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Estimating Fascicle Surface Area of Khasi Pine—*Pinus kesiya* Royle ex Gordon

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Methods are suggested for estimating the surface area of fascicles of *Pinus kesiya* Royle ex Gordon. Measurements of length, radii, and angle between the radii (at equidistant intervals along the fascicle) were obtained for all the three needles in a fascicle. Simpson's one-third and Weddle's rule (Milne 1949) were applied for measuring the surface area. Error percentage of the surface area calculated under assumption of cylinder, cone and Baker's (1949) estimate from that of the proposed method were obtained. Length of the fascicle, a non-destructive measure, was taken as the only independent variable for model construction. Various ways of modifying the proposed model are discussed.

Key Words: Surface area, Simpson's one-third and Weddle's rule, ***Pinus kesiya***

Introduction

Several methods have been proposed for determining the surface area of pine fascicles. But most of these assume that they confirm to simple geometric shape (Tiren 1926, Kozlowski & Schumacher 1943, Baker 1948, Cable 1958, Kumagai 1962, Pollard & Wareing 1968). Madgwick (1964) and Harms (1971) have discussed non-destructive estimates. Beets (1977) has discussed various models for determining surface area, which involve determination of a constant appropriate to the shape. The object of the present study is to find a suitable method for estimating surface area of fascicles of *Pinus kesiya*.

Material and Methods

Samples of mature needle fascicles were collected from a four year old even aged plantation located at Mawlai in Shillong at an altitude of 1250 m. Fascicles were of the second flushing which appear in June and become mature by December-January. Sixty-nine fascicles were collected randomly, irrespective of their position in the canopy, taking care that all the available length classes are uniformly represented. Abnormal fascicles with two or four needles were excluded from the study. Length of only green photosynthetic portion of the fascicle above the sheath was measured to the nearest 0.5 mm. Length of mature fascicles ranged from 33 to 250 mm.

Since the needles vary in width throughout their length with a taper of about 5 mm, they were sectioned at four different positions, viz., the place where they enter the sheath, 5 mm from the tip and at two more intermediate equidistant positions. Cross-sections were then drawn on plain paper with the help of camera lucida. From these figures the radii(r) to the nearest 0.5 mm and angle(θ) between the radii to the nearest 0.5° were measured. Radii at three more equidistant points were obtained by linear interpolation.

The surface of *P. kesiya* needle consists of three parts—two flat surfaces forming the inner surface, inclined at angle θ to each other and bounded by a curved surface forming the outer area. The flat surface was measured by applying Simpson's one-third and Weddle's rule (Milne 1949). Since for the taper the width changes faster than rest of the needle, it is being measured separately. Its length 5 mm does not confirm with the requirements of Simpson's and Weddle's rule which demand equidistant intervals. Thus, its flat surface area is measured separately.

The area bounded by the curve $X=f(x)$, X-axis, and the ordinates Y_o at X_o, Y_n at X_{o+nh}, according to Simpson's one third rule, is given by

$$S=\int_{x_o}^{x_o+nh} f(x)dn = \frac{h}{3}\Big[(y_o+y_n)+4(y_1+y_3+\ldots\ldots+y_{n-1})+2(y_2+y_4+\ldots\ldots+y_{n-2})\Big] \quad \ldots(1)$$

and the same by weddle's rule is

$$W=\int_{x_o}^{x_o+nh} f(x)dx = \frac{3h}{10}\Big[Y_0+5y_1+y_2+6y_3+y_4+5y_5+2y_6+\ldots+2y_{n-6}+5y_{n-5}+y_{n-4}+6y_{n-3}+y_{n-2}+5y_{n-1}+y_n\Big]. \quad \ldots(2)$$

In (1) $n+1=4$, an even number as required are four widths measured at equidistant positions. In (2) $n=6$, 'a multiple of six' as required. Besides the above four observations used in (1), (2) uses the radii obtained through linear interpolation. However, while doing so a certain degree of error is unavoidable.

Here, Y_1's are the ordinates measured at subsequent intervals of width h. And in the present study these are taken as radii measured at equidistant intervals of h.

The inner area for the taper is measured as a triangle and outer areas are obtained as

$$oij = \frac{\theta}{2}(r_i+r_j)\,Lij$$

where Oij is the curved surface bounded by i^{th} and j^{th} position, r_i, r_j are radii at these two positions and

$$Lij = \sqrt{(r_j - r_i)^2 + h^2}$$

These inner and outer areas added for all the three needles, gives the total surface area of the fascicle.

