (*Betula pubescens ssp. czerepanovii*, syn.: *B. czerepanovii* N.I. Orlova) taller than 1.3 m growing in the Vuoskojärvi Integrated Monitoring area are presented. The models were based on allometric relationships between biomass component and tree size characteristic: stump diameter ($d_{0.1}$), breast height diameter ($d_{1.3}$) and height (h) of 20 specimens. Correlation analysis indicated that $d_{1.3}$ and $d_{1.3}^2h$ were the best variables explaining biomass. Logarithm (natural) transformation of both $d_{1.3}$ and biomass component resulted in higher correlation coefficients. The linear regression model describing the relationship between $\ln(d_{1.3})$ and ln(biomass) of each component was highly significant ($p < 0.0001$) with R^2 values ranging from 62% (dead branches) to 98% (stem). Using $\ln(d_{1.3}^2h)$ did not notably improve the models. The stand above-ground biomass for a plot where all stems had been measured in 1995 was estimated at 21.2 t ha^{-1} (stems 61%, live branches 29%, dead branches 2% and leaves 8%).

Introduction

Mountain birch *(Betula pubescens ssp. czerepanovii*, *B. czerepanovii* N.I. Orlova) is a subspecies of downy birch and is endemic to north Scandinavia, Iceland and south Greenland (Hämet-Ahti *et al.* 1992). It reportedly also occurs in northern Scotland (Blamey and Grey-Wilson 1989). Besides occurring mixed with Scots pine (*Pinus sylvestris* L.) in the northern boreal zone, woodlands composed of pure stands of mountain birch occur in the subalpine zone above the coniferous forest tree line. It grows in both monocormous (single-stemmed) and polycormous forms (with up to 30 stems per genet) (Verwijst 1988). In its polycormous form, a group of stems are connected to the same genet below ground giving the appearance of being individual stems. Typically, the trunks of mountain birch are crooked and have both living and dead branches.

Ecosystems at high latitudes are likely to be the most strongly affected by global warming and climate change (Karjalainen *et al.* 1991). This may be expected to have a major effect on the composition and growth of forests in northern Finland

(Talkkari and Hypén 1996). However, little has been published concerning the growth and biomass production of mountain birch. Sveinbjörnsson *et al*. (1992) dealt with nutrient status, Karlsson and Nordell (1987) with nitrogen uptake, and Kauhanen (1986) with the photosynthesis of mountain birch. Biomass functions for mountain birch growing near Abisko, in Swedish Lapland were presented by Sveinbjörnsson (1987), but this study only concerned juvenile trees and the functions were based on plant height.

In this paper, we present linear regression models for estimating the above-ground biomass (oven-dry weight) of individual mountain birch trees. The models are based on the allometric relationship between breast height diameter and stem, branch and leaf biomass components. We intend to use these models to estimate the amount of stand biomass and, subsequently, the amounts of nutrients and base cations that have accumulated in the mountain birch woodlands in the Vuoskojärvi catchment as part of a biogeochemistry study.

Material and methods

The Vuoskojärvi catchment

The study was carried out in the Vuoskojärvi Integrated Monitoring (IM) area (69°44´N, 26°57´E). Vuoskojärvi (also known by its original Sami name: Vuoskojavri) is situated in the northern part of the Kevo Strict Nature Reserve which was incorporated into the original Kevo Reserve in 1982. In terms of geobotanical zonation (Ahti *et al*. 1968), Vuoskojärvi belongs to the continental subzone of the subalpine mountain birch zone, being situated at the northern boundary of the northern boreal zone (Hämet-Ahti 1963, Ahti *et al*. 1968).

