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morphology of jack pine and tamarack needles in dense stands

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MORPHOLOGY OF JACK PINE AND TAMARACK IN DENSE STANDS NEEDLES

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Studies of biomass production in forest stands require measuring the leaf area of sample trees. In order to increase the precision of biomass estimates for our research in Wisconsin, we carried on a preliminary study to find out whether jack pine *(Pinus banksiana)* and tamarack *(Larix laricina)* needles differed in shape and size from one part of the crown to another. The results of this study are reported here.

Techniques used for determining leaf area of coniferous species are more complex than those for broadleafed species. Several methods have produced satisfactory estimates (Kozlowski and Schumacher 1943, Barker 1968, Balderston 1972, and Drew and Running 1975). The method used in this study was similar to that used by Madgwick (1964) and Harms (1971). The needle surface is expressed as a function of length and circumference measured at three points along the needle. The advantage of such a method is that it accounts for the irregular shape of the needle, and it is as precise as other methods as well as quicker.

METHODS

Needles were collected from 6-year-old jack pine and tamarack trees planted at spacings of 9 by 9, 12 by 12, and 24 by 24 inches. Two codominant trees were selected from each plot for a total sample of six trees of each species. Needle samples were collected in the upper, middle, and lower thirds of the crowns. Collections from jack pine trees included single needles from both the current and previous years. The sample from tamarack trees included single needles from current shoots and needles from whorls on lateral spurs.

One needle from each crown level was chosen at random and divided into four parts by cutting through the middle and removing 1/6 of the total needle length from each end (fig. 1). Magnified cross sections were photographed jointly with a stage micrometer used as a scaling device. The circumference of each needle section was then measured on the photograph with a linear map measuring device and adjusted to a real value. The surface area (S) of each needle was obtained as follows:

$$S = \frac{L}{12}(4b + 3r_1 + 3r_2) \qquad (1)$$

where L is the needle length and b, r_1 and r_2 circumferences of the middle and two end cross sections, respectively. The discrepancy between L and the correct slanted needle length averaged less than 0.3 percent and was neglected in the equation (1).

The length and dry weight were determined from a second sample of five needles collected at each crown level. The needles were dried at 70C for 48 hours and weighed to the nearest 0.1 mg.

Allometric relations were established between needle length and needle surface area and between needle length and needle dry weight. These two regressions were consolidated into one relating needle surface area to needle dry weight. This equation was validated on a small sample of needles for which surface area and dry weights were obtained on identical needles. Needle surface area was obtained in the same way as described earlier.

Curvilinear relations between the original values of needle length and surface area or dry weight, and between needle surface area and dry weight were linearized by logarithmic transformation (i.e., allometric model) and data fitted by the least square method. One additional advantage of the logarithmic transformation was normalization of variance of the data. To account

