Selecting Plot Sizes When Quantifying Growing Conditions in Understories

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ABSTRACT: *While the importance of selecting a neighborhood size for competition studies has been documented, the choice of plot sizes has received little attention when measuring the influence of overstory trees on growing conditions of understory seedlings. Based on data from four sites, we show how plot sizes for measures of overstory cover (using a "cone" approach) and basal area (using an angle gauge) were related. The relationship was a function of the height/diameter ratio of the overstory trees, with taller trees increasing the plot sizes for "cone" plots and trees with larger diameters increasing the plot sizes for basal area plots. Further, we point out that data derived from measurements of diffuse noninterceptance (DIFN) using the "cone" approach varied with the choice of cone opening. Smaller cone openings led to a greater range in DIFN values. Linear correlations between these data and 2 yr seedling height pointed out that the optimal plot size, i.e., cone opening, differs among the sites. The lack of any obvious stand characteristics that would explain these differences indicated the need for further investigations. North. J. Appl. For. 19(3):137–140.*

Key Words: Competition, overstory cover, neighborhood size, eastern white pine, regeneration.

An important component of quantifying growing conditions of plants is accurately assessing the influence of all competitors. The area surrounding an individual plant that includes all influential competitors, but excludes other vegetation, has been referred to as the "zone of influence" (e.g., Bella 1971) or "neighborhood" (e.g., Wagner and Radosevich 1991). Several studies examining competitive conditions have used an inverted cone projected above a "target" tree to incorporate the influence of overtopping vegetation on light availability and growth (e.g., Howard and Newton 1984, Puettmann and Reich 1995). However, these studies focused on vegetation of similar height to the "target" tree and/or did not go into depth about their choice of cone opening, i.e., plot size (defined as α in Figure 1), and how it relates to height of competing vegetation.

The approach to use an inverse cone has the advantage that it quantifies vegetation of similar size to seedlings (e.g., herbs and shrubs) and overstory trees into a single measure. The increased use of partial-cut silvicultural systems (Puettmann and Ek 1999) created more interest in this aspect. In the past, average stand-level variables have commonly been used as indicators of the influence of overstory conditions on seedling growth (e.g., Minckler 1961). While these measures may be sufficient in homogeneous stands, the gap-dominated nature of partially harvested stands results in a heterogeneous spatial distribution of environmental conditions (Coates and Burton 1997) and light (Canham et al. 1994) and other resources.

Due to its ease of measurement and high, unbiased correlation with average growing season transmittance (Comeau et al. 1998, Gendron et al. 1998), diffuse noninterceptance (DIFN) as determined by the LICOR® LAI 2000 has been used to quantify competitive conditions, especially light availability, for trees (e.g., Puettmann and Reich 1995, Comeau et al. 1998. Machado and Reich 1999, Saunders and Puettmann 1999). For this measure, the impact of overstory leaf area on light penetration is measured in a cone upwards from each seedling (see Puettmann and Reich 1995). Several studies have related DIFN to understory light conditions (e.g., Gendron et al. 1998, Machado and Reich 1999); however, the implications of deciding which cone opening, i.e., α value or

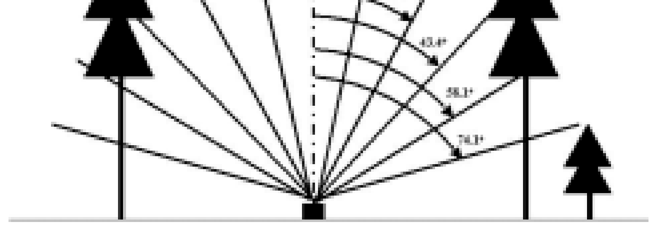

Figure 1. α **values used by the LAI-2000 Plant Canopy Analyzer (LI-COR® Inc., 1992) to measure diffuse noninterceptance (DIFN).**

