LIGHT, CANOPY CLOSURE, AND OVERSTORY RETENTION IN UPLAND OZARK FORESTS

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Abstract—Foresters, wildlife biologists, and naturalists manipulate forest composition and structure for numerous reasons including forest regeneration, timber production, wildlife habitat, conservation of native biodiversity, and ecosystem restoration. Light conditions in the understory of forests and woodlands are often key in meeting the management objectives. In this study, predictive models were developed relating mean diurnal understory photosynthetically active radiation (PAR) (400 to 700 nm) as percentages of above canopy (understory PAR) to measures of canopy closure, stocking, basal area, and density. Relationships between percent crown closure and density in Missouri's upland oak (*Quercus* spp.) and oak-pine (*Pinus* spp.) stands are not well defined, nor are the relationships between each measure and light conditions near the forest floor. Our objectives for this paper were: (1) to analyze the relationships between understory PAR and stand metrics and (2) to analyze the relationships between canopy closure and stand metrics. Understory PAR may be predicted by models utilizing stocking, basal area, or stand density, but understory PAR was primarily controlled by canopy closure. Canopy closure was related to stocking and density.

INTRODUCTION

One of the primary reasons to alter stand density and structure is to increase the amount of light that reaches the understory (Blizzard and others 2007, Larsen and others 1999, Minckler and others 1973). Although foresters are interested in altering the amount of light in stands, they seldom measure light levels during routine forest inventories. Instead, they collect information that can be used to quantify stand density including the number of trees per unit area, quadratic mean diameter, basal area, stocking, and less commonly, canopy closure. Therefore, many studies utilize stand metrics to predict seedling and sprout growth and recruitment (Dey and others 2008, Jensen and Kabrick 2008, Larsen and others 1997).

Light is rarely measured by foresters, but physiological studies develop growth guidelines based upon photosynthetically active radiation (PAR) (Johnson and others 2002, Pallardy and Kozlowski 2007). Models relating the percent of above canopy PAR that reaches the understory would bridge between stand metrics and physiology studies. With understory PAR—stand metrics models, foresters would be able to predict understory PAR based upon the level of overstory retention.

We conducted this study to examine the relationships between light, canopy closure, and stand density in oak-pine (*Quercus* spp.-*Pinus* spp.) stands having a range of residual stocking levels in the Ozark Highlands of southeastern Missouri. Our objectives for this paper were: (1) to analyze the relationships between understory PAR, canopy closure, and stand metrics, and (2) to analyze the relationships between canopy closure and stand metrics. We hypothesized that these measures of stand density may be used individually to estimate (1) understory diurnal PAR as a percentage of above canopy PAR and (2) canopy closure under mature oak-pine canopies following clearcut, seed tree, light shelterwood, or heavy shelterwood treatments.

METHODS

The study was conducted on the Sinkin Experimental Forest located on the Salem Ranger District of the Mark Twain National Forest. The Sinkin Experimental Forest is located in the Current River Oak-Pine Woodland/Forest Hills landtype association in the Ozark Highlands (Nigh and Schroeder 2002). Overstory species included white oak (*Q. alba* L.), post oak (*Q. stellata* Wangenh.), black oak (*Q. velutina* Lam.), scarlet oak (*Q. coccinea* Münchh.), shortleaf pine (*P. echinata* Mill.), mockernut hickory [*Carya tomentosa* (Lam.) Nutt.], and black hickory (*C. texana* Buckley). Midstory and understory species included blackgum (*Nyssa sylvatica* Marsh.), persimmon (*Diospyros virginiana* L.), and dogwood (*Cornus florida* L.). Soils were mapped as Coulstone-Clarksville, 3 to 35 percent slope (loamy-skeletal, siliceous, semiactive, mesic Typic Paleudults) and Nixa (loamy-skeletal, siliceous, active, mesic Glossic Fragiudults)-Clarksville, 1 to 3 percent slope. Plots were located on broad ridges and upper backslopes in parent materials derived from dolomite of the Gasconade Formation.

