Practical Field Methods of Estimating Canopy Cover, PAR, and LAI in Michigan Oak and Pine Stands

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ABSTRACT: *With the increased use of variables such as canopy cover, photosynthetically active radiation (PAR) and overstory leaf area index (LAI) in forestry research, relationships between these variables and traditional forestry variables must be defined before recommended levels of these research variables can be achieved by forestry practitioners on the ground. We measured basal area, canopy cover, Ozalid percent full light, PAR, and overstory LAI in thinned and unthinned plots within oak and pine stands with the objectives of: (1) determining the relationships between these variables in two common forest types, (2) investigating the feasibility of using basal area to estimate and achieve recommended levels of canopy cover, PAR, and LAI in the field, and (3) examining the possibility of using direct canopy cover and Ozalid light measurements for estimating PAR and LAI. Very strong relationships ($r^2 > 0.90$ and $P < 0.0001$) were indicated between basal area and canopy cover, PAR, and LAI. Direct canopy cover and Ozalid light measurements were also strongly related to PAR and LAI. It is likely that the even-aged structure of the stands studied contributed to these results. The strength of the relationships between the measures examined suggest that practical variables such as basal area could potentially be used by forestry practitioners to estimate and achieve recommended levels of canopy cover, PAR, and LAI in similar oak and pine stands. The possibility also exists for strong relationships between these variables in other stand types that resemble those studied in terms of overstory structure. North. J. Appl. For. 16(1):25–32.*

Multidisciplinary approaches to difficult forest management problems have increased over the past decade. Work on the oak regeneration problem, for example, has included studies involving genetics, physiology, microclimate, and ecology as well as silviculture. Ecological and physiological studies routinely involve variables such as canopy cover, overstory leaf area index (LAI), and photosynthetically active radiation (PAR) that are critical to understanding the performance of tree species and effects of competition.

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Suppose an extensive, long-term research project results in a recommendation of PAR levels near 1000 μmol s^{-1} m^{-2} and an overstory LAI value of approximately 1 m^2/m^2 for successfully regenerating a particular tree species. Two questions would arise immediately in the mind of the forestry practitioner interested in applying these recommendations: How do I go about marking trees to produce these conditions, and how can I be sure that I have achieved the recommended levels of PAR and LAI after the treatment has been applied?

Excellent instruments are available that measure these research variables directly. Unfortunately, the cost of many of these instruments prohibits their widespread use by forestry practitioners, and most must be used under fairly narrow sets of conditions in the field (e.g., dry weather, certain sky conditions, or particular time periods during the day). Even if everyday use of these instruments by forestry practitioners were feasible, it would still be necessary to relate LAI and PAR to traditional forestry variables such as basal area or stem density in order to set up and apply treatments with the aim of achieving recommended conditions. Thus, there is a need for examining and defining the relationships between variables used in physiological and ecological research and variables that are easier and more practical to measure in various forest types.

We measured basal area, canopy cover, overstory LAI, and light in thinned and unthinned plots in natural, second-growth oak stands and red pine (*Pinus resinosa* Ait.) plantations on moderately productive sites in northern Lower Michigan. These stand types and similar second-growth oak and pine types are well represented in the northern Lake States and other regions of the eastern United States (Braun 1950, Stone 1958). Objectives were to: (1) determine the relationships between these variables in two common forest types, (2) investigate the feasibility of using basal area to estimate and achieve recommended levels of canopy cover, PAR and LAI in the field, and (3) examine the possibility of using direct canopy cover and Ozalid light measurements for estimating PAR and LAI.

Methods

Second-growth natural oak stands and unthinned red pine plantations were studied on two sites in southern Crawford County, Michigan (84°45'W, 44°31'N, elevation 400 m) and on one site in southern Roscommon County, Michigan (84°41'W, 44°14'N, elevation 300 m). All stands closely resembled Ecological Landtype Phase (ELTP) 21 of the Ecological Classification and Inventory System of the Huron-Manistee National Forests (USDA Forest Service 1993). Soils were sandy, mixed, frigid, Alfic Haplorthods developed in pitted outwash (Kim et al. 1996) with slopes less than or equal to 5%.