NOTE: K.J. Puettman can be reached at (541) 737-8974; Fax: (541) 737–1393; E-mail: Klaus.Puettmann@orst.edu. The authors are grateful for the help of Mathew Smidt, Matt Duvall, Mike Saunders, and Jerry Krueger in setup and maintenance of the field sites. The projects were funded by the Legislative Commission for Minnesota Resources, the Iron Range Resources and Rehabilitation Board, the Minnesota DNR, and the St. Louis County Land Department. The work was done while the senior author was with the Department of Forest Resources, University of Minnesota, St. Paul, MN.

plot size, is appropriate were not considered in these studies. On the other hand, Pretzsch (1992) compared how various cone openings (α) related to the ability to predict height and diameter growth of trees in stands with multiple canopy layers. Increasing the angle beyond $\alpha = 30^o$ (the smallest cone opening) did not result in improvement of model predictions and Pretzsch (1992) concluded that the question regarding the optimal angle needed further investigations.

While several studies have documented the correlation between DIFN and overstory measures such as basal area or leaf area index (e.g., Vales and Funnel 1988, Jenkins and Chambers 1989, Gendron et al. 1998, Küßner and Mosandl 2000), sampling criteria for using these measures to quantify understory growing conditions have not been evaluated. Because the plot sizes (determined by α values and basal area factors for "cone" and basal area plots, respectively) of these measures vary with stand characteristics, the zones of influence defined by these measures also differ. In order to accurately incorporate measures such as DIFN and basal area into an assessment of growing conditions of seedlings, plot size differences between the different measures must be considered. This note aims at pointing out (1) how these plot size relationships vary between two common measures (DIFN and basal area) for different stand conditions, (2) how the choice of cone openings affects DIFN data, and (3) how this choice can affect the analysis of seedling growth response to understory conditions.

Methods

Site Description

This study was conducted on four sites in northern Minnesota, Aitkin (AK), Two Harbors (TH), Cloquet (CQ), and Itasca (IT). These sites were partially harvested between 1994–1996 to create a range of overstory conditions. The residual overstories on the AK and TH sites were comprised of northern hardwoods and dominated by red oak (*Quercus rubra* L.) and sugar maple (*Acer saccharum* Marsh.) and sugar maple and paper birch (*Betula papyrifera* Marsh.), respectively. On the AK site, intermediate and suppressed trees and dominant and codominant trees with poor form were felled or girdled. Harvesting on the TH site removed all merchantable trees, with a preference to harvesting paper birch. Treatments in both stands resulted in a range of gap conditions distributed randomly across each site. The CQ site was occupied by a naturally regenerated red pine (*Pinus resinosa* Ait.) stand, while the IT site was a jack pine (*Pinus banksiana* Lamb.) plantation. The CQ stand was free-thinned in 1996, and additional red pine mortality created several larger canopy gaps. The IT jack pine stand was strip thinned with 6 m in the thinned strip and 12 m between strips. Average stand conditions are presented in Table 1. All sites were underplanted with bareroot 3-0 white pine (*Pinus strobus* L.) seedlings in the spring of 1996.

Field Measurements

The field sites were part of a larger study to investigate the growing conditions of white pine seedlings. One-hundred-eighteen square 36 m^2 plots were chosen for this analysis, with the AK, TH, CQ, and IT study sites contributing 38, 23, 33, and 24 plots, respectively. Plot layout within each stand was stratified to ensure coverage of the full range of overstory densities present in the stands, but within this constraint locations were determined randomly. Basal area (m^2/ha) was measured in each plot center using a 2 m^2/ha basal area factor (BAF) prism at the AK, IT, and CQ sites and a 1 m^2/ha BAF prism at the TH site. Light conditions were measured with a LI-COR® LAI-2000 Plant Canopy Analyzer during the summer of 1997 directly above the leader of 24 seedlings within each plot, utilizing 4 rows (either 1 or 2 m apart) and 6 seedlings (1 m apart) in each row. Only rows that had received either monthly or annually weed control (i.e., where no overtopping understory vegetation was present), were used, ensuring that the readings quantify only the overstory conditions. The Plant Canopy Analyzer calculates the amount of diffuse light penetrating the canopy and compares these readings with values from a simultaneous measurement in open conditions to calculate diffuse non-interceptance. It uses a lens containing five silicon ring detectors, each limiting a different angle (12.3°, 28.6°, 43.4°, 58.1°, and 74.1°) (LI-COR® Inc., 1992) (see Figure 1) and readings may be restricted to specific angles. We took readings using all angles and averaged the readings for each angle in each plot. Since all white pine seedlings were from the same seed source and nursery operation, we used 2-yr seedling height measurements from seedlings that received monthly weed control (and thus were not influenced by understory vegetation) to quantify seedling response to overstory conditions.

