Stem Volume and Site Index Equations for European Larch in Maine

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ABSTRACT. *Stem analysis data collected from 101 sample trees located in 12 plantations established between 1930 and 1982 throughout central Maine were used to develop total and merchantable stem volume prediction equations, and site index prediction equations for plantation-grown European larch. The inside bark merchantable volume equation (4 in. top dob and 12 ft minimum merchantable bole) using a weighted combined variable was very similar to one for Japanese larch in Pennsylvania. Site index curves from this study were identical to those developed in southern New York and New England below a breast height (bh) age of 20 yr; after bh age 20, our curves predicted increasingly greater height growth and show a 6–12 ft superiority in height at a bh age of 50. North. J. Appl. For. 10(2):70–74.*

Shortages in the spruce-fir fiber supply are projected in New Brunswick (Baskerville 1983), Maine (Seymour and Lemin 1989), and the Lake States (Einspahr et al. 1984) if passive forest management practices continue. Projected fiber shortages have stimulated research examining expanded use of fast-growing exotic larch species into the fiber supply of northeastern pulp mills (Hatton 1987, Lawford 1987). Impressive early height and volume growth of exotic larches have been observed in numerous provenance tests and plantation trials throughout the Northeast (Carter et al. 1981, Park and Fowler 1983, Einspahr et al. 1984, Mroz et al. 1988, Boyle et al. 1989).

Despite its potential, only one study has been done to provide basic mensuration properties for European larch (*Larix decidua* Miller) in North America. Aird and Stone's (1955) site index curves for European larch plantations in southern New York and southern New England are untested in more northerly locations. In addition, Shipman and Fairweather's (1986) volume equations for Japanese larch in Pennsylvania have not been tested elsewhere or for other *Larix* species. This study was designed to test the applicability of previous work to European larch plantations in Maine and to develop new equations as warranted.

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Methods

Thirty-one plots were established in 12 plantations located in central Maine following a northeasterly band from Rumford to Milo. A plantation was considered suitable if it was well stocked (free of significant mortality), unfertilized, composed predominantly of European larch, and apparently free from intense competition. If more than one plot was established within a plantation, locations were selected to incorporate site differences as suggested by edaphic or physiographic features.

Three vigorous dominant or codominant site trees (2 plots had 4 site trees) having well-developed, apparently healthy crowns with no indication of suppression or damage were selected for stem analysis. Data collected from nonsite trees (intermediate crown class damaged during the felling of site trees) were also included in the volume equations. A total of 101 trees (95 site trees and 6 nonsite trees) were destructively sampled. After felling, outside bark diameters (dob) were marked, measured, and recorded to the nearest 0.04 in. at the stump (6 in.), breast height (bh = 4.5 ft), and at successive 3.28 ft intervals above bh. Field data, originally measured in metric, were converted to English units. A disk approximately 1 in. thick was removed from each site tree at the marked sections. Disks from site trees were labeled and returned to the laboratory where they were sanded and aged. For each tree, the time to attain bh was determined by subtracting the bh age (i.e., number of rings in bh disk) from the plantation age (as determined by landowner records).

Volume Equations

Data collected from 101 trees (Table 1) were used to generate total volume equations. Only dob measurements were recorded in the field; thus it was necessary to obtain diameter inside bark (dib) and bark thickness measurements in the laboratory 6 to 8 mo after field collection. Disks that were broken in handling or had lost excessive amounts of bark were not remeasured; consequently, it was necessary to use the bark ratio method (Wenger 1984, p. 208) in order to obtain dib estimates. Disk shrinkage (from air drying) was also evident. It was assumed that shrinkage caused a proportional reduction in radius of the wood and bark for each disk. A subsample of 1400 disks from 82 trees were remeasured and the dib/dob ratio, as well its standard error were calculated (Cunia 1984).

Individual tree volumes [outside bark (ob) and inside bark (ib)] were calculated based on the assumption of a conic shape using the equation (Husch et al. 1972,):

$$V = (L / 3) * (A_b + A_t + (A_b * A_t)^{1/2}) \quad (1)$$

for the frustrum sections, and

$$V = (A_b * L) / 3 \quad (2)$$

for the last conic section, where

V = volume of section,

L = length of section,

A_b = area of the section base (ob or ib), and

A_t = area of the section top (ob or ib).

Tree volumes were computed by summing the individual section volumes. Merchantable stem volume equations were generated from 82 trees (Table 1) having a minimum 4 in. top diameter and a minimum bole length of 12 ft. Several common models (Schumacher 1933, Spurr 1952, Honer 1965) were evaluated using Furnival's (1961) index.