The study was designed to simulate clearcut, seed tree, light shelterwood, and heavy shelterwood cuttings. Forty-eight 1-acre experimental units were thinned (12 each of 0, 20, 40, and 60 percent stocking) and residual stocking was checked randomly within each plot using a 10 basal area factor prism. Thinning occurred in 2005 to 2007. The ranges of acceptable basal areas were <10, 20 to 30, 50 to 60, and 60 to 80 square feet per acre, respectively. Oak and shortleaf pine stocking levels were calculated individually and summed to determine total stocking (Gin[g]rich 1967, Rogers 1983). Preferred residual trees were well spaced, with ≥11 inches diameter at breast height (d.b.h.) and healthy crowns. Some 6- to 10-inch

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d.b.h. trees were retained to meet stocking objectives. Order of preference for retention was: (1) shortleaf pine and white oak, (2) post oak, (3) scarlet oak, and (4) black oak. The midstory and understory were cut near the ground using chainsaws leaving a few dogwoods.

In the center of each 1-acre experimental unit, we established a circular 0.2-acre plot for collecting stand density, canopy closure, and PAR data. We sampled the quantity of PAR (400 to 700 nm) using one Onset S-LAI-M003 PAR in the center of each plot for over 48 hours (Onset Computer Corp., Bourne, MA). We also placed a sensor in a field to record above canopy PAR. The sensors were connected to Onset HOBO® H21-002 Micro Station dataloggers set to record microE per second for 1 second every 60 seconds and to average every hour. Hourly estimates were summed for each day and understory PAR was calculated as a percentage of above canopy PAR. Only the day with the highest readings was used for each group of 16 plots: group 3—June 22, group 1—August 5, group 2—August 15, 2008. Each group contained a mixture of stocking levels, but the plots were analyzed as completely randomized.

Canopy closure readings were taken by the same observer on all plots with a convex spherical densiometer model A (Robert E. Lemmon, Forest Densiometers, Bartlesville, OK) (Lemmon 1956). The recorded reading was the average of four readings taken facing the cardinal directions, with the spherical densiometer at plot center. Hemispherical color canopy photographs were taken above the center stake on cloudy days using a Canon EOS Rebel® 35 mm film body and a Sigma® 8mm F3.5 EX DG circular fisheye lens set on infinite focus. A polarizing gel was placed behind the lens running northsouth (top to bottom) in the space provided by the manufacturer. The camera was placed over plot center, leveled on a tripod with the top of the camera pointed north, and with the top of the lens at 39 inches from the ground. The film was developed and photographs were digitized from film. Projection calibration data were faxed from Sigma® and entered into the Gap Light Analyzer software (GLA) (Frazer and others 1997, 1999). The geographic coordinates and corresponding date that the light was measured on were entered into the GLA for each plot. Canopy closure was calculated in the GLA for each plot and then compared as a percentage of the values calculated for photograph taken in the open field to account for the ring of trees seen in the photographs of the clearcuts and the open field.

Linear and nonlinear models, for estimating understory PAR as a percentage of above canopy PAR and for estimating canopy closure measured by a spherical densiometer, were compared by predictor variables. Nonlinear models were selected that best fit the general relationship of the independent-dependent relationships. Logic tests were then applied. For instance, quadratic models were disqualified because they indicated an increase in understory light or a decrease in canopy closure in dense stands. The remaining model forms were tested for each independent-dependent variable relationship. Regression was performed using PROC MIXED and PROC NLMIXED (SAS 9.1, SAS Institute Inc., Cary, NC). *F*-values were used to test for model significance. Akaike's information criterion (AIC) was used to select between models that fit the general relationship of the dependent-independent relationships (Burnham and Anderson 2003). AIC was also used to select between linear and nonlinear models for each predictor rather than R-squared.

RESULTS

Percent of Above Canopy Diurnal Photosynthetically Active Radiation in the Understory

Percent of above canopy diurnal PAR measured in the understory of oak and oak-pine clearcut, seed tree, and light and heavy shelterwood stands was better predicted by spherical densiometer canopy closure based upon the lower AIC value (table 1). Understory PAR was inversely proportional to both measures of canopy closure (figs. 1A and 1B). The rate of change remained steady as canopy closure increased, rather than leveling off or declining at an increasing rate. In contrast, the percentage of above canopy diurnal PAR that reached the understory rapidly declined then leveled off as overstory retention increased based upon stocking, basal area, or density (figs. 2A, 2B, and 2C).