The Vuoskojärvi catchment covers an area of 178 ha. The elevation varies from 135 to 240 m a.s.l. Lake Vuoskojärvi covers 18 ha (10%), and mires and other non-wooded areas ca. 17 ha (10%). The area of woodland is ca. 143 ha (80%), most of which (120 ha) is classified as subalpine mountain birch forests (Tuominen and Mäkelä 1995). In 1964–65, the geometrid moth, *Epirrita autumnata* (*Lepidoptera*, *Geometridae*), defoliated large areas of the birch woodland in the vicinity (Kallio and Lehtonen 1973) and such damaged woodlands cover ca. 7 ha of the Vuoskojärvi catchment. There are also stands of Scots pine present, which may be regarded as disjunct fragments of the coniferous zone (Hämet-Ahti 1963). Both monocormous and polycormous forms of mountain birch grow in the Vuoskojärvi catchment.

The long-term (1962–90) mean annual temperature measured nearby (Kevo Meteorological Station, 69°45´N, 27°02´E, 107 m a.s.l.) is –2 °C, the mean annual precipitation is 395 mm, and the vegetation period (3 + 5 °C) lasts for 112 days on average (Finnish Meteorological Institute 1991).

Biomass sample trees

A 100 × 100 m grid (± 10 m) was marked out in the catchment with wooden poles. There were 188 such poles within the catchment. The grid was established as an aid to surveying the environmental and ecological resources of the catchment. Each pole was used as the centre of a 100 m^2 circular plot ($r = 5.64$ m) for a survey of the vegetation within the catchment (EDC 1993).

In July 1996, when the mountain birches were in full leaf, harvesting for biomass determination was carried out near twenty of the circular plots described above. The 20 plots were located throughout the catchment at all elevations. The plots were selected to ensure that each breast height diameter classes was represented and that they were distributed among the three types of subalpine mountain birch woodland (*Empetrum-Lichenes*, *Empetrum-Lichenes-Pleurozium* and *Empetrum-Myrtillus*) in proportion to their area (Tuominen and Mäkelä 1995).

The first mountain birch encountered after a distance of at least 10 m from the edge of each plot in a westward direction from its centre, taller than 1.3 m, and of "normal" form (i.e. not exceptional in terms of foliage cover, stem form, and numbers of dead branches) was selected for harvesting. If the selected tree was of a polycormous form, a single representative stem was harvested.

The sample stem was carefully felled onto a thick plastic sheeting so as not to loose any of the leaves, bark or dead branches. The stem diameter at heights of 0.1 m ($d_{0.1}$) and 1.3 m ($d_{1.3}$) were measured in two perpendicular directions (1 mm precision) and stem height (*h*) of the tree from ground level (1 cm precision). The branches were cut and the stem then sawn into 1 m bolts.

The weight of each bolt was then recorded, and a sample disk sawn from the butt end for determination of the stem fresh: oven-dry weight ratios. A disk of the stem was also taken at a height of 1.3 m. Branches were divided into living and dead, and their fresh weights recorded after removing the leaves. A representative branch from each bolt was selected and cut into small pieces. The fresh weight of a sample of these pieces was recorded and taken for later oven-dry weight determination. The branch component includes all branches and twigs attached to the main branch. Similar samples were taken from a dead branch (if present) from each stem bolt. The fresh weight of all leaves was recorded and a sample of known fresh weight taken for later determination of oven-dry weight. All weights were measured to a precision of 1 g. The diameter and height of the harvested stems are described in Table 1.

Laboratory measurements

After recording the fresh weight of the samples from each biomass component, they were put into plastic bags to keep moisture loss to a minimum during transport to the laboratory. The fresh weight was checked in the laboratory on the same day, although biomass samples kept in closed plastic bags have been shown not to lose weight during one day (Ferm and Hytönen 1984).

The samples of living branch, dead branch and leaf biomass components were oven-dried for 24 hours at 80°C and the stem component samples for 48 hours. After drying, the sample were weighed and the fresh to oven-dry weight ratios calculated. These ratios were used to convert the fresh weights of each biomass component into oven-dry weights (Table 1).

Model development

The Pearson's correlation coefficients and the results from previous biomass studies were used to identify useful predictor variables of biomass. Stem height (*h*), stump diameter ($d_{0.1}$), breast height diameter ($d_{1.3}$), and a combination of the square of breast height diameter and height ($d_{1.3}^2h$) were compared.