Site Index Curves

The direct use of height age data obtained from stem analyses in a model to predict height growth will result in a bias that underestimates total height (Dyer and Bailey 1987). To correct for this bias, heights were adjusted upward using the technique described by Carmean (1972) and modified by Newberry (1991).

Because of the variability encountered in the time to attain bh, an index age utilizing bh age was chosen. An index age of 20 yr bh was selected because of the lack of older plantations in Maine and the short rotation potential for European larch. Fifty-three trees from 17 plots in 6 plantations having an average total age of 53 yr (range 33 to 60 yr), an average number of years to attain bh of 6 yr (range 3 to 12 yr), and an average height at bh age 20 of 49 ft (range 37 to 64 ft) were used to generate the site index prediction equations.

Average height-age pairs were generated for the three (sometimes four) trees for each plot with the three-parameter, nonlinear Richards (1959) function used by others (Lundgren and Dolid 1970, Payandeh 1974, Monserud 1984, Steinman 1992), and fit to a simple monomolecular nonlinear height-growth function (Lundgren and Dolid 1970):

$$HTBH_i = H[b_1 + b_2 \exp(b_3 BHAGE)] + \varepsilon$$

where

b_k = parameter estimates,

$HTBH_i$ = predicted height above bh,

$BHAGE$ = breast height age,

H = height above bh at $BHAGE = 20$,

exp = base of a natural logarithm, and

ε = error $NID \sim (0, \sigma^2)$.

Site Index Prediction from Early Height Growth

Height above bh values for bh ages 1 through 10 were either obtained directly, or interpolated when there was a difference in bh age of 2 or more years between 3.28 ft sections, and averaged for each plot. Visual analysis of the graphed relationship of the average SI_{20} per plot expressed as a function of the average total height at individual early growth periods (bh ages 1–10) failed to suggest a clear pattern. The data were first fit to a second-order polynomial and the coefficient for the quadratic term was found to be insignificant. Therefore, the quadratic term was eliminated and the simple linear model was used:

$$SI_{20} = b_0 + b_1 EG(X) + \varepsilon \quad (4)$$

where

SI_{20} = plot site index at bh age = 20,

b_i = parameter estimates,

$EG(X)$ = plot average of the early height growth for bh ages $X = 1 - 10$, and

ε = error NID $\sim (0, \sigma^2)$.

Table 1. Mensurational characteristics of trees used to generate volume equations.[a]

Equations generated[b]	No. trees	Dbh (in.)	Height (ft)	
			Total	Merch.
TVOL	101	10.6 (2.9–20.6)	63 (18–110)	56 (14–97)
MVOL	82	11.9 (5.0–20.6)	72 (31–110)	56 (14–97)

[a] Means above, ranges in parentheses below.
[b] TVOL = total volume (ft^3), MVOL = merchantable volume (ft^3).

Results and Discussion

Volume Equations

Examination of graphs of the dib/dob bark ratio plotted against stem height showed no relationship, suggesting that the ratio was independent of height and diameter (which varies inversely with height). The dib/dob bark ratio was 0.934 with a standard error of 0.0000305. The small standard error was due to a combination of the large sample size (1400 observations) and the low variation in the ratio itself.

In order to assess the maximum error that could be introduced by our assumption that shrinkage due to drying was uniform for bark and wood, the bark ratio was computed under two scenarios: (i) all shrinkage occurred in the bark; and (ii) all shrinkage occurred in the wood. These two situations represent the two possible extremes, neither of which is likely. The average differences between the bark ratio computed under the assumption of equal shrinkage and under scenarios (i) and (ii) were 0.00005 and –0.0004, respectively. Spurr's (1952, p. 94) model with the variance weighted by $(D^2H)^{-2}$ (Table 2) was determined to best satisfy the assumptions of least squares and have the best overall fit based on Furnival's (1961) index. The weighted Spurr model has worked well for many species, including Norway spruce (Jokela et al. 1986) and white spruce (Morton et al. 1990). A graphical comparison between the IBMVOL prediction equation for Japanese larch in Pennsylvania and European larch in Maine (Figure 1) showed a negligible difference. Evidently, Japanese and European larch trees have a similar form when plantation-grown in Pennsylvania and Maine, respectively.