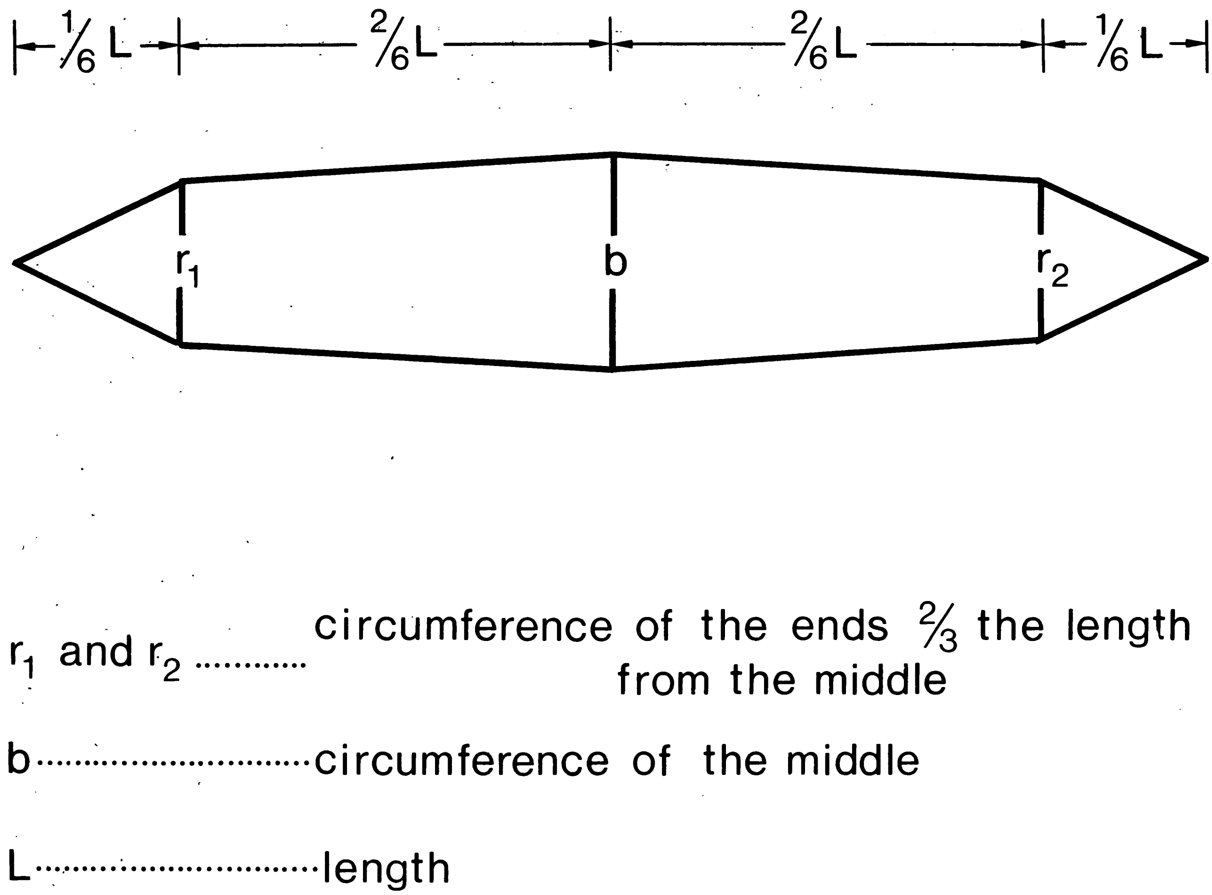

Figure 1. — *Model of needle surface area determination.*

for the inherent bias when values are retransformed from allometric regressions back into arithmetic units, correction factors were calculated according to Baskerville (1972). All statistical tests were performed using the 0.05 level of significance.

RESULTS

Jack Pine

The six jack pine trees ranged from 3.2 to 3.5 m in height and from 25 to 36 mm in. d.b.h. Since no differences were apparent in relations between needle characteristics and tree size or between the 1974 and 1975 samples, all data were pooled for the analysis.

Needle lengths (L) and surface area of the needles used to determine surface area ranged from 18 to 62 mm and 46 to 211 mm^2, respectively (fig. 2). The allometric regression was:

$$\ln S = 1.46 (\ln L) - 0.63; R^2 = 0.97, S_{y.x} = 0.08 \quad \text{Correction Factor} = 1.003 \qquad (2)$$

Needle lengths and dry weights (DW) of the second needle sample ranged from 21 to 68 mm and from 1.0 to 21.2 mg, respectively (fig. 3). The formula for estimating needle dry weight was:

$$\ln DW = 2.02 (\ln L) - 5.30; R^2 = 0.92, S_{y.x} = 0.18 \quad \text{Correction Factor} = 1.016 \qquad (3)$$

The allometric regression relating needle dry weight and needle surface area, obtained by consolidating equation (2) and (3) was:

$$\ln S = 0.72 (\ln DW) + 3.20 \qquad (4a)$$

The sample needles used for validating the consolidated regression ranged from 20 to 61 mm in length, from 37 to 202 mm^2 in surface area, and from 2.0 to 20.4 mg in dry weight. The measured and estimated values of surface area were not significantly different ($p = 0.05$). The allometric regression based on the validation sample was:

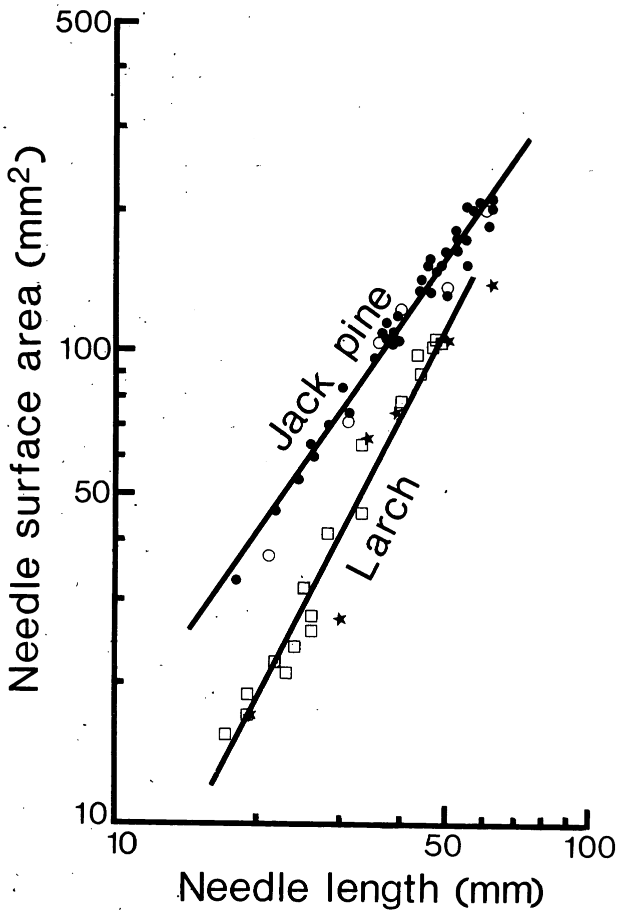

Figure 2. – *Allometric relation between length and surface area in jack pine (●) and larch (□) needles. Needles used for validation of the model are shown (○) for jack pine and (*) for larch.*

$$\ln S = 0.72 (\ln DW) + 3.14;\ R^2 = 0.99;\ S_{y.x} = 0.09 \quad \text{Correction Factor} = 1.004 \quad (4b)$$

Tamarack

The six tamarack trees ranged from 4.0 to 4.6 m in height, and from 21 to 33 mm in d.b.h. Needle values for individual trees were pooled because they showed no relation to tree size.

Sample needles used for surface area determination ranged from 19 to 49 mm in length and from 16 to 107 mm² in surface area (fig. 2). The allometric regression was:

$$\ln S = 2.03 (\ln L) - 3.15;\ R^2 = 0.97,\ S_{y.x} = 0.13 \quad \text{Correction Factor} = 1.001 \quad (5)$$

Needle length of the second sample ranged from 17 to 52 mm and the dry weight from 0.4 to 7.6 mg. The allometric regression for needle dry weight was (fig. 3):

$$\ln DW = 2.98 (\ln L) - 9.52;\ R^2 = 0.96,\ S_{y.x} = 0.20 \quad \text{Correction Factor} = 1.020 \quad (6)$$

The allometric regression relating needle dry weight and surface area, obtained by consolidating equations (5) and (6), was:

$$\ln S = 0.68 (\ln DW) + 3.20 \quad (7a)$$

The sample needles ranged from 19 to 63 mm in length, from 17 to 138 mm² in surface area, and from 0.7 to 9.7 mg in dry weight. These values were not significantly different from values predicted from equations (5), (6), and (7). The allometric regression based on the validation sample was:

$$\ln S = 0.71 (\ln DW) + 3.12;\ R^2 = 1.00,\ S_{y.x} = 0.06 \quad \text{Correction Factor} = 1.002 \quad (7b)$$

