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Component Biomass Equations for Black Spruce in Maine

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Abstract

Component biomass prediction equations are presented for young black spruce (*Picea mariana* B.S.P. (Mill.)) in northern Maine. A weighted least squares model was used to construct the equations for small trees from 1 to 15 cm d.b.h., and an ordinary least squares model for trees less than 2 m in height. A linearized allometric model was also tested but was not used. Equations were developed for oven-dry needle, branch, bolewood, bolebark, aboveground, root, and complete tree biomass components. Aboveground components accounted for approximately 80 percent, and stump (less than 6 cm in height) plus roots accounted for 20 percent of the complete tree oven-dry biomass accumulation.

Introduction

Black spruce (*Picea mariana* B.S.P. (Mill.)) is a geographically wide-ranging species that occurs on 76,000 hectares in the State of Maine alone (Ferguson and Kingsley 1972). High fiber quality, ability to grow on poor sites, and apparent resistance to spruce budworm (*Choristoneura fumiferana* (Clem.)) defoliation make black spruce an increasingly valuable fiber resource. The development of whole-tree harvesting and utilization technologies, to make more efficient use of wood crops, has created a need for reliable estimates of tree biomass. Equations relating individual tree diameter and height to component biomass dry weight have been developed by Young *et al.* (1964, 1980) for mixed species of spruce in Maine. Other equations have been published for black spruce in Minnesota (Schlaegel 1975) and in Canada (Alemdag 1982, Freedman *et al.* 1982, Ker 1980, 1984, Moore and Verspoor 1973, Ouellet 1983).

The objective of this study was to develop component biomass prediction equations for naturally regenerated, unmanaged, poor-site black spruce in Maine. The equations were constructed to relate component biomass dry weight to diameter outside bark at breast height and diameter outside bark at 15 cm above ground line.

Study Area

The study was conducted immediately north of Square Lake (latitude 47°06″, longitude 68°23″) in T-16 R-5 Aroostook County, Maine. The climate is characterized as humid, cool, continental (Arno 1964) with a mean yearly temperature of 3.6°C. Annual temperature extremes range from a mean low of −11.9°C in January to 18.0°C in July. A frost-free season of 107 days (May 30 to September 16) is typical. Average annual precipitation in the area is 92 cm (Ruffner 1978).

The soils are relatively uniform, consisting of poorly and very poorly drained complexes formed in lake-laid lacustrine deposits and are overlain by varying depths of organic materials, mostly of *Sphagnum* spp. origin. The microtopography is an intricate association of hummock and hollow relief. Overall, the area (1200 ha) is level and is situated 6 m above the surface of Square Lake at an elevation of 183 m.

The black spruce stand (98 percent pure) occupying the site developed following clearcutting in 1957. The stand is even-aged, but the age of individual trees varies by as much as 20 years due to advanced regeneration, layering, and ingrowth. A wide range of diameters and heights (1 to 11 cm and 1 to 8.5 m, respectively) results in an uneven canopy surface. Density of stems greater than 0.5 m in height is as high as 14,000 per hectare, and open areas as large as 4.5 m in diameter occur occasionally.

Methods

Field and Laboratory Procedures

A total of 39 trees from 1 to 15 cm d.b.h. was randomly selected to represent the range of diameters present. Root systems were excavated from 20 of these 39 trees. To account for small trees, an additional 25 trees with diameters from 1 to 3 cm at 15 cm above ground were sampled. Trees with broken tops and distorted or forked boles were excluded from the sample. Sample trees came from unmanaged areas, except for the largest trees which were located adjacent to drainage ditches. In these areas, stand development was enhanced and larger trees were available for sampling.

Sample trees were measured at breast height to the nearest 0.1 cm, cut to within 6 cm of the ground, and total tree height measured to the closest 0.01 m. Dead branches and live crown were cut from the trees and weighed separately in the field (± 0.01 kg). To account for moisture content changes within the crown and to accommodate the maximum capacity of the field scale, crowns of the largest trees were cut and weighed in three sections, those of moderate size trees in two sections, and the crowns of the smallest trees were weighed as a single unit. A whorl of branches was removed from the center of each live-crown section and from the area of dead crown for moisture content and percent foliage determination.