Oak stands were dominated by northern red oak (*Quercus rubra* L.), with smaller amounts of white oak (*Quercus alba* L.), eastern white pine (*Pinus strobus* L.), red maple (*Acer rubrum* L.), and red pine. Red pine plantations contained occasional white oak, jack pine (*Pinus banksiana* Lamb.), northern red oak, trembling aspen (*Populus tremuloides* Michx.), and red maple. Canopy heights of oak and pine stands were approximately 24 m and 21 m, respectively. Oak stands were 88–100 yr old and pine plantations were 59–75 yr old.

Major components of the understory herb layer (approximately 0–0.25 m above ground) were grasses, sedges, blueberry (*Vaccinium angustifolium* Ait. and *Vaccinium myrtilloides* Michx.), and red maple seedlings. Important components of the shrub layer (approximately 0.25 m above ground to stems 0.0254 m in diameter at breast height (dbh)) were bracken fern (*Pteridium aquilinum* [L.] Kuhn) and red maple saplings. Small quantities of witch hazel (*Hamamelis virginiana* L.), beaked hazel (*Corylus cornuta* Marsh.), black cherry (*Prunus serotina* Ehrh.) saplings and trembling aspen saplings also occurred in the shrub layer. Hardwood stump sprouts were present in the thinned and clearcut plots, particularly in the oak stands.

Four overstory treatments were randomly assigned to 66 × 66 m (0.44 ha) plots within three similar stands of each type: clearcut, 25% canopy cover, 75% canopy cover, and uncut (control) (Figure 1). Four understory treatments were randomly assigned to 15 × 15 m (0.02 ha) plots within each canopy cover treatment: shrub layer removal (herbs, shrubs, saplings > 0.25 m tall up to stems of saplings 0.0254 m dbh), herb layer removal (herbs, shrubs, tree seedlings < 0.25 m tall), litter removal down to the humus layer, and a control (Figure 1).

Plots with partial canopy cover were thinned from below (Smith 1986). Subcanopy stems > 0.0254 m dbh were marked to be cut first, followed by additional canopy trees if necessary. Plots were marked to achieve 25% or 75% canopy cover using visual estimation, a 10-factor prism, and rough approximations of appropriate basal areas from curves relating basal area to canopy cover published for northern hardwoods (Godman and Tubbs 1973). All stems over 0.0254 m dbh were removed in clearcuts.

Following treatment, basal area and canopy cover were measured at the center of each understory plot. Basal area was measured with a 10-factor prism, and percent canopy cover was measured with a concave spherical densiometer (Lemmon Forest Densiometers, Bartlesville, OK). Densiometer counts were taken in the four cardinal directions and averaged.

Overstory LAI was measured with two calibrated Li-Cor LAI-2000 plant canopy analyzers (Li-Cor Inc., Lincoln, NE). One plant canopy analyzer was used to measure LAI in each of the 25% cover, 75% cover, and uncut overstory plots, while the other was mounted on a tripod in the nearest clearcut to obtain synchronous reference measurements of open sky. Instantaneous PAR (μmol s^{-1} m^{-2}) was measured within each understory plot at 0.15 and 1 m above the ground with a model SF-80 Sunfleck Ceptometer (Decagon Devices Inc., Pullman, WA). To allow calculation of percent transmitted PAR (TPAR), synchronous measurements of PAR were obtained in the center of clearcuts with Li-Cor LI-190 quantum sensors mounted on stakes 1 m above the ground. All measurements were obtained between 12:00 and 2:00 p.m., Eastern Daylight Savings Time. PAR measurements were obtained at seven sampling points within each understory plot using methods adapted from the standard protocol used by the USDA Forest Service and U.S. Environmental Protection Agency's Forest Health Monitoring Program (Isebrands and Steele 1993). Measurements collected at each of the seven sampling points were averaged to provide a mean TPAR value for each understory plot.

Percent full light was measured with packets of light-sensitive Ozalid paper. Packets were constructed with slight modifications to the method described by Friend (1961) and protected by plastic petri dishes. Three packets were placed 5 m apart along a 0–180° azimuth bisecting each understory plot. An additional packet was placed on a 2 m stake in the center of each clearcut as a reference. Packets were exposed between 9:20 a.m. and 7:10 p.m. EDST on a clear day. After exposure, packets were developed with ammonium hydroxide vapor, and the number of layers exposed by sunlight were counted. Percent full sun was calculated by dividing the number of layers exposed within understory plots by the number of layers exposed in packets placed in clearcuts.