Table 1—Models relating percent of above canopy photosynthetically active radiation in understory to canopy closure and stand metrics

Models		*F*-value	AIC[a]	R^2
X = Canopy closure (spherical densiometer, %)	95.4407 – 0.8189 X	450.86[b]	345.3	0.91
X = Canopy closure (photograph, %)	106.2700 – 1.1713 X	202.28	376.4	0.81
X = Stocking (%)	71.2541 exp (–0.03362 X) + 22.4371	144.32	364.9	0.87
X = Basal area (square feet per acre)	68.2547 exp (–0.02839 X) + 25.2099	124.23	371.0	0.85
X = Density (trees per acre)	65.9156 exp (–0.03174 X) + 27.6884	147.87	363.9	0.86

[a] AIC = lowest Akaike's information criterion value was used to determine if the linear or exponential model was the better fit given the model complexity.

[b] *F*-values for all models were significant ($P < 0.00001$).

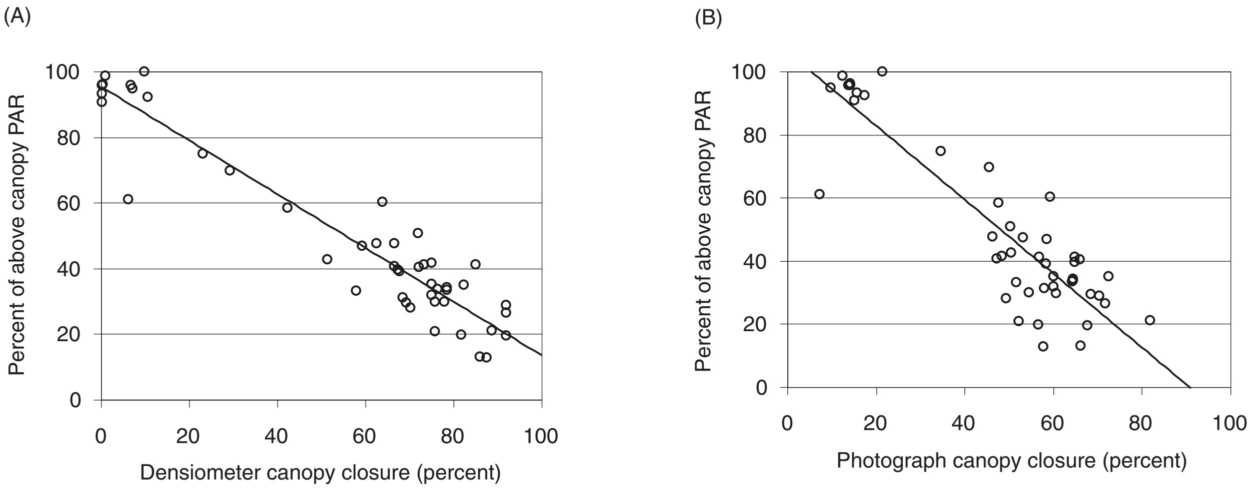

Figure 1—Percent of above canopy diurnal photosynthetically active radiation (PAR) (400 to 700 nm) that reach the understory by: (A) spherical densiometer canopy closure and (B) calibrated hemispherical photograph canopy closure. The percent of PAR that reached the understory was inversely related to canopy closure.