Sampled whorls were sealed in double plastic bags and transported to the laboratory where fresh weight (± 0.1 g) was recorded within 36 hours. Branch samples with needles were oven-dried at 65°C to constant weight and percent moisture computed. Moisture content data were applied to the fresh weight of each crown section and summed to obtain the dry weight of the entire crown. Needles were separated from live-crown sample whorls and weighed to determine the percent needle component. This ratio was used to calculate needle and branch dry weight for each crown section and then summed for the whole crown.

Boles were cut into 1.22-m bolts and weighed (± 0.1 kg) in the field. A disk (4 to 7 cm thick) was cut from the base of each bolt, placed in a double plastic bag, and transported to the laboratory. Bark, including cambium, was separated from the wood of each disk and fresh weight (± 0.1 g) of bark and wood recorded separately within 36 hours. Wood and bark were oven-dried at 65°C to constant weight and percent moisture was calculated. The dry weights of bark and wood were calculated for each bolt and summed for the entire bole.

These procedures were followed for all aboveground sampling except for the smallest trees sampled. In these instances, the entire tree, by component, was transported to the laboratory for both fresh and oven-dry weight determination.

Root systems were confined almost entirely to the surface organic soil with only a few small roots extending into the subsurface mineral soil. The area of an individual tree root system was estimated as similar in size to the area of the trees live crown projected onto the ground around its base. From within this defined area, stump and roots were excavated. Roots which extended beyond the estimated area were traced and removed, as well as possible. The extracted root systems were cleaned of soil, cut into manageable pieces, bagged, and taken to the laboratory. Roots were then carefully cleaned, weighed, oven-dried at 65°C, and oven-dry weight recorded (± 0.1 g). Small roots and fine rootlets lost in the excavation were not accounted for and are not included in the biomass estimates.

Statistical Procedures

For trees from 1 to 15 cm d.b.h., the diameter outside bark at breast height was chosen as the independent variable for the biomass prediction equations as this variable has been shown to be strongly correlated with individual tree biomass and is an easily obtained inventory measurement. Graphical analysis of the sample data substantiated that the relationship between component biomass and d.b.h. was curvilinear and that the variation in component biomass increased with increasing diameter. Two models were tested to fit the data:

(I) weighted least squares

$$y = B_1 + B_2 * d + B_3 * d^2 + e$$
$$e \sim N(0, d^4, \sigma^2)$$

(II) linearized allometric

$$\ln(y) = \ln(B_1) + B_2 * \ln(d) + \ln(e)$$
$$\ln(e) \sim N(0, \sigma^2)$$

where y = component biomass dry weight (kg)
d = d.b.h. (cm) and
B_1, B_2, and B_3 are unknown parameters.

Graphs of the conditional variance of component biomass by diameter class verified that the variances were proportional to the 4th power of diameter. Furnival's Index (1961) was used to determine whether model I or II best fit the data.

Graphical analysis of sample data for trees with diameters from 1 to 3 cm at 15 cm above ground showed that the relationship between biomass and tree diameter at 15 cm was linear and that the conditional variance of component biomass was homogeneous. The ordinary least squares method was used to fit the following linear model for these trees:

$$y = B_1 + B_2 * d + e \qquad e \sim N(0, \sigma^2)$$

where y = component biomass dry weight (kg)

d = diameter (cm) at 15 cm and

B_1 and B_2 are unknown parameters.

Results and Discussion

Sample-tree mensurational and component biomass data are summarized in Table 1. Complete sample-tree dry weight ranged from 0.1 to 85.4 kg and above ground weights from 0.1 to 69.1 kg.

Model I was selected to construct the prediction equations for trees 1 to 15 cm d.b.h. Although neither model, based upon Furnival's Index (1961), consistently provided better results (Table 2), the weighted least squares model has advantages which favor its selection. This model facilitates the calculation of unbiased biomass prediction and confidence limits (Fig. 1). In addition, the model provided a statistically better fit to the data for bolewood and bolebark, the tree components most commonly utilized. The model also provided a better fit for root and complete tree biomass than did the linearized allometric model. Several other researchers have supported use of the weighted least squares model in the construction of biomass equations (Crow and Laidley 1980, Cunia 1979, Schreuder and Swank 1973).