The function for each biomass component was based on the following linear regression model:

$$\ln(y_i) = a + b\ln(x) + \text{error}$$

where *a* and *b* are constants, *x* the independent variable (tree h, $d_{0.1}$, $d_{1.3}$ or $d_{1.3}^2h$), and y_i the dependent variable (oven-dry biomass of the *i*th component).

The fit of the models was described by the degree of determination (R^2), and by the relative root mean square error (RRMSE). With the logarithmic models, RRMSE was computed as $[(\exp(s_f^2)-1)]^{1/2}$, where s_f is the standard error of the estimate. Logarithmic (natural) transformations of both dependent and independent variables were used to linearize the relationships. Because of the logarithmic transformations, a correction term, $s_f^2/2$, was added to the constant *a* in the linear model (Finney 1941, Nyyssönen and Mielikäinen 1978, Laasasenaho 1982).

Results

Correlation analysis

The Pearson's correlation coefficients were all either extremely significant ($p < 0.001$) or very significant ($p < 0.01$) (Table 2). The highest correlation coefficients were associated with $d_{1.3}$ and $d_{1.3}^2h$ variables and the lowest with *h* and the dead branches. Stem oven-dry biomass had the strongest correlation with $d_{1.3}^2h$, but the correlation co-

Table 1. Quartile summary statistics describing the size characteristics and oven-dry biomass of the sample trees (*n* = 20).

Tree characteristic/ Biomass component	25% Percentile	Median	75% Percentile
Diameter 0.1, mm	59	83	109
Diameter 1.3, mm	38	60	84
Height, cm	37.0	48.5	58.5
Stem, g	1 570	4 160	11 400
Live branches, g	837	1 570	3 630
Dead branches, g	31	80	178
Leaves, g	254	471	820

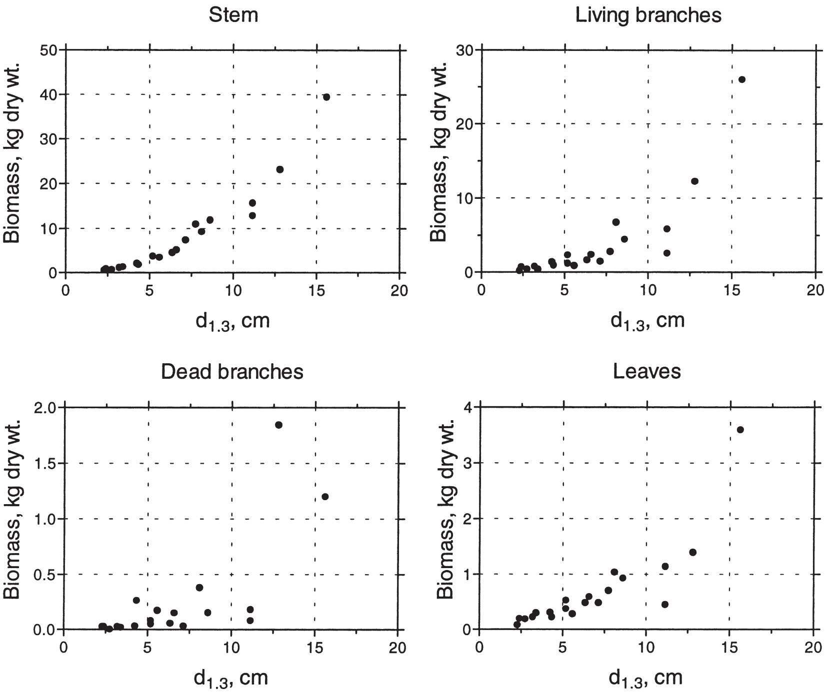

Fig. 1. Relationship between breast height diameter ($d_{1.3}$) of the harvest sample trees and oven-dry biomass for each above-ground compartment.

efficient was almost as high with $d_{1.3}$. Branch oven-dry biomass was best correlated with $d_{0.1}$, but $d_{1.3}$ gave a similar result. Leaf oven-dry biomass had the strongest correlation with $d_{1.3}$. The correlation coefficients were generally higher when ln (natural logarithm) transformed variables were used, indicating curvilinear relationships. The curvilinear relationship between the oven-dry biomass of each component and breast height diameter ($d_{1.3}$) is shown in Fig. 1.