Data Analysis

To put the plot sizes in perspective, the average overstory tree heights and diameters (see Table 1) for each stand were used to calculate average "cone" plot sizes and basal area plot sizes. These equations were combined and solved to illustrate the relationship between "cone" and basal area plot sizes using the following formula:

$$\alpha = \tan^{-1}\left(\frac{0.5D}{H\sqrt{BAF}}\right)$$

Table 1. Average stand conditions of the four study sites. Unless labeled otherwise, standard errors in parentheses.

	Site			
	AK	CQ	IT	TH
Age	Uneven-aged	100	50	72
Diameter at breast height (cm)	33.0 (0.67)	38.4 (0.50)	22.4 (0.23)	22.9 (0.48)
Height (m)	17.1 (0.30)	23.1 (0.56)	20.7 (0.33)	17.1 (0.45)
Height/diameter ratio	52	60	92	75
Basal area (m^2/ha)	17.9 (1.4)	29.1 (2.6)	20.1 (1.8)	11.3 (1.1)
Major species (% of basal area)	Red oak (40%) Sugar maple (31%)	Red pine (97%)	Jack pine (93%)	Sugar maple (45%) Paper birch (29%)

where

H = average tree height

D = average tree diameter

BAF = basal area factor

α = cone angle

$\tan^{-1}$ = arctangent

[Derived from the formulas for: (1)"cone" plot size: $R = H * \tan(\alpha)$; and (2) basal area plot size: $R = 0.5\ D / \sqrt{(BAF)}$, where: R = plot radius.] To relate the two approaches, combinations of α and basal area factors that result in the same plot sizes were plotted for each site.

Linear correlations were made between plot averages of DIFN, using various α values and plot averages of 2-yr seedling height. All statistical analyses used SAS (SAS Institute Inc. 1999).

Results and Discussion

The relationships between plot sizes for "cone" and basal area plots at the four study sites (assuming average tree sizes as listed in Table 1) are presented in Figure 2. Since the size of the "cone" plots is determined by tree height and the size of the basal area plots by tree diameter, the differences between the relationships on the four sites are a function of the average height/diameter ratio of the overstory trees. For the extreme sites (AK and IT, with an average height/diameter ratio of 52 and 92, respectively), the difference in cone angle (α) that match a 2 m^2/ha BAF plot is 39%. For the study sites, α values of 37°, 37°, 32°, and 22° are appropriate angles that match "cone" and basal area plots for AK, TH, CQ, and IT, respectively (Note that a 1 m^2/ha BAF was used for TH). Consequently, basal area and DIFN measurements on the AK, TH, CQ, and IT sites did not match up as intended in the study layout. Instead the "cone" plots were 20, 20, 32, and 56% larger than the basal area plots used for AK, TH, CQ, and IT, respectively. This example points out that the tools used to measure percent overstory cover or residual overstory basal area (e.g., densitometers, prisms) are not generically interchangeable, and their choice will influence plot size and therefore the data collected (see below).