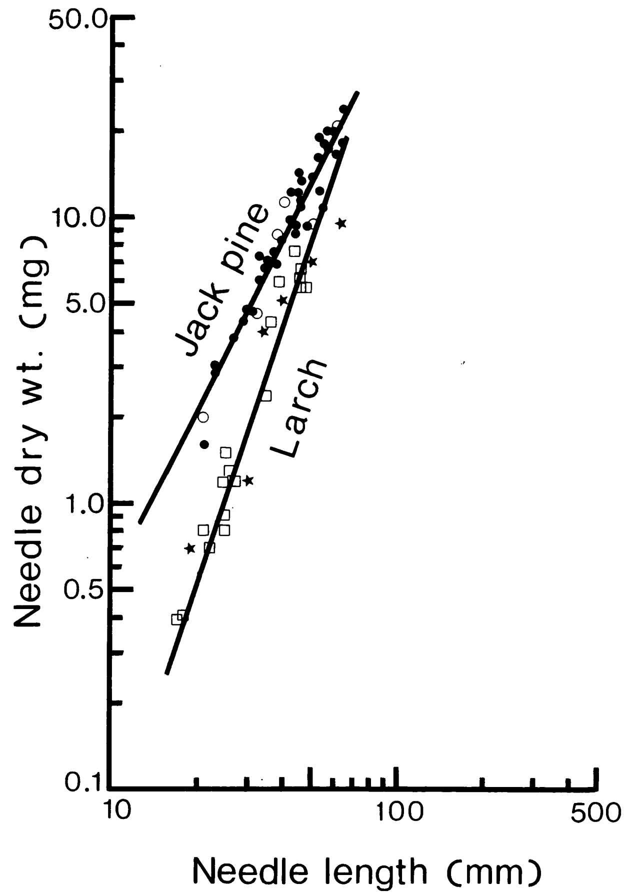

Figure 3. – *Allometric relation between length and dry weight of jack pine (●) and larch (□) needles. Each point represents five needles. Needles used for validation of the model are shown (○) for jack pine and (*) for larch.*

Effect of Crown Position on Needle Morphology

Lengths, surface areas, and dry weights of individual needles of both species were strongly affected by their location in the crown. Needles from the lower third of the crown were consistently, and in most instances significantly, shorter and had significantly smaller surface areas and dry weights than needles from the upper third of the crown (tables 1 and 2). Lengths, surface areas, and dry weights of needles collected from the middle third of the crown were intermediate.

The differences resulting from the position in the crown were greater in samples collected from dense plantations, especially in magnitude of surface areas and dry weights. For example, dry weights of 1975 jack pine needles from the 9- by 9-inch plantation averaged 19.2 and 3.1 mg for the upper and lower thirds of the crown, respectively—a ratio of 6.2. The ratio was 5.2 for the 12- by 12-inch plantation and only 1.9 for the 24- by 24-inch plantation. The corresponding ratios for the 1974 jack pine needles were less diverse—2.3, 2.2, and 1.3—and for tamarack 7.3, 17.6, and 6.2

The relation of needle size to position in the crown also held for specific needle area. For jack pine needles

Table 1. — *Last- and current-year's length, surface area, and dry weight of jack pine needles (mean length and dry weight are based on 10 determinations, mean surface area on 2 determinations)*