Areas were also measured under the assumptions of a cylinder, a right circular cone (with radius measured at the base), as 4.09 RL, where R is the radius of the needle in the middle and L is the length of the needle. Baker (1948) has assumed that cross-section of the needle represents one-third of a circle. The error percentages of the areas obtained under these assumptions from that of the proposed method were also calculated.

Results

An increasing trend was always observed for 'r' from base to the second position of the needle. From second to third, r either decreases or remains constant. The value of r at the tip is just less than two-third of that at the base.

The radial and angular dimensions of the three needles within a fascicle were found to vary among themselves. However, if the radius of one needle at a particular position is smaller than that of another needle of the same fascicle at the same position then the same holds true for the remaining positions as well. Furthermore, the needle with a smaller radius is always accompanied with a greater angle. Thus, the three needles countribute more or less equal proportions to the total fascicle area.

The taper, neglected in most of the earlier works, was found to contribute 0.8 to 4.3% of the total fascicle area in *P. kesiya*.

Differences between the estimates due to Simpson's one-third and Weddle's rule never exceeded 0.001 cm^2; so for later studies only Simpson's rule was used.

Table 1 gives a summary of the measurements of various fascicle characters. Fascicle area shown therein is the one obtained by Simpson's rule. Error percentages of the areas obtained under different assumptions from that of the above method i.e. the one using Simpson's one-third rule, are presented in table 2. On the average, the cylinder and Baker's assumption overestimates the fascicle surface area whereas conical assumption underestimates this—magnitude of error percentage being maximum in the latter case.

Table 2 *Error percentages of the surface area estimates under the assumption of various geometric shapes from the proposed method*

Assumption	Minimum	Maximum	Mean
cylinder	— 3.24	20.36	6.42
Cone	—30.02	—54.06	—42.80
Baker's estimate	— 5.01	19.21	7.07

As discussed the fascicle area depends on three variables—length (L), angle (θ) and radius (r) at different positions along the needle. However, only L, which is the only non-destructive measure, is used as a predictor. Surface area A is linearly related to fascicle length (L) with $r = 0.98$. Thus, it can be written as

$$A = a + bL$$

where a and b are coefficients determined by the principle of least squares (figure 1).

Table 1 *Variations in the dimensions of fascicles of* P. kesiya

	Variable	Number of fascicles/ needles	Minimum	Maximum	Mean	Coefficient of variation (%)
Fascicle	Length (cm)	69	3.3	25.0	14.56	35.88
	Area (cm^2)	69	3.922	30.479	15.21	49.84
Needle	Radius (cm)					
	Base	207	0.055	0.151	0.091	20.88
	5 mm from tip	207	0 042	0.087	0.068	10.29
	Angle (degrees)	207	93.85	137.22	118.54	8.22

