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A Comparison of Two Techniques for Measuring Canopy Closure

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Studies of wildlife habitat relationships frequently involve the estimation of canopy closure, defined as the percentage of ground area shaded by overhead foliage (Daubenmire 1959). Estimates of canopy closure are also becoming increasingly important in forest management. For example, they figure importantly in management recommendations for both the northern spotted owl *(Strix occidentalis caurina)* and the northern goshawk *(Accipiter gentilis)* (Thomas et al. 1990, Reynolds et al. 1992). Because of the importance of these estimates in habitat assessment and forest management, accurate and precise techniques for estimating canopy closure are desirable.

Several techniques have been used to estimate canopy closure, including the spherical densiometer (Lemmon 1956), hemispherical photography (Evans and Coombe 1959), a sighting tube (James 1971), an inverted monocular (Laymon 1988), and ocular estimates (O'Brien and Van Hooser 1983). Laymon (1988) compared these techniques across a series of plots. He found no significant differences among techniques, with the exception of ocular estimates and the sighting tube when only 10 sample points were used. He did not measure the effect of inter-observer variation (Block et al. 1987, West and Hatton 1990) on estimates obtained using different techniques, however, and he did not compare variability among techniques within plots.

Spherical densiometers are used frequently for estimating canopy closure, but these estimates may have low accuracy and low precision (Strickler 1959, Griffing 1985). Although both problems may be reduced by mounting the densiometer on a tripod (Strickler 1959), this does not eliminate the subjectivity involved in using the instrument. In addition, both convex and concave densiometers are used; some field crews use the densiometer as described in Lemmon (1956), whereas others use modifications proposed by Strickler (1959, see also Griffing 1985), and some crews record only branch and foliage "hits" whereas others record stem hits as well (C.B. Edminster, pers. comm.). Thus, the accuracy and precision of estimates obtained using a spherical densiometer are questionable. Here, we compare estimates of canopy closure obtained using a spherical densiometer with those obtained using a sighting tube. Specifically, we compare interobserver variation between these techniques.

We sampled canopy closure on 60 0.1 ha plots in ponderosa pine (*Pinus ponderosa* Laws.) forest in north-central Arizona. All plots were located randomly by spinning a compass twice behind an observer's back, once to determine a direction and again to determine the number of paces from a starting point to plot center, with the constraint that plot centers were separated by ≥100 m.

For each plot, we laid out a transect 36 m long, centered at plot center and oriented in a randomly chosen direction (see above), using a measuring tape. We then sampled canopy closure along this transect using two techniques. The first technique used a hand-held, concave spherical densiometer as described in Lemmon (1956). Five estimates were taken, at 0, 9, 18, 27, and 36 m. These five estimates were averaged to estimate percent canopy closure on the plot.

The second technique involved using a sighting tube with an internal crosshair. We used a tube made of PVC pipe with a crosshair fashioned out of baling wire. At each meter mark along the tape (1–36), the observer looked directly overhead through the tube and recorded whether or not the crosshair intercepted overhead foliage. We calculated canopy closure as the percentage of sample points containing overhead foliage.

Three observers sampled all plots using both techniques. For each observer, the order in which the techniques were used was reversed between subsequent plots to minimize any potential bias caused by the order in which techniques were used. Information on canopy closure was not shared among observers during sampling.

We used a paired t-test (Zar 1984, p. 121–124) to test the hypothesis of no difference between densiometer and sighting tube estimates within each observer, using plot as the pairing factor. We also used a paired t-test to test for differences in the range of estimates per plot between the two techniques. We used repeated measures analysis of variance (MANOVA, Norusis 1988, Chap. 6) to test for differences in estimates among observers. We used Pearson's product-moment correlation coefficient to examine the relationships between canopy closure (based on sighting tube estimates) and variability between techniques and among observers.

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Estimates of canopy closure on the plots ranged from 14–87% for densiometer estimates and from 0–94% for sighting tube estimates. Use of the densiometer generally resulted in higher estimates of canopy closure than use of the sighting tube. Fifty-seven percent of all densiometer estimates showed canopy closure >50%, versus only 38% of sighting tube estimates (Figure 1).

Estimates of canopy closure varied significantly between techniques for all three observers (Table 1). The difference between techniques generally decreased with increasing canopy closure (Table 2), but the relationship was significant (at $P < 0.05$) for only one observer ($R = -0.11, -0.21$, and -0.31 for the three observers).

Estimates also varied significantly among observers for both techniques (densiometer, $F = 22.7$, $P < 0.001$; sighting tube, $F = 5.04$, $P = 0.008$). Among-observer variability was positively but nonsignificantly correlated with canopy closure for both techniques ($R = 0.14$ for densiometer estimates and 0.30 for sighting tube estimates).