Basal area, canopy cover, TPAR, and Ozalid light data measured within 15 × 15 m understory plots were averaged over sample points and understory plots to obtain means for

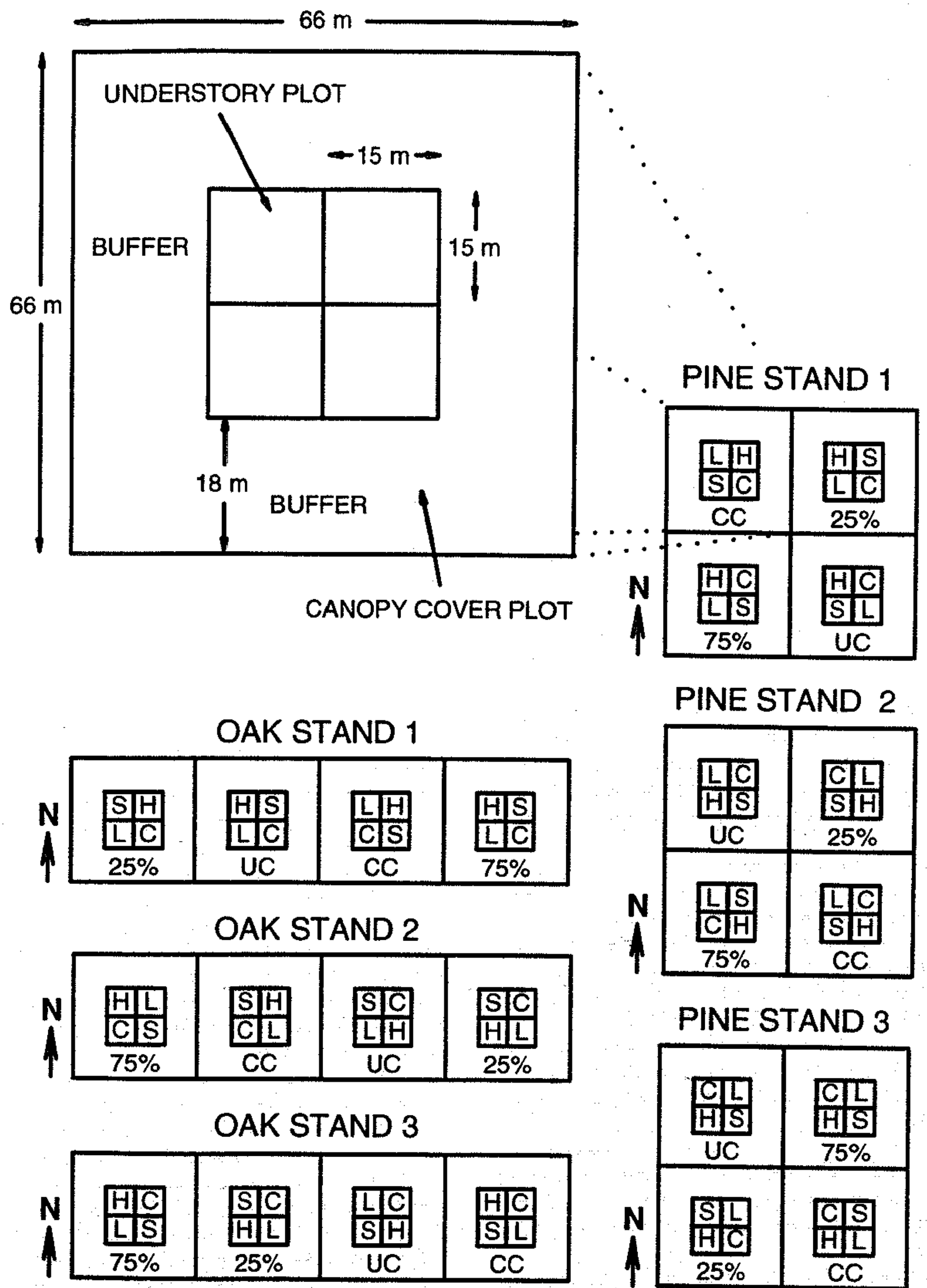

Figure 1. Canopy cover and understory treatment plots (to scale) within similar oak and pine stands. True spatial relationships between stands have been altered for the purpose of efficient presentation. For canopy cover treatments, CC = clearcut, 25% = 25% cover, 75% = 75% cover, UC = uncut. For understory treatments, C = control, L = litter removal, H = herb removal, S = shrub removal.

each 66 × 66 m overstory plot. These means and single LAI values for each overstory plot were analyzed with linear regression (Neter et al. 1989) to examine relationships among variables. Separate regression analyses were run for oak and pine stands. The adequacy of each regression model was checked through inspection of scatter, residual, and normal probability plots. Log_{10} and power transformations were used when necessary to improve linearity, homogeneity of variances, and normality.