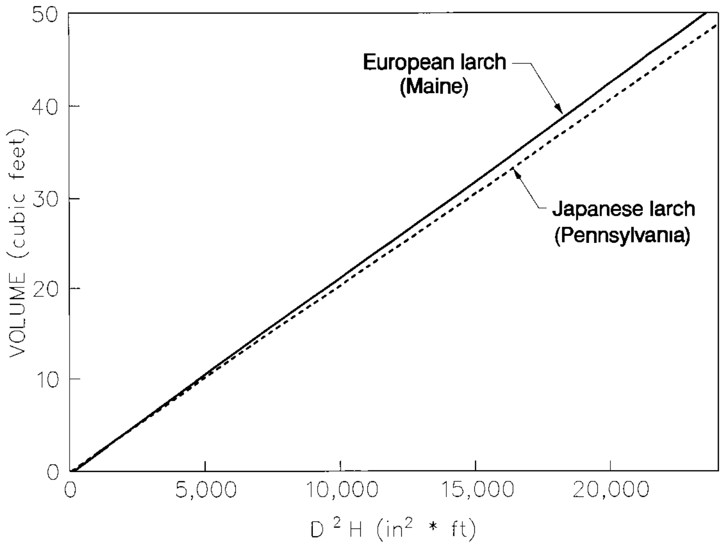

Figure 1. Graphical comparison of the inside bark merchantable volume equations for Japanese larch in Pennsylvania (Shipman and Fairweather 1986) and European larch in Maine.

Site Index Curves

The 17 plot SI_{20} values averaged 54 ft (range of 44 to 60 ft). Site index curves developed from this study (Figure 2) were compared to those developed by Aird and Stone (1955) as formulated by Carmean et al. (1989). For Aird and Stone's (1955) curves, the time period to attain bh was assumed to be 3 yr (Carmean et al. 1989) which is equivalent to an index age of 47 yr at bh (SI_{47}). The two sets of site index curves agree closely up to a bh age of 20 yr then diverge (Figure 3). The site index curves from this study are supported by data within the range depicted, whereas the $SI_{47} = 88$ curve of Aird and Stone (1955) is extrapolated beyond the range of the original curves.

Site Index Prediction from Early Height Growth

During the period of early height growth, the differences in height development among the site index curves are small; the curves tend to converge as bh age decreases (Figure 2). Projecting future height growth from young height-age pair information (< 10 yr at bh) with these curves (Figure 2) could provide an inaccurate estimate of site quality.

Because of the indeterminate height growth pattern characteristic to the genus *Larix,* it is not possible to use the conventional growth intercept method which relies on the measurement of the distance between readily identifiable annual whorls Results from the regressions of site index on average annual height growth for the first 10 yr following attainment of bh show marked improvement with increasing bh age (Table 3). Coefficients of determination increase and root mean square errors decrease as bh age increases from 1 to 10 yr. The root mean square error does not fall below 3 ft (which separates the curves at index ages of < 10 yr) until bh age reaches 5 yr. A bh age of 5 yr is likely the minimum time required to obtain a projected future height of reasonable accuracy. That height measurement would have to be determined either from stem analysis or from annual measurements at the end of the growing season; it could not be obtained from observation of annual branch whorls

Table 2. Parameter estimates, their standard error, mean square error, and coefficients of determination for Spurr's weighted model to predict OBTVOL, IBTVOL, OBMVOL, and IBMVOL.

				Model	
Volume predicted[a]	Parameter estimate[b]		Standard error	MSE	r^2
OBTVOL	b_1	0.1460	2.051E–2	5.0E–8	0.99
	b_2	2.426E–3	2.627E–5		
IBTVOL	b_1	0.1270	1.790E–2	1.0E–8	0.99
	b_2	2.117E–3	2.293E–5		
OBMVOL	b_1	-0.3319	0.1243	1.0E–7	0.98
	b_2	2.400E–3	3.958E–5		
IBMVOL	b_1	-0.3497	0.1273	1.0E–7	0.98
	b_2	2.088E–3	3.669E–5		

[a] OBTVOL = outside bark total volume; IBTVOL = inside bark total volume; OBMVOL = outside bark merchantable volume; IBMVOL = inside bark merchantable volume.

[b] Volume = $b_1 + b_2(D^2H)$ where D = dbh (in.), and H = total height (ft).