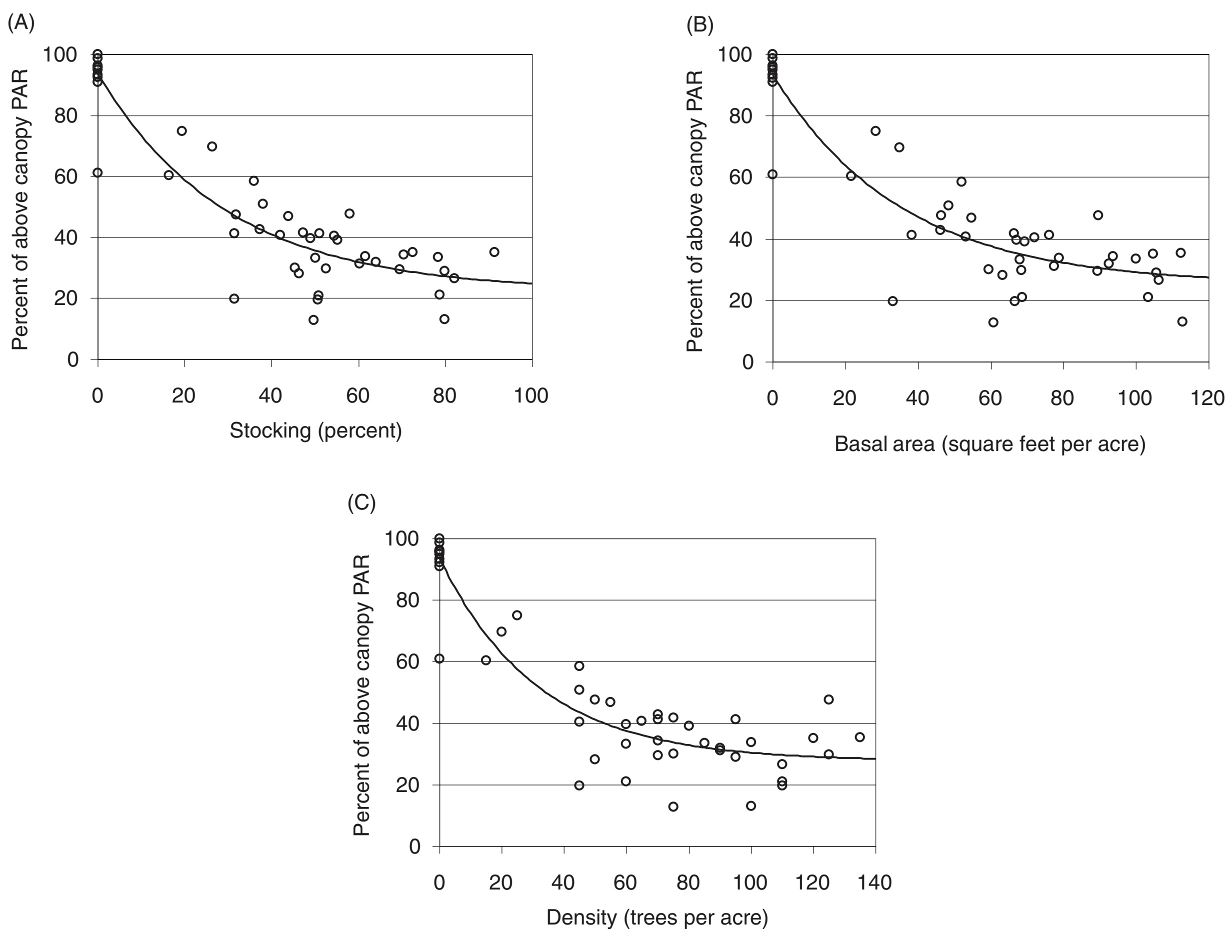

Figure 2—Percent of above canopy diurnal photosynthetically active radiation (PAR) (400 to 700 nm) that reached the understory by (A) stocking, (B) basal area, and (C) density. The exponential model reflects a rapid decrease followed by a leveling off as overstory retention increases.

Canopy Closure

Canopy closure measured by a spherical densiometer in oak and oak-pine clearcut, seed tree, and light and heavy shelterwood stands increased rapidly and leveled off as overstory retention increased (figs. 3A, 3B, and 3C). Stocking and density were the more reliable of the stand metric canopy closure indicators based upon AIC values, but not as good as directly measuring with a hemispherical photograph (table 2). The relationship of hemispherical photography canopy closure to spherical densiometer canopy closure was not 1 to 1. Spherical densiometer canopy closure had a wider range than the canopy closure calculated from hemispherical photographs, reflecting roughly 20 percent lower maximum readings and roughly 5 percent higher minimum readings even after calibrating with the photograph taken in a 5-acre field (fig. 3D).

DISCUSSION

Light under a forest canopy is affected by both species and structure of the stand (Brown and Parker 1994, Guo and Shelton 1998, Minckler and others 1973, Poulson and Platt 1989). For example, pines generally have a lower crown density than do oaks (Oliver and Larson 1996). Stands with multiple canopy layers generally have a more complex vertical arrangement of trees than do stands that are thinned from below (Lhotka and Loewenstein 2006, 2008; Motsinger and others 2010). Stands with canopy gaps will have a greater range of understory PAR levels across the stand. Consequently, relationships between measures of canopy closure or stand density and light levels need to be established for specific forest types and forest structures to meet the needs of managers. This project focuses on modeling understory PAR following clearcut, seed tree, and light and heavy shelterwood treatments of pine-oak and oak-pine stands.