Results

Relationships among basal area, canopy cover, TPAR, Ozalid light, and LAI were all very strong. All analyses had coefficients of determination (r^2) > 0.90 and $P < 0.0001$. The best linear relationship between basal area and canopy cover was achieved by taking the square root of basal area. The relationship between the square root of basal area and canopy cover was somewhat stronger in the pine stands than in the oak stands (Figure 2a, b). A greater amount of basal area was associated with a given level of canopy cover in the pine stands than in the oak stands (Figures 2a, b).

The strength of the relationship between the square root of basal area and TPAR at 1 m above the ground was roughly equivalent between the oak and pine stands (Figures 2c, d). Percent transmitted PAR at 1 m diminished less rapidly with increasing basal area in the pine stands than in the oak stands (Figures 2c, d).

The square root of basal area had the strongest relationship to TPAR at 0.15 m above the ground in both stand types. The relationship was stronger in the pine than in the oak stands (Figures 2e, f). Values of TPAR at 0.15 m were greater at a given basal area in the pine stands than in the oak stands (Figures 2e, f).

No transformations were required to linearize the relationship between basal area and Ozalid light at 0 m above the ground. The relationship was stronger in the oak stands than in the pine stands (Figures 2g, h). Overall, Ozalid values dropped more gradually with increasing basal area than TPAR values (Figures 2c–h), and Ozalid values were lower in oak stands than pine stands (Figures 2g, h).

Similarly, no transformations were needed to linearize the relationship between basal area and LAI. This relationship was strong in the oak stands and exceptionally strong in the pine stands (Figures 2i, j).

Percent transmitted PAR at 1 m above the ground was strongly related to canopy cover in both stand types (Figures 3a, b). No transformations were necessary to linearize this relationship or the relationship between canopy cover and TPAR at 0.15 m.

The relationship between canopy cover and TPAR at 0.15 m above the ground was stronger in the pine stands than in the oak stands (Figures 3c, d). The departure from linearity for TPAR at 0.15 m was greater in clearcuts than in the other overstory treatments in the oak stands (Figure 3c).

The best linear relationship between canopy cover and Ozalid light at 0 m above the ground was obtained by squaring canopy cover prior to analysis. The strength of the relationship between canopy cover squared and Ozalid light was nearly equivalent between the oak and pine stands (Figures 3e, f). Overall, Ozalid light diminished far less than TPAR with increases in canopy cover (Figures 3a–f).

Using the square root of LAI provided the best linear relationship between canopy cover and LAI. The relationship between canopy cover and the square root of LAI was exceptionally strong in the pine stands and somewhat weaker in the oak stands (Figures 3g, h).

Following $\log_{10}$ transformations of both independent and dependent variables, relationships between $\log_{10}$ Ozalid light at 0 m and $\log_{10}$ TPAR at 1 m and 0.15 m were quite strong in both stand types (Figures 4a–d). The strength of the relationship between $\log_{10}$ Ozalid light at 0 m and TPAR at 1 m was roughly equivalent across stand types (Figures 4a, b). The relationship between $\log_{10}$ Ozalid light and $\log_{10}$ TPAR at 0.15 m was somewhat weaker in the oak than in the pine stands (Figures 4c, d).

No transformations were necessary in the analysis of the relationship between Ozalid light at 0 m and LAI. This relationship was stronger in the oak stands than in the pine stands (Figures 4e, f).

Discussion

Due to the relationship between the stems of canopy trees and canopy foliage, and the relationship between canopy foliage and light levels beneath the canopy, it is clear that basal area, canopy cover, overstory LAI, and measures of light should all be related. How the nature and strength of relationships between these variables might change between stands differing in age, composition, and structure is less clear. Significant changes in the strength and nature of relationships between variables may occur due to differences within and between tree species in overall form, crown architecture, and developmental stage. In northern hardwood stands, for example, the relationship between canopy cover and basal area has been shown to vary substantially, depending on species and diameter (Godman and Tubbs 1973). In the oak and pine stands we measured, it is likely that innate differences in crown characteristics between red pine and oak were partially responsible for the differences between stand types in the regression equations describing relationships between a given pair of variables (Figures 2–4). One obvious difference was the greater crown diameter of the oaks. More basal area was associated with a particular level of canopy cover in the pine stands than in the oak stands (Figures 2a, b).