Table 1.—Black spruce sample tree mensurational data and mean biomass by component (kg)

Sample tree size class d.b.h. (cm)	Range of sample d.b.h.	Range of sampled height	Needle	Branch	Bolewood	Bolebark	Above-ground	n	Stump & root	Complete tree	n
	cm	*m*			*kg*				*kg*		
1	0.9- 1.1	1.7- 1.8	0.24	0.17	0.23	0.06	0.72	5	0.25	0.95	1
3	2.0- 3.1	2.9- 3.8	.60	.47	.78	.20	2.05	5	.44	2.44	4
5	5.0- 5.3	4.6- 6.2	1.13	1.13	2.46	.52	5.24	6	1.22	6.13	4
7	6.9- 7.0	6.5- 7.8	2.01	1.80	5.43	1.01	10.25	5	2.23	12.88	2
9	8.9- 9.1	7.7- 9.0	3.46	3.49	10.36	1.62	18.95	5	4.68	23.53	4
11	10.9-11.1	9.6-10.6	4.54	5.79	19.15	3.08	32.56	5	9.94	43.22	2
13	12.8-13.4	8.8-11.7	8.36	10.83	26.40	3.83	49.42	5	14.36	62.74	2
15	14.8-15.2	10.0-12.1	9.60	16.70	37.56	5.30	69.14	3	18.13	85.45	1

Diameter at 15 cm (cm)	Diameter range	Range of sampled height	Needle	Branch	Bolewood	Bolebark	Above-ground	n	Stump & root	Complete tree	n
	cm	*m*			*kg*				*kg*		
1.0	0.9-1.2	0.74-1.05	0.031	0.026	0.027	0.010	0.093	—	0.034	0.127	7
1.5	1.3-1.7	.69-1.19	.054	.049	.042	.015	.160	—	.046	.206	9
2.0	1.8-2.4	1.24-1.63	.191	.154	.122	.037	.503	—	.141	.644	6
3.0	2.5-3.5	1.86-1.93	.261	.262	.224	.072	.820	—	.205	1.025	3

Table 2.—Comparison of the fit of weighted least squares and linearized allometric models to component biomass data using Furnival's Index[a]

	Model	
Component	Weighted least[b] squares	Linearized[c] allometric
Needle	1.82	0.74
Branch	1.20	.85
Bolewood	.81	1.50
Bolebark	.15	.33
Aboveground	3.44	2.41
Stump and root	.58	1.05
Complete Tree	1.55	3.33

[a] The smaller value of Furnival's Index, the better the model fits.
[b] $y = B_1 + B_2 * d + B_3 * d^2 + e \qquad e \sim N(0, d^4 \sigma^2)$
[c] $\ln(y) = \ln(B_1) + B_2 * \ln(d) + \ln(e) \qquad \ln(e) \sim N(0, \sigma^2)$