Spacing Position in crown (third)	Mean length 1974		Mean length 1975		Mean surface area 1974		Mean surface area 1975		Mean dry weight 1974		Mean dry weight 1975	
	mm	*SD*[1]	*mm*	*SD*	*mm²*	*SD*	*mm²*	*SD*	*mg*	*SD*	*mg*	*SD*
9 x 9"												
Upper	[2]54.2[a]	3.4	58.3[a]	2.1	164.5	15.6	204.7	6.8	18.0[a]	3.7	19.2[a]	1.3
Middle	49.4[a]	4.9	27.6[b]	1.1	126.9	32.8	61.5	2.0	15.2[a]	5.5	4.1[b]	0.4
Lower	36.8[b]	3.9	25.6[b]	5.2	112.9	3.5	58.7	36.4	7.7[b]	1.7	3.1[b]	1.7
12 x 12"												
Upper	54.2[a]	10.4	49.6[a]	8.4	171.8	54.9	156.4	5.1	18.9[a]	5.2	15.0[a]	3.0
Middle	41.8[a]	9.2	32.6[b]	3.6	136.1	45.7	83.5	19.5	10.6[ab]	3.5	5.9[b]	1.6
Lower	39.2[a]	7.4	23.1[c]	0.8	106.4	46.4	49.7	5.4	8.5[b]	2.8	2.9[c]	0.3
24 x 24"												
Upper	50.7[a]	3.8	54.6[a]	9.6	156.6	23.2	170.8	25.8	12.2[a]	0.9	15.7[a]	2.7
Middle	51.4[a]	9.8	43.0[b]	2.0	190.7	13.5	123.8	25.8	13.4[a]	3.9	9.2[b]	0.6
Lower	45.8[a]	9.4	43.2[b]	5.9	130.4	34.0	124.5	9.1	9.2[a]	1.9	8.1[b]	1.6

[1]SD = standard deviation.
[2]Within each spacing and year, means followed by the same letter are not significantly different (p = 0.05).

Table 2. — *Length, surface area, and dry weight of tamarack needles (mean length and dry weight are based on 10 determinations, mean surface area on 2 determinations)*

Spacing Position in the crown (third)	Mean length		Mean surface area		Mean dry weight	
	mm	*SD*[1]	*mm²*	*SD*	*mg*	*SD*
9 x 9"						
Upper	[2]41.0[a]	6.2	95.3	9.7	5.85[a]	1.34
Middle	25.2[b]	3.1	38.9	10.3	1.20[b]	0.42
Lower	22.7[b]	3.4	23.1	6.2	0.80[c]	<0.01
12 x 12"						
Upper	44.7[a]	4.5	103.4	5.7	7.05[a]	0.78
Middle	23.7[b]	1.9	32.8	13.2	0.95[b]	0.35
Lower	18.2[c]	0.9	16.3	0.8	0.40[c]	<0.01
24 x 24"						
Upper	45.2[a]	4.5	92.4	19.8	5.85[a]	0.21
Middle	30.8[b]	5.0	44.6	25.9	1.85[b]	0.78
Lower	24.2[c]	3.7	21.5	0.2	0.95[c]	0.35

[1]SD = standard deviation.
[2]Within each spacing, means followed by the same letter are not significantly different (p = 0.05).

that weighed 2 and 20 mg (i.e., about the range of weights used in the study) specific needle areas were about 200 and 110 cm^2/g needle weight (equations 4a and 4b). For tamarack needles weighing 0.8 and 8.0 mg the specific needle areas were 264 and 126 cm^2/g needle dry weight (equations 7a and 7b).

DISCUSSION

In both species the curvilinearity in relations between needle length and surface area or dry weight and between needle weight and surface area was eliminated by logarithmic transformation. The curvilinearity among needle measurements and its linearization by applying the allometric model was discussed by Madgwick (1964) in his studies on red pine. An allometric model was also used by Harms (1971) for estimating fascicle needle area of loblolly pine; for the same species Kinerson *et al.* (1974) and Higginbotham (1971) used simple linear regressions in relation between foliage weight or needle fascicle length and the corresponding surface area. However, Kinerson *et al.* (1974) and Higginbotham (1971) had to develop separate equations for the upper, middle, and lower thirds of the crown to account for differences in needle morphology which is apparently not needed when using the allometric model.

In both species the smallest needles were in the lower third and the largest in the upper third of the crown. As a result, the specific leaf area, expressed in cm^2/g of needles decreased from the lower to the upper third of the crown. The relation of specific needle (or foliage) area to position in the crown was also reported in other studies. Using Kinerson's *et al.* (1974) data for loblolly pine, we calculated specific foliage areas of 122, 99, and 92 cm^2/g for the lower, middle, and upper thirds of the crown, respectively. Assuming that the distribution of needles in crowns of red pine studied by Madgwick (1964) was similar to the distribution found in our studies, the specific needle area of the smallest fascicles (18.9 mg) of red pine would be about twice that of the largest fascicles (119.5 mg).