The best explanation for the strong relationships between the variables measured is the even-aged structure of the oak and pine stands studied. The vertical structure of the second-growth oak stands was less complex than stand types (e.g., uneven-aged or old-growth northern hardwoods) which typically contain stems of several ages and sizes. The presence of old, partially burned pine stumps and the history of these counties (Whitney 1986) indicate that most of the oaks in the oak stands became established just after logging and burning at the turn of the century. The lack of species such as sugar maple (*Acer saccharum* Marsh.) and beech (*Fagus grandifolia* Ehrh.) that typically form multiple canopy layers also contributed to the

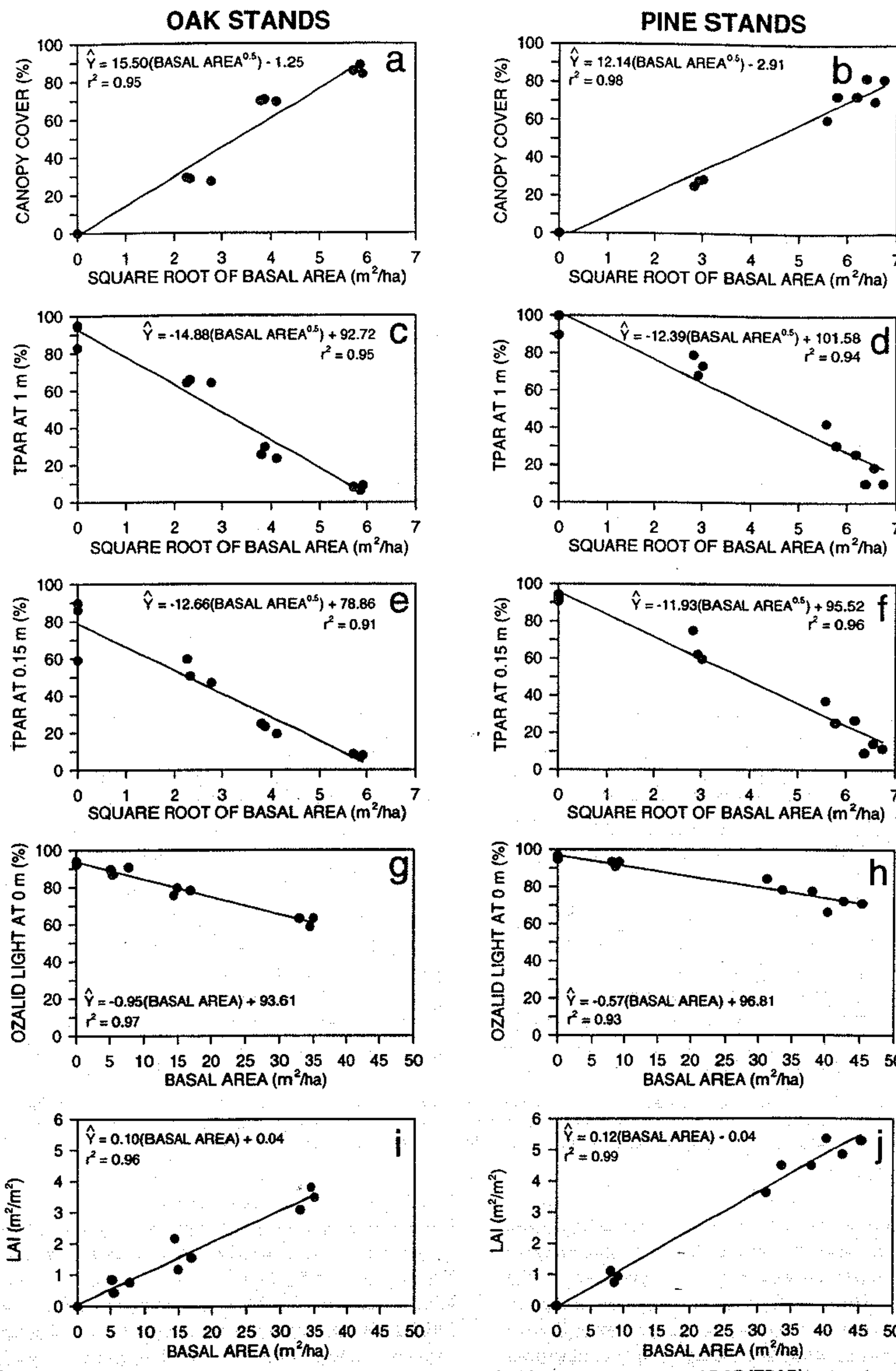

Figure 2. Relationships between basal area and canopy cover (a, b), percent transmitted PAR (TPAR) at 1 m (c, d), TPAR at 0.15 m (e, f), Ozalid light at 0 m (g, h), and overstory LAI (i, j) for oak and pine stands, respectively. Included are regression lines, regression equations, and coefficients of determination (r^2). For all regressions, $P < 0.0001$.