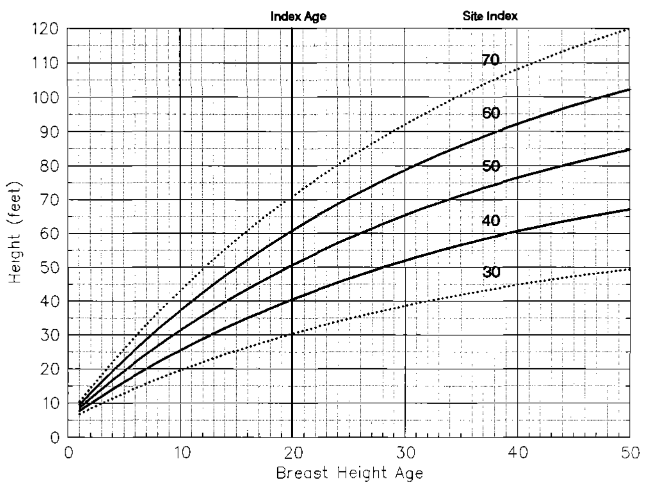

Figure 2. Site index curves for European larch. Curves constructed within the range of stem analysis data are indicated with solid lines. Extrapolated curves are indicated with dotted lines. The equation used to generate site index curves was: *HTBH* = 4.5+*H*[2.325–(2.300 * exp(–0.028 * *BHAGE*))], where *HTBH* = height above bh (ft), *H* = height (ft) at bh age=20 yr–4.5 ft, *BHAGE* = bh age, and exp= base of the natural logarithm.

Management Implications

The similarity of our equation for merchantable inside bark volume with that reported by Shipman and Fairweather (1986) for Japanese larch in Pennsylvania suggests that both species exhibit a similar form. Until more regional volume equations become available for exotic larches, we recommend the use of our equations to predict volume from dbh and height (Table 2) for European larch in the Northeast.

The site index equations developed in this study were similar to those reported by Aird and Stone (1955) up to a bh age of 20 yr, beyond which, the Aird and Stone (1955) curves underestimate the height development of European larch in Maine. Our curves are based on bh age, which reduces much of the variability in height growth encountered during the early years of plantation development. Site index can be estimated from Figure 2 by plotting breast height age and total height, then interpolating (if necessary) between the upper and lower curves.

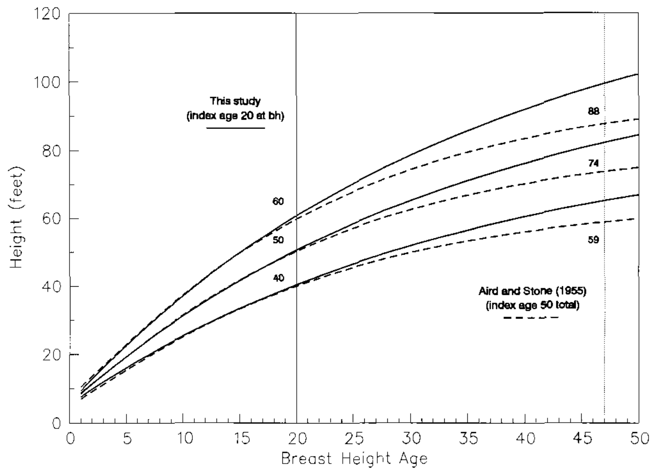

Figure 3. Graphical comparison of site index curves developed for European larch in Maine (this study), and in southern New York (Aird and Stone 1955). Time to bh for the curves of Aird and Stone (1955) assumed to be 3 yr (Carmean et al. 1989).

It is important to point out that estimates of site index for trees less than 5 yr bh are subject to large errors.

In addition to its importance as an indicator of site quality, height development is a required input for many growth and yield models. The model developed to predict yield of second growth Douglas-fir by Mitchell (1975) is one of the better known models. Height growth patterns are used to simulate crown development and subsequently, bole increment. The height development patterns reported here will facilitate application of those growth models to European larch.

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Table 3. Parameter estimates, their standard error, model root mean square error ($S_{y.x}$), and coefficients of determination for the prediction of SI_{20} from heights at bh ages 1–10.

	Parameter Estimates				Model	
Bh age	b_0	SE	b_1	SE	$S_{y.x}$	r^2
1	30.62	5.44	2.413	0.553	3.4	0.56
2	32.47	4.78	1.701	0.371	3.3	0.58
3	31.37	6.25	1.467	0.319	3.3	0.58
4	27.99	5.28	1.424	0.285	3.2	0.62
5	24.19	5.28	1.411	0.247	2.9	0.68
6	20.79	5.64	1.405	0.236	2.8	0.70
7	15.63	6.01	1.467	0.228	2.7	0.73
8	10.11	6.33	1.537	0.220	2.5	0.76
9	7.32	6.38	1.516	0.206	2.4	0.78
10	5.10	5.87	1.470	0.175	2.2	0.82

[a] Model: $SI_{20} = b_0 + b_1 EG(X)$ where, SI_{20} = plot site index; $EG(X)$ = plot average of the total height (ft) at bh ages X = 1–10.

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