Biomass functions

Because using ln-transformed values of both independent and dependent variables resulted in overall improvement in linearity, we used them to derive the functions for the biomass components. Functions with both $d_{1.3}$ and $d_{1.3}^2h$ as the independent variable were computed. As there was no noticeable improvement (i.e. increased $R^2$and reduced s_f) when $d_{1.3}^2h$ was used, we present only

Table 2. Pearson correlation coefficients[1] between the oven-dry biomass and tree size parameter of the sample biomass trees (n = 20).

Biomass component	Tree size parameter							
	$d_{0.1}$	$d_{1.3}$	h	$d_{1.3}^2h$	ln($d_{0.1}$)	ln($d_{1.3}$)	ln(h)	ln($d_{1.3}^2h$)
Stem	0.887	0.941	0.847	0.995	0.860	0.834	0.780	0.832
Live branches	0.783	0.822	0.712	0.946	0.727	0.688	0.635	0.685
Dead branches	0.876	0.712	0.662	0.780	0.744	0.608	0.587	0.609
Leaves	0.747	0.833	0.742	0.935	0.727	0.720	0.673	0.718
ln(Stem)	0.881	0.955	0.943	0.817	0.968	0.990	0.949	0.993
ln(L.branches)	0.879	0.918	0.863	0.838	0.932	0.914	0.849	0.991
ln(D.branches)	0.811	0.789	0.780	0.728	0.819	0.789	0.763	0.791
ln(Leaves)	0.839	0.904	0.870	0.828	0.906	0.911	0.860	0.911

[1] All correlation coefficients are very significant ($p < 0.01$ when correlaton coefficient > 0.561) and most, extremely significant ($p < 0.001$ when correlation coefficient > 0.679).

the models using $d_{1.3}$ (Table 3). The degree of determination, R^2, was > 62% for all biomass components and the standard error of the estimate, s_f, decreased in the order: dead branches > living branches > leaves > stem.

Stand biomass estimates

The ln–ln biomass regression models based on $d_{1.3}$ (Table 3) were used to calculate stand biomass (t ha^{-1}) for one of the permanent monitoring plots in the catchment (Starr *et al.* 1995). The plot (plot 2, 40 × 40 m) was located in the lowest part of the catchment and in an area with the biggest birches to be found. The birches on the plot were measured on three occasions: 1989, 1992 and 1995. Breast height diameter of selected sample stems (1989), and all the stems (1992 and 1995) from each genet were measured. For each stem on the plot, the biomass of each component was calculated using the 1995 $d_{1.3}$ measurements ($n = 928$). The values were summed to give the total biomass of each component on the plot. Using the area of the plot, these values were then converted into stand biomass values (t ha^{-1}). The results are presented in Fig. 2. The above-ground stand biomass (oven-dry) was 21.2 t ha^{-1} (stems 62%, live branches 29%, dead branches 2% and leaves 8%). There was no significant difference ($p < 0.05$) between the biomass estimates using the data from the other measurement years.

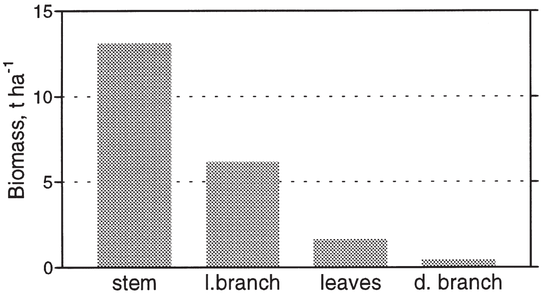

Fig. 2. Estimated stand oven-dry biomass for each biomass component calculated from breast height diameters ($d_{1.3}$). (Data from plot 2; Starr *et al.* 1995.)