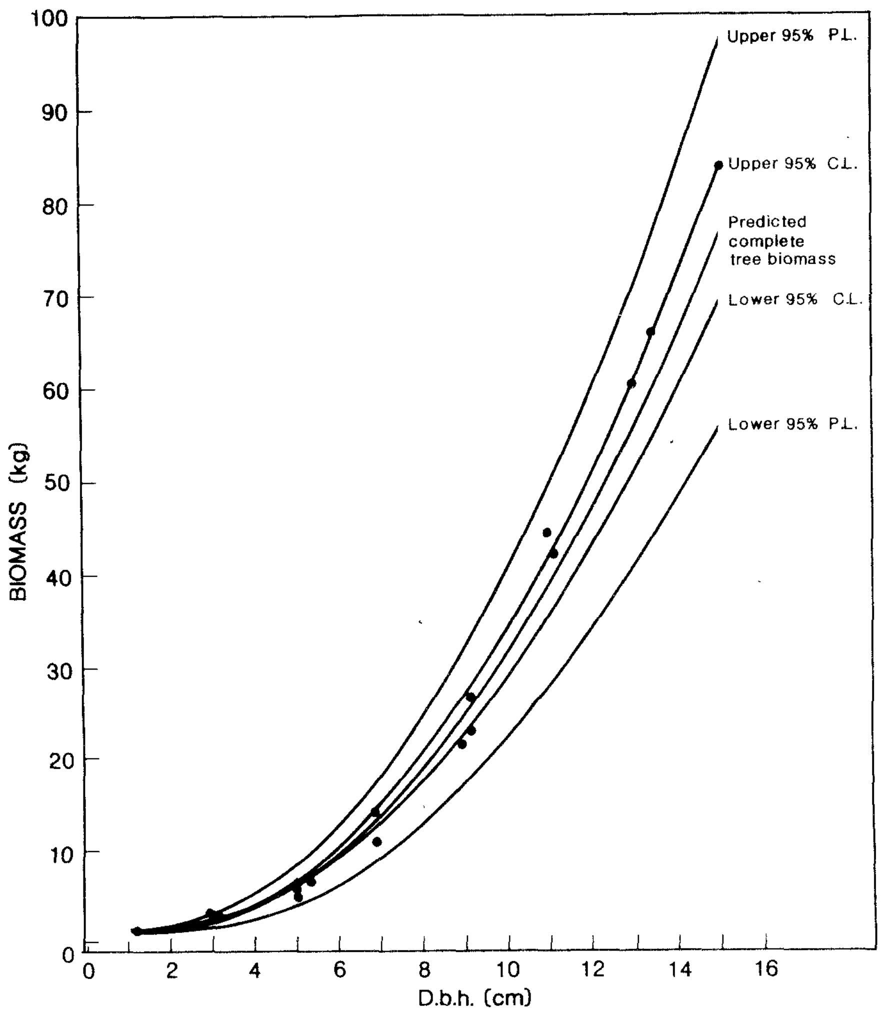

Figure 1.—Relationship of black spruce complete tree biomass and d.b.h. with 95 percent confidence limits (95% C.L.) and 95 percent prediction limits (95% P.L.).

Coefficients for the weighted least squares regression of component biomass on d.b.h. are given in Table 3 for trees from 1 to 15 cm d.b.h.[1] The coefficients of determination for complete tree, aboveground, bolewood, bolebark, and root and stump biomass are high (0.98, 0.83, 0.96, 0.95, and 0.93, respectively) while those for branch and needle components are lower (0.62 and 0.32, respectively). These differences reflect the complexity of the stand canopy and thus a high degree of variation in crown components. These factors were not considered in sample tree selection.

Prediction equations for small trees, diameter measured at 15 cm, are presented in Table 4. Height of these small trees was also considered as an independent variable in equation construction. However, it did not prove to be a good predictor of biomass. It is important to measure small trees because they can be a significant portion of stand biomass. In some of the stands sampled, there were more than 62,000 stems per hectare of these small trees.

[1] Confidence and prediction limit for oven-dry biomass components are available upon request from the senior author.

Table 3.—Coefficients for the weighted least squares regressions of component biomass for black spruce trees on d.b.h., from 1 to 15 cm.

Component	Coefficients[a] b_o	b_1	b_2	r^2	s^{2b}	n
Needle	0.29	−0.0799	0.04894	0.32	0.00291	39
Branch	.25	−.1378	.06293	.62	.00120	39
Bolewood	.49	−.4480	.17931	.96	.00056	39
Bolebark	.07	−.0284	.02429	.95	.00002	39
Aboveground	1.09	−.6941	.31546	.83	.01019	39
Stump and root	.48	−.3117	.09359	.93	.00024	20
Complete tree	1.50	−.9325	.39532	.98	.00168	20

[a] The model is: $y = b_o + b_1d + b_2d^2$
where y = component biomass (kg)
d = diameter outside bark at breast height (cm)

[b] $S^2y{\cdot}x = d^4s^2$

Table 4.—Coefficients for the ordinary least squares regression of component biomass of black spruce trees on diameter, from 1 to 3 cm, at 15 cm.