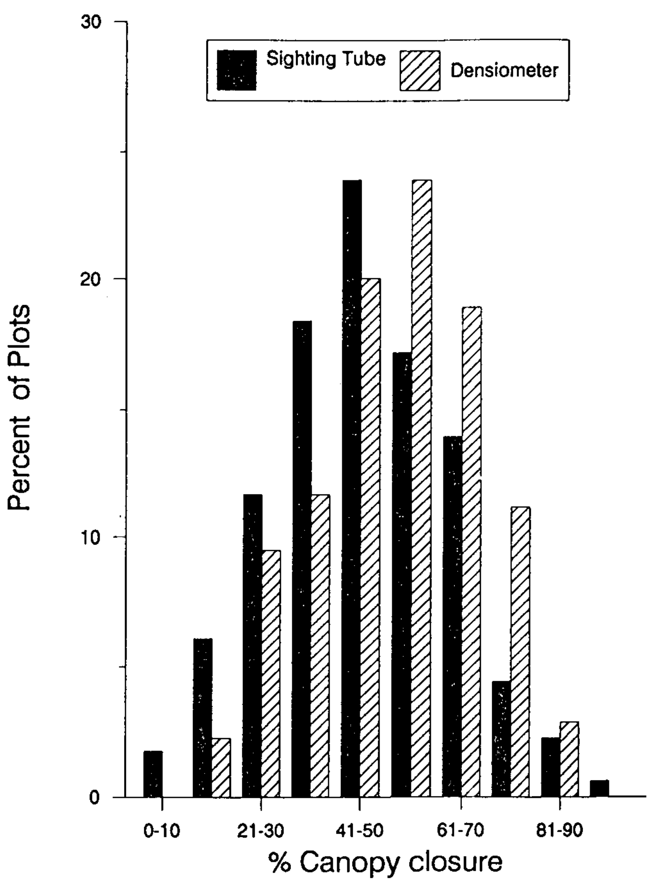

Figure 1. Percent of estimates in different canopy closure classes, based on densiometer and sighting tube estimates by 3 observers on 60 plots in a ponderosa pine forest, north-central Arizona.

Estimates obtained using the sighting tube were more consistent among observers. Within-plot variation among observers averaged $8.2 \pm 5.4\%$ (SD) (range = 0-25%) for the sighting tube versus $12.9 \pm 8.3\%$ (range = 1–46%) for the densiometer ($T = 4.06$, df = 59, $P < 0.0001$). The difference in average estimates among observers was also greater for the densiometer (8.3%) than for the sighting tube (2.8%; Table 1). With the sighting tube, among-observer variation in estimates was < 10% on 73% of all plots, while only 38% of plots had among-observer variation < 10% using the densiometer.

Our results, unlike Laymon's (1988), suggest that the two techniques tested do not provide similar estimates of canopy closure. We are unsure whether this reflects a real difference among studies or is due to differences in methodology. Laymon (1988) used a convex densiometer, whereas we used a concave densiometer. Laymon also did not examine variation between techniques within plots.

The difference between techniques appeared to be slightly greater at lower canopy closures, while variability among observers was slightly greater at higher canopy closures. Although we are not sure how to interpret these patterns, we suspect that variability among observers and between techniques may depend as much on the configuration of foliage as on the total amount of foliage. For example, small differences in positioning of the densiometer or sighting tube should have little effect where canopy is relatively open or relatively continuous, but could have significant effects where canopy foliage is patchy. If so, then using a tripod with the densiometer and attaching a leveling bubble to the sighting tube to ensure that it is held in a completely vertical position should reduce the amount of variability somewhat. These practices would not eliminate variability due to slight differences in observer position, however.

Because we have no control for comparison, it is impossible to determine which technique provides the most accurate estimate. Furthermore, our results are valid only for concave densiometers using Lemmon's (1956) methodology. We cannot address the precision of convex densiometers or either type of densiometer using Strickler's (1959) methodology. However, our results suggest that estimates may not be comparable among techniques, and that inter-observer variation in estimates can be considerable. In light of the increasing importance of measures of canopy closure in management of forested habitats, we believe that further work to standardize these measures and improve their accuracy and precision is needed.

Until such work is accomplished, however, we recommend using the sighting tube (with ≥20 sample points per plot; Laymon 1988) over the densiometer whenever multiple observers are involved in measuring vegetation plots. The sighting tube provides greater precision among observers, it is easy to use, and plots can be measured quickly using this technique. In our opinion, determining whether or not a crosshair intercepts foliage is easier, less ambiguous, and quicker (particularly if time spent leveling a tripod is considered) than estimating the amount of canopy cover with a densiometer. Sighting tubes are also less costly than

Table 1. Comparisons of estimates of percent canopy closure using densiometer and sighting tube.

Observer	Densiometer mean	Sighting tube mean	Mean difference	P^1
1	47.4	44.3	3.08	0.040
2	55.7	47.1	8.58	<0.001
3	54.1	46.3	7.75	<0.001

[1] Significance values based on paired t-test with 59 degrees of freedom.

Table 2. Difference between densiometer and sighting tube estimates of percent canopy closure.

Observer		% canopy closure			
		0–20	21–40	41–60	>60
1	N	5	18	30	7
	$\bar{X}$	11.8	9.9	8.4	7.6
	SD	8.0	9.2	7.0	5.2
2	N	4	19	23	14
	$\bar{X}$	17.0	14.1	11.7	8.7
	SD	9.8	9.0	8.3	6.5
3	N	5	17	21	17
	$\bar{X}$	15.0	15.2	12.2	7.2
	SD	11.1	8.4	8.1	6.5

densiometers. For point measures, the densiometer may still be the best available "quick and easy" method. We concur with Strickler (1959, see also Griffing 1985) that the instrument should be mounted on a tripod to reduce error due to observer movement. In addition, techniques should be standardized in terms of general methodology [i.e., Lemmon (1956) vs. Strickler (1959)] and whether or not stem hits are recorded.

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