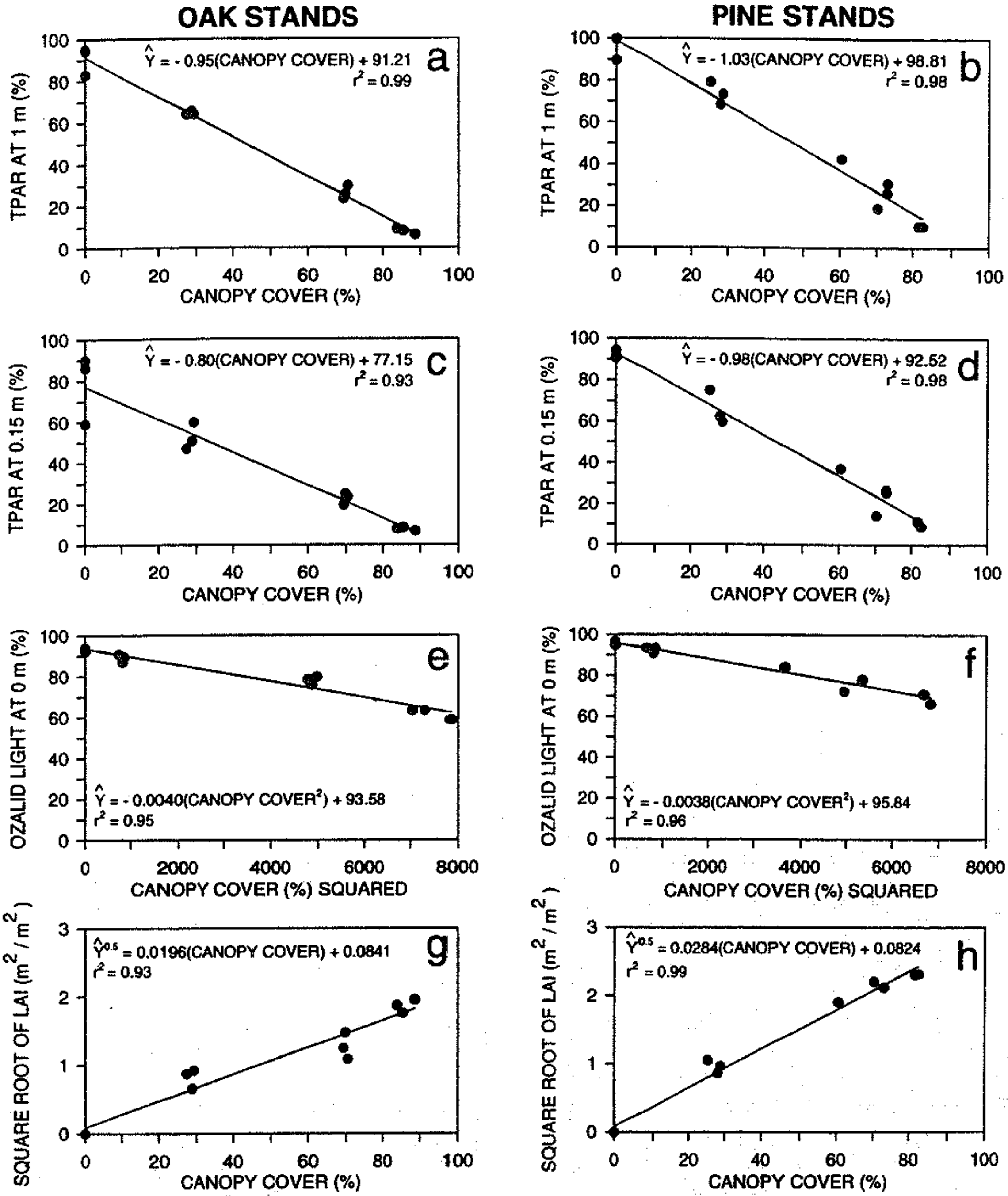

Figure 3. Relationships between densiometer canopy cover and TPAR at 1 m (a, b), TPAR at 0.15 m (c, d), Ozalid light at 0 m (e, f), and overstory LAI (g, h) for oak and pine stands, respectively. Included are regression lines, regression equations, and coefficients of determination (r^2). For all regressions, $P < 0.0001$.

uniform structure of the oak stands. Apparently, these species were excluded by the moderate productivity of these sites. The uniformity of the pine stands is clearly the result of their origin as plantations. Very few stems of other species were able to outcompete the red pines planted on 1.8 m centers. Thinning from below contributed further to structural uniformity in the thinned plots. Although the stands studied were much more uniform than certain stand types (e.g., uneven-aged and old-growth northern hardwoods), similar thinned and unthinned second-growth oak stands and pine plantations are abundant in the northern Lake States due to the history of turn-of-the-century logging and subsequent reforestation shared by Minnesota, Wisconsin, and Michigan.

Comparison of TPAR measurements at 0.15 and 1 m indicate that understory vegetation influenced light levels on the forest floor. The effect of red maple saplings, bracken fern, and blueberry on light levels is illustrated by the slightly lower values for TPAR at 0.15 m than at 1 m (Figures 2c–f, 3a–d). Effects of understory vegetation on TPAR were strongest in the clearcut and 25% cover plots, where the response of understory vegetation to overstory treatment was greatest.