More information is available on the specific leaf area distribution of broadleaved species. Pieters (1974) reported that sun leaves of *Quercus borealis* and *Acer pseudoplatanus* were about twice as thick as shade leaves. In *Fagus sylvatica* (Vanseveren 1973) the specific leaf area of fully developed leaves ranged from 104 to 284 cm^2/g for leaves collected from the upper and lower thirds of the crown. The average specific leaf areas of quaking aspen leaves collected from the upper and lower thirds of the crown of a codominant tree were 120 and 147 cm^2/g, respectively (Zavitkovski 1971). Our unpublished studies of dense plantations of *Populus* 'Tristis #1' indicate that the average specific leaf area of leaves collected from the upper third of crowns is about 102 cm^2/g whereas from the lower third it is about 211 cm^2/g. It must be noted that in calculations of specific leaf area only one side of the broadleaved leaves, but the entire surface of needles is considered.

The differences in needle morphology resulting from the position in the crown were more pronounced in samples collected from dense plantations in which the lowermost needles were growing in dense shade and the uppermost in full sunlight. This seems to be consistent with studies of Pieters (1974) who concluded that leaf thickness increases with light and decreases with temperature. The same principle applied to loblolly pine in which needles developing in the shaded part of the crown were thinner and had a smaller area than needles exposed to full light (McLaughlin and Madgwick 1968).

The difference in the mean values between the 1974 and 1975 needles of jack pine trees, and, as a consequence, the absence of a pronounced relation in the 1974 needle length, surface area, and dry weight with position in the crown, could have resulted from a premature death and fall of the short needles that predominate in the lower third of the crown. Late summer 1975 sampling of the 1974 needles would then be biased in favor of the larger needles. This conclusion is supported by our unpublished studies on the periodicity of leaf fall in plantations of *Populus* 'Tristis #1' which revealed that the smallest leaves senesce and fall first.

We found no relation between tree d.b.h. and needle length, which was reported for ponderosa pine by Cable (1958), probably because of the relatively narrow d.b.h. range of our sample trees that grow in even-aged plantations.

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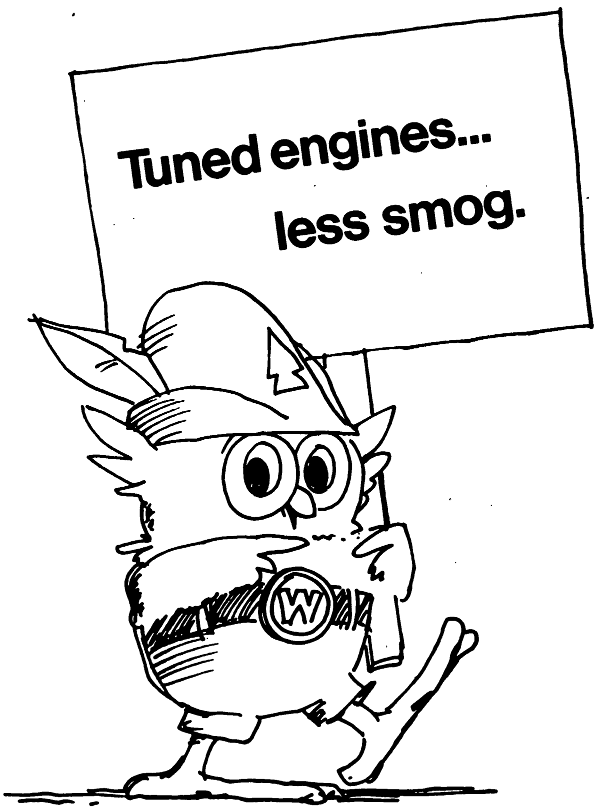
Tuned engines...
less smog.