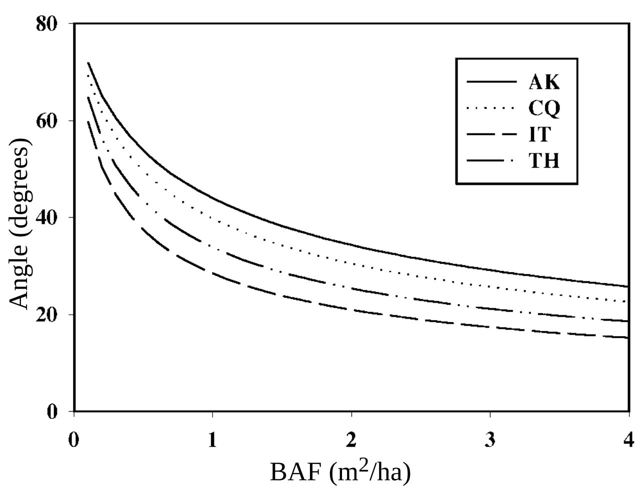

Figure 2. Relationship between basal area factors and α values for the different study sites. Lines represent *BAF*-α combination for which the plot sizes for the "cone" and basal area plots are equal, assuming average tree sizes. *BAF*-α combinations above or below the lines represent conditions where the size of the "cone" plot is larger or smaller, respectively, than the size of the basal area plot.

Figure 3 points out how predicted DIFN values differ for the four sites when different cone openings (α) were used. As expected, for all sites the ranges of DIFN values increased as the cone opening decreased (Table 2). Larger cone openings lead to plot sizes that could not differentiate as well between individual gaps and areas with a denser overstory, but averaged conditions over a larger area. Also, the results pointed out that a bias due to selection of plot sizes is larger in areas with more open stand conditions. Figure 3 also indicated that the choice of α must be considered when using the LAI-2000 Plant Canopy Analyzer for estimation of available light. Past studies used α values of 58.1° (listed as 60° in Machado and Reich 1999) and 74.1° (Gendron et al. 1998) to develop relationships between DIFN and available light. Using light estimates from improper cone openings (smaller or larger than zone of influence) may result in biased relationships between light availability and seedling growth responses.

As an indication of the implication of choosing "cone" plot sizes (α) to assess competitive conditions, linear correlations between DIFN and 2 yr seedling heights are presented in Table 3. The measurements using an α value of 58.1° had the highest correlations on the CQ and TH sites, whereas measurements made with an α value of 28.6° had the highest correlations for the AK and IT sites. There seems to be no obvious stand characteristic (e.g., conifer vs. hardwoods, average tree height, height/diameter ratio, stand age, or spatial patterns of openings) that would explain these results, pointing out the difficulty in drawing generalities regarding appropriate α value and overstory characteristics. The inconsistencies between sites illustrate that selection of an inappropriate α value can lead to overestimation or underestimation of the importance of competitive conditions (sensu Welden and Slauson 1986) for seedlings and points out the need for further studies.