Discussion

The models based on $d_{1.3}{}^2h$ made no noticeable improvement over those in which $d_{1.3}$ was used; therefore, the time and costs of collecting tree height data in the field can be saved without sacrificing the accuracy of the biomass estimates. Furthermore, a breast height diameter can be more reliably measured than a tree height. The tree height can also be affected by non-growth related factors, such as mechanical damage and broken tops. Thus, the breast height diameter is generally considered to have higher accuracy in estimating biomass than the tree height (Björklund and Ferm 1982, Hakkila 1989). Both Crow (1978) and Green and Grigal (1978) found only a weak dependency between biomass and tree height. However, the biomass functions for mountain birch presented by Sveinbjörnsson (1987), which were based only on tree height, had high degree of determination values (> 90%).

The error associated with our biomass estimates is difficult to quantify. As mentioned above, measurement error is smaller for the tree breast height diameter than for the tree height. Although our models were based on a small sample size, we used an objective sampling design. The methods used during harvesting, sorting and sampling of the biomass components were similar to those used in many other biomass studies (Pardé 1980). We also paid particular attention to harvesting and weighing the biomass components and the fresh

Table 3. Linear regression models for estimating tree ln(biomass, g oven-dry) for each component using ln($d_{1.3}$, mm) as the independent variable.

Biomass component	$a^†$	b	F	p	%R^2	s_f
Stem	–0.313	2.140	895	< 0.0001	98.0	0.174
Live branches	–0.305	1.953	92	< 0.0001	83.6	0.495
Dead branches	–3.368	2.041	28	< 0.0001	62.2	0.931
Leaves	0.525	1.398	87	< 0.0001	82.9	0.363

† after adding the correction term, $s_f^2/2$

weight of the samples was checked by reweighing in the laboratory.

The logarithmic transformation of variables to linearise the relationships in biomass functions is common practice (Pardé 1980). However, a difficulty concerning simple logarithmic models is that the correction of systematic errors in the outermost data is not as easy as with untransformed data (Björklund and Ferm 1982). The biomass model for the stem component was the most reliable (lowest s_f value) and that for the dead branch component, the least (highest s_f value). The regression estimates have the largest confidence in the middle of the range in the data.

The biomass functions for mountain birch we have presented were derived from specimens in the Vuoskojärvi catchment. However, for trees of similar size and condition as those in Vuoskojärvi, our functions would offer a simple and cheap means of estimating the biomass of mountain birch trees and stands at other sites.

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References

Ahti T., Hämet-Ahti L. & Jalas J. 1968. Vegetation zones and their sections in northwestern Europe. *Ann. Bot. Fennici* 5: 169–211.

Björklund T. & Ferm A. 1982. Biomass and technical properties of small-sized birch and grey alder. *Folia Forestalia* 500, 37 pp. [In Finnish with English abstract].

Blamey M. & Grey-Wilson C. 1989. *The illustrated flora of Britain and Northern Europe,* Hodder and Stoughton, London, 544 pp.

Crow T. 1978. Common regressions to estimate tree biomass in tropical stands. *Forestry Science* 24: 110–114.

EDC. 1993. *Manual for Integrated Monitoring. Programme Phase 1993–1996*. UN ECE Convention on Long-Range Transboundary Air Pollution. International Co-operative Programme on Integrated Monitoring on Air Pollution Effects, Environment Data Centre, National Board of Waters and the Environment, Helsinki, 114 pp.

Ferm A. & Hytönen J. 1984. Effect of sample storage in determination of tree dry mass. *Metsäntutkimuslaitoksen tiedonantoja* 132, 16 pp. [In Finnish with English abstract].

Finney D.J. 1941. On the distribution of a variable whose logarithm is normally distributed. *Journal of the Royal Statistical Society*, Ser. B7: 155–161.