Component	Coefficients[a] b_o	b_1	r^2	$s^2y{\cdot}x$	n
Needle	−0.1627	0.1583	0.86	0.00143	25
Branch	−.1655	.1530	.88	.00114	25
Bolewood	−.1231	.1194	.93	.00037	25
Bolebark	−.0356	.0362	.94	.00003	25
Aboveground	−.4869	.4669	.92	.00700	25
Stump and root	−.1231	.1227	.87	.00082	25
Complete tree	−.6100	.5397	.92	.01149	25

[a] The model is: $y = b_o + b_1d$
where y = component oven-dry biomass (kg)
d = diameter outside bark at 15 cm (cm)

Oven-dry *biomass distribution* by component indicates that approximately 80 percent of complete tree biomass is accumulated aboveground and approximately 20 percent in the stump and roots. Bolewood accounts for the largest proportion of complete tree biomass (40 percent) and bolebark the least (7 percent).

Oven-dry component biomass distribution as a percentage of total tree biomass changes with tree size (Fig. 2). *The percentage of complete* tree biomass in needles, branches, bolebark, and aboveground components decreases (from 19 to 12, 17 to 15, 8 to 6, and 82 to 79 percent, respectively) from size class 1 to 7 cm d.b.h., to size class 9 to 15 cm *d.b.h. Bolewood and root biomass* increase (from 37 to 44 and 19 to 21 percent, respectively) for the same two size classes. Similar biomass distributions have been reported for black spruce by Freedman and others (1982) and Ker (1984).

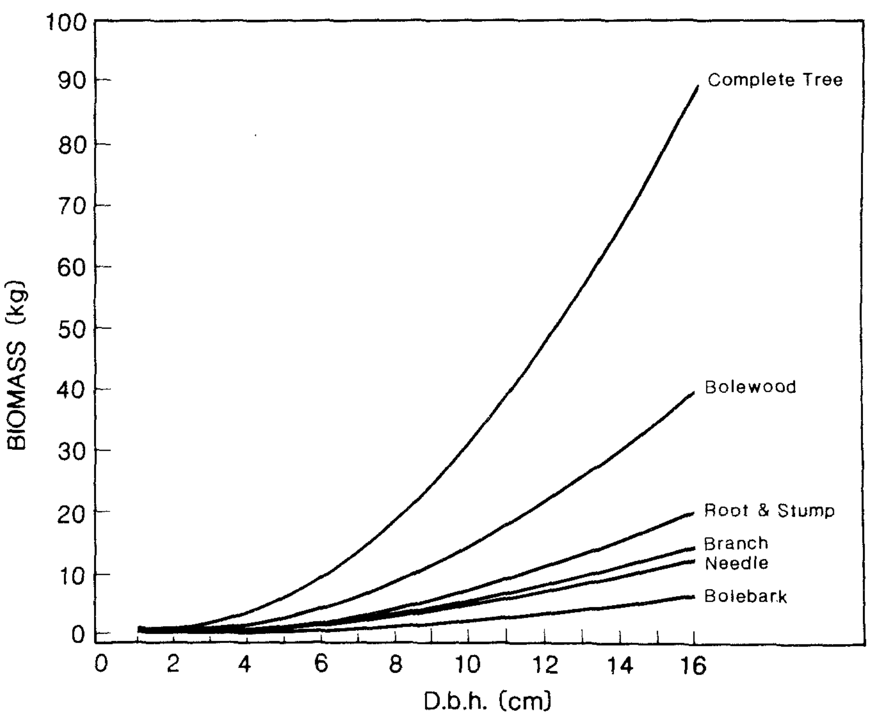

Figure 2.—Relationship of black spruce component biomass and d.b.h. as predicted by regression equations.

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Keywords: Black spruce, biomass distribution

Headquarters of the Northeastern Forest Experiment Station are in Broomall, Pa. Field laboratories are maintained at:

- Amherst, Massachusetts, in cooperation with the University of Massachusetts.
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