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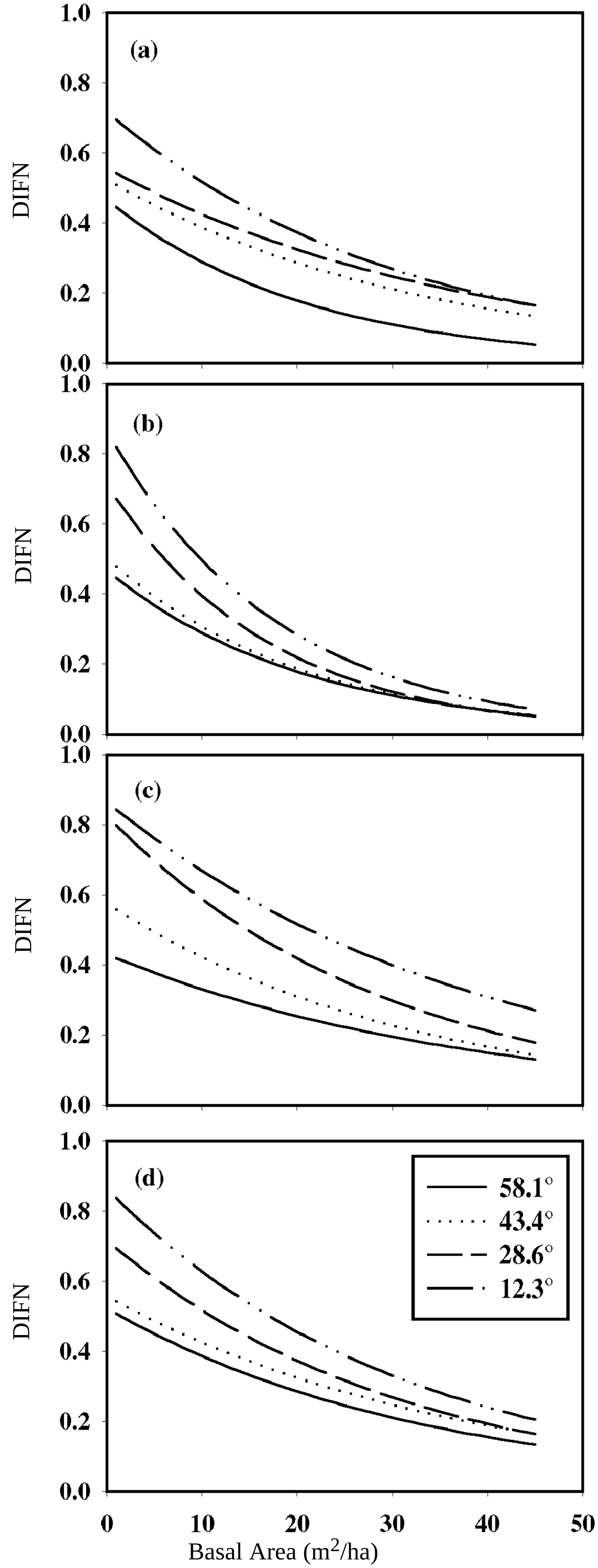

Figure 3. Predicted diffuse noninterceptance (DIFN) (see equation in text and parameter estimates in Table 2) at the(a) AK, (b) TH, (c) CQ, and (d) IT sites for various α values and residual basal areas.

Table 2. Parameter estimates (standard errors in parentheses) for equations predicting DIFN as a function of overstory basal area for different cone openings, i.e., α values. Regression equation: $DIFN = ae^{-b(basal\ area)}$. Sample sizes: AK = 38, CQ = 20, IT = 33, and TH = 33. All equations were significant at $P < 0.001$.

Site	α	*a*	*b*	r^2
AK	58.1°	0.4683 (0.062)	0.0482 (0.0095)	0.53
	43.4°	0.5026 (0.075)	0.0495 (0.011)	0.44
	28.6°	0.7136 (0.10)	0.0591 (0.011)	0.50
	12.3°	0.8652 (0.14)	0.0557 (0.013)	0.61
TH	58.1°	0.9378(0.18)	0.1155 (0.023)	0.38
	43.4°	1.2339 (0.23)	0.1287 (0.024)	0.31
	28.6°	1.4342 (0.31)	0.1347 (0.027)	0.33
	12.3°	1.4254 (0.38)	0.1215 (0.033)	0.49
CQ	58.1°	0.4310 (0.073)	0.0264 (0.0069)	0.53
	43.4°	0.5760 (0.10)	0.0310 (0.0076)	0.50
	28.6°	0.8261 (0.14)	0.0340 (0.0074)	0.43
	12.3°	0.8657 (0.15)	0.0258 (0.0068)	0.53
IT	58.1°	0.5239 (0.045)	0.0303 (0.0051)	0.47
	43.4°	0.5575 (0.054)	0.0271 (0.0057)	0.48
	28.6°	0.7184 (0.048)	0.0328 (0.0041)	0.31
	12.3°	0.8646 (0.068)	0.0320 (0.0048)	0.40

Table 3. Pearson's correlation coefficients between white pine seedling height two years after planting and diffuse noninterceptance (DIFN) detected by plant canopy analyzer using various cone openings, i.e., α values. All coefficients are significant at $P < 0.01$.

	α			
Site	58.1°	43.4°	28.6°	12.3°
AK	0.2020	0.2087	0.2320	0.1052
TH	0.6266	0.6154	0.6028	0.5596
CQ	0.7508	0.7107	0.7149	0.7108
IT	0.3755	0.3576	0.4860	0.4583

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