Finnish Meteorological Institute. 1991. Climatological Statistics in Finland 1961–1990. Supplement to the Meteorological Yearbook of Finland. Volume 90, part 1-1990. Finnish Meteorological Institute. Helsinki, 125 pp.

Green D. & Grigal D. 1978. Generalized biomass estimation equations for jack pine (*Pinus banksiana* Lamb.). College of Forestry, University of Minnesota, *Minnesota Forestry Research Notes*, No. 268: 1–4.

Hakkila P. 1989. *Utilization of Residual Forest Biomass*. Springer-Verlag Series in Wood Science, Berlin, 568 pp.

Hämet-Ahti L. 1963. Zonation of the mountain birch forest in northernmost Fennoscandia. *Annales Botanici Societatis zoologicae botanicae 'Vanamo'* 34(4): 1–127.

Hämet-Ahti L., Palmén A., Alanko P., Tigerstedt P.M.A. & Koistinen M. 1992. Suomen puu- ja pensaskasvio. Publications of the Finnish Dendrological Society 6, Helsinki, 373 pp.

Kallio P. & Lehtonen J. 1973. Birch forest damage caused *by Oporinia autumnata* (Bkh.) 1965–66 in Utsjoki, Northern Finland. *Reports from the Kevo Subarctic Research Station* 10: 55–69.

Karlsson P. & Nordell K. 1987. Effects of leaf duration, nutrient supply, and temperature on the seasonal pattern of growth and nitrogen uptake in tree seedlings in a subarctic environment. *Canadian Journal of Botany* 67: 211–217.

Kauhanen H. 1986. Stomatal resistance, photosynthesis and water relations in mountain birch in the subarctic. *Tree Physiology* 2: 123–130.

Karjalainen T., Kellomäki S., Lauhanen R. & Tuovinen J. 1991. Ilmaston muutoksen vaikutus metsäekosysteemiin ja metsäkäyttöön: mekanismeja ja kehityssuntia. *Silva Carelica* 19, 157 pp.

Laasasenaho J. 1982. Taper curve and volume functions for pine, spruce and birch. *Communicationes Instituti Forestalis Fenniae* 108, 74 pp.

Nyyssönen A. & Mielikäinen K. 1978. Estimation of stand increment. *Acta Forestalia Fennica* 163, 40 pp. [In Finnish with English summary.]

Starr M., Kokko A. & Mäkelä K. 1995. Permanent sampling plots and location of related terrestrial subprogrammes. In: Bergström I., Mäkelä K. & Starr M. (eds.), *Integrated Monitoring Programme in Finland, Ministry of the Environment, Environment Policy Department Report 1 1995*, Nordmannin Kirjapaino Oy, Forssa, pp. 32–34.

Pardé J. 1980. Forest Biomass. Forestry Abstracts 41(8): 343–362.

Sveinbjörnsson B. 1987. Biomass proportioning as related to plant size in juvenile mountain birch near Abisko, Swedish Lapland. *Reports from Kevo Subarctic Research Station* 20: 1–8.

Sveinbjörnsson B., Nordell O. & Kauhanen H. 1992. Nutrient relations of mountain birch growth at and below the elevational tree-line in Swedish Lapland. *Functional Ecology* 6: 213–220.

Talkkari A. & Hypén H. 1996. Effect of climate change on forest resources in Finland during 1990–2100. In: Roos J. (ed.), *The Finnish Research Programme on climate change. Final report. Publications of the Academy of Finland 4/96*, Edita, Helsinki, 268–274 pp.

Tuominen S. & Mäkelä K. 1995. Vuoskojärvi — Vegetation. In: Bergström I., Mäkelä K. and Starr M. (eds.). *Integrated Monitoring Programme in Finland. First National Report. Ministry of the Environment, Environment Policy Department Report 1 1995*, Nordmannin Kirjapaino Oy, Forssa, pp. 30–31.

Verwijst T. 1988. Environmental correlates of multiple-stem formation in Betula pubescenes ssp. tortuosa. *Vegetatio* 76: 29–36.

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