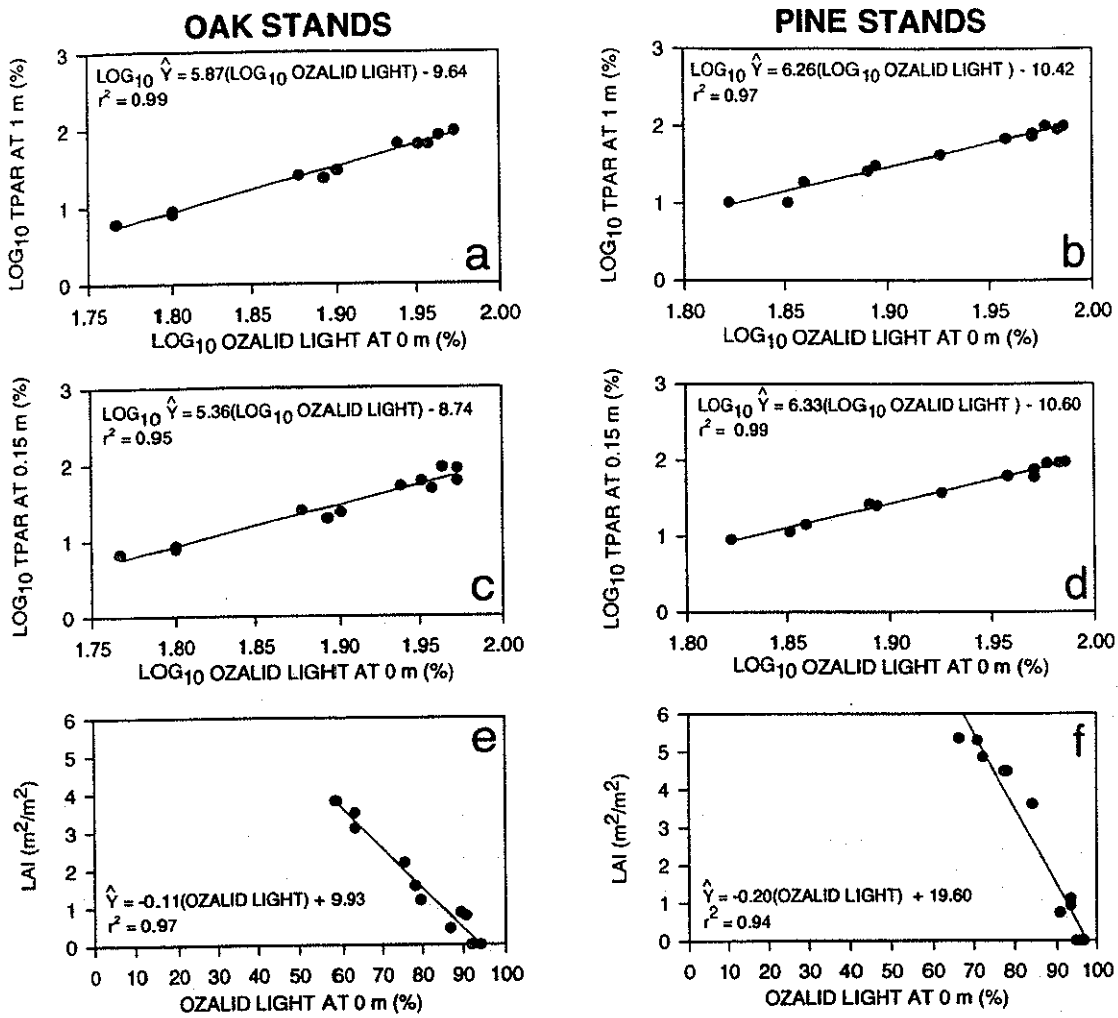

Figure 4. Relationships between percent full light measured with Ozalid paper at 0 m and TPAR at 1 m (a, b), TPAR at 0.15 m (c, d), and overstory LAI (e, f) for oak and pine stands, respectively. Included are regression lines, regression equations, and coefficients of determination (r^2). For all regressions, $P < 0.0001$.

The greater abundance of red maple saplings and stump sprouts in the oak stands than in the pine stands was probably responsible for the slightly lower levels and greater variability of TPAR at 0.15 m in the oak stands (Figures 2e, f, 3c, d). Although overstory effects were stronger, the influence of understory vegetation on light could be important for small seedlings, even in clearcuts.

Conclusions

The strength of the relationships between the measures examined suggest that prism estimates of basal area, Ozalid light values, and densiometer estimates of canopy cover could potentially be used by forestry practitioners to estimate and achieve recommended levels of PAR and LAI in the field. It also appears that levels of canopy cover could be estimated and created in the field using prism basal area measurements, although the possibility of variability in the relationship between canopy cover and basal area should be considered (Godman and Tubbs 1973).

Of the measures evaluated in this study, basal area measurements are the most efficient to obtain, most applicable to the setup of silvicultural treatments, and the most likely to be used by forestry practitioners. Ozalid papers and densiometers would be useful, however, in stand types where relationships between basal area and light or basal area and canopy cover are poor, or when more direct estimates of light levels and canopy cover are desired. Measurements with both Ozalid paper and spherical densiometers have been criticized for various shortcomings (Bardon et al. 1995, Bunnell and Vales 1990, Cook et al. 1995), and instruments such as the Sunfleck Ceptometer and Plant Canopy Analyzer measure over much