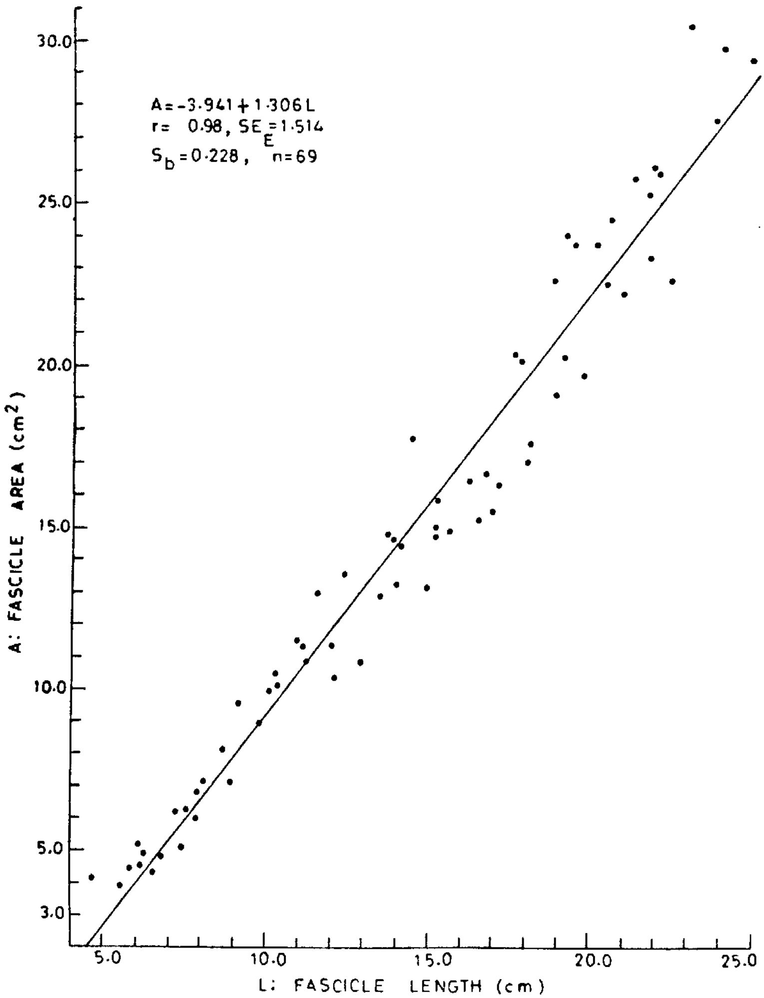

Figure 1 Relationship between Fascicle Area *(A)* and Fascicle Length *(L)* of *Pinus kesiya* Royle ex Gordon.

r, Coefficient of correlation; SE_E, Standard Error of the estimate; S_b, Standard deviation of the regression coefficient *b;* n, Number of fascicles studied.

Discussion

The possibility of developing a non-destructive method for estimating surface area was first discussed by Madgwick (1964). Harms (1971), developed a method for *Pinus taeda*, wherein the surface area was found to be linearly related to the fascicle length after logarithmic transformation. For *P. kesiya* surface area and fascicle length are linearly related.

Kozlowski and Schumacher (1943), Cable (1958) have assumed fascicles to be of right circular cone in shape which leads to an average underestimation of 42.8% for *P. kesiya*. An underestimation of an average 19.5% was also observed by Madgwick (1964) while using this assumption for *P. resinosa*. Tiren's (1926) cylindrical assumption over estimates leaf area of *P. sylvestris* by 7 to 10% and when used by Madgwick (1964) for *P. resinosa*, overestimated by an average of 5.6%. For *P. kesiya* this overestimation was found to be 6.42%. Baker (1948) has assumed the cross section of *Ponderosa* pine needles to be one-third of a circle. In the present study, however, the angular measurement was found to vary between 93.85 and 137.32 degrees contradicting the Baker's assumption. Thus, even though Baker's method is simple it is not proper to apply it for *P. kesiya*.

Madgwick (1964) used repeated Simpson's rule for estimating surface of revolution of needle profile and compared the estimates so obtained with those obtained under different assumptions used by previous authors. He took measurements from only one needle per fascicle to estimate the total surface area. The present study, however, shows the difference in radial and angular dimensions among the three needles within a fascicle. While obtaining the percentage error for cylindrical and conical assumption, the three needles of the same fascicle gave different percentages for the total fascicle area, the differences ranging from 0 to 18.26% in case of cylinder and 0 to 15.95 in case of cone. Harms (1971) obtained the inner surface area by plotting the radii over length on a cross-section paper and counting area under the profile curve drawn. While considering the outer surface area, he assumed fascicles to be of right cylinder in shape. Beets (1971) measured the fascicle diameter at equidistant intervals and assumed that the fascicle is having a circular outline.

Whilst surface area of the fascicles could be estimated based on fascicle length, as proposed above, coefficients of the models presented here are to be recalculated whenever the average radius changes markedly (Harms 1971, Beets 1977). One of the causes of such a change may be positioning of needles at different canopy levels. The needles at the top of the canopy are more exposed to light than those at the bottom. The time of appearance of needles is also important—the needles coming late in the season may be very different from those appearing earlier. Significant differences in the needle growth characteristics were observed at different canopy positions and also for the three flushes of needles coming up within a year in *P. kesiya* (Das & Ramakrishnan, unpublished). This can be overcome by considering a new set of fascicles and re-evaluating the coefficients. But this will lead to destructive sampling everytime whenever a marked change in the radius is noted. On the other hand determining the coefficients by using a sufficiently large sample taking into account all the above mentioned sources of variation, one can avoid repeated destructive sampling but has to sacrifice certain degrees of accuracy.

Changes in leaf area resulting from growth can be observed by periodic measurements. According to Harms (1971), since fascicle age and length are highly correlated, the inclusion of age as another independent variable does not significantly improve the model. As fascicle grows in length, radius also changes; however, both may be changing at different rates. Thus, it would be better to construct models at different stages of growth or finding a length-radius relationship a priori.

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