greater areas of the overstory or understory. Despite these drawbacks, our results suggest that very strong relationships between Ozalid paper or densiometer measurements and those obtained with electronic instruments can exist, and that these methods can be viable alternatives when the use of electronic instruments is not feasible.

Thinning of the extensive pine plantations in Michigan (Stone 1958) and elsewhere in the northern Lake States is a common, ongoing practice, and shelterwoods have been recommended as a means for increasing regeneration success of oak species (e.g., Gottschalk and Marquis 1983, Johnson et al. 1986, Buckley et al. 1998). Provided that composition, overstory structure, and site productivity compare with the stands studied, the regression equations presented in Figures 2–4 could be used as a guide in setting up silvicultural treatments to achieve particular levels of canopy cover, TPAR, or LAI in similar oak and pine stands, and in estimating these variables following treatment. Due to the greater uniformity of red pine and plantations, it is likely that the equations presented for the red pine plantations are applicable to a broader range of geographic locations and habitat types than the equations for the oak stands.

Clearly, the regression equations developed from our data would not be appropriate for stands that differ substantially from those studied in terms of composition or structure. Different regression equations would be required for different stand types. The potential exists for similar strong relationships in other second-growth stand types, and determination of the relationships among these variables in various cover types would be useful. In addition, incorporating forestry variables such as basal area into ecological and physiological research and placing emphasis on expressing recommendations in terms of variables that can be measured easily in the field will expedite the application of research results on the ground.

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