Measures of stand density have been used to predict growth of reproduction due to their ease of monitoring before, during, and after stand alteration (Brookshire and Shifley 1997, Gwaze 2004, Shifley and Brookshire 2000, Shifley

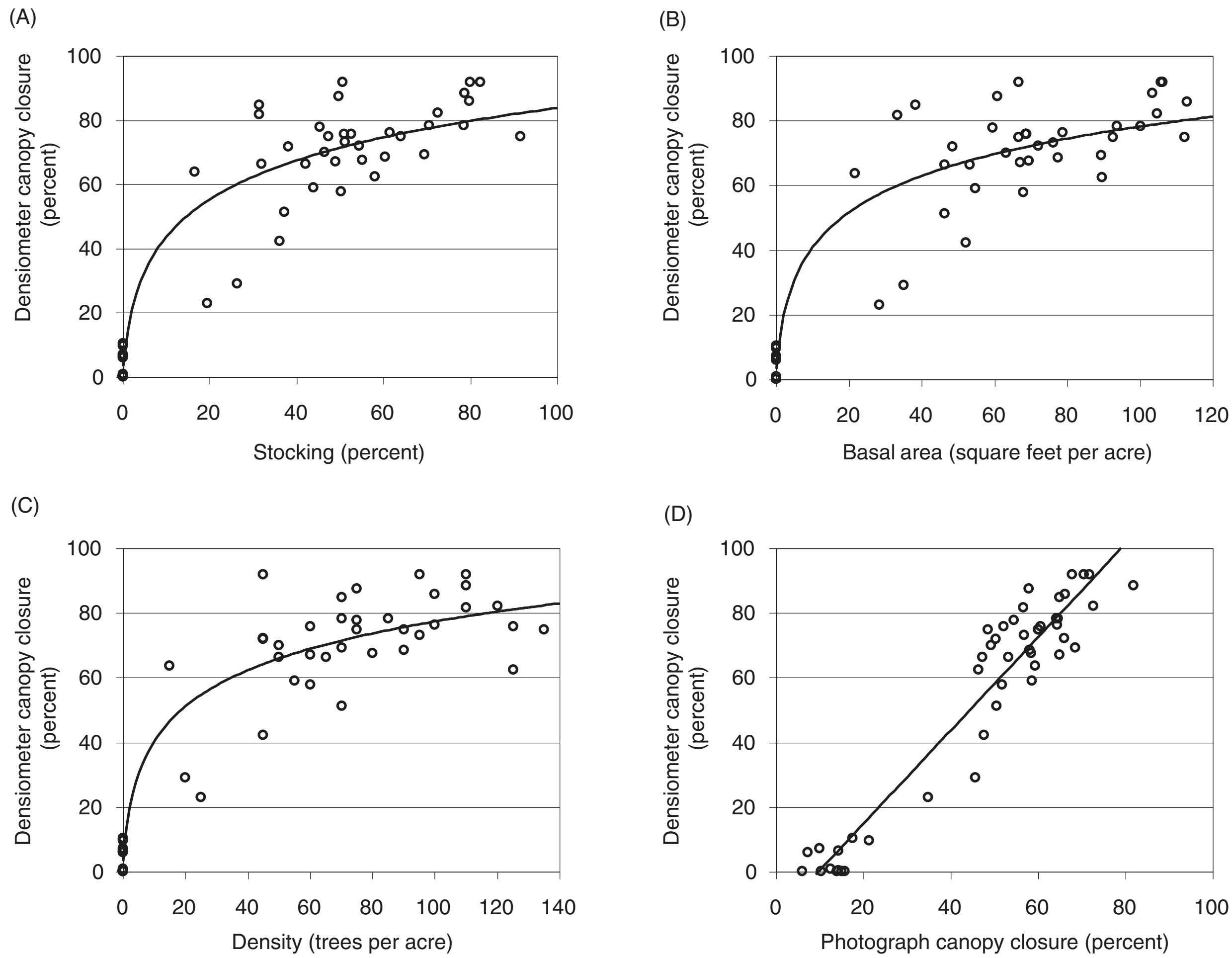

Figure 3—Canopy closure measured with a convex spherical densiometer by: (A) stocking, (B) basal area, (C) density, and (D) calibrated hemispherical photograph canopy closure. The logarithmic model reflects a rapid increase in canopy closure followed by a slower increase as overstory retention increases. Observed canopy closure increased linearly as canopy closure estimated from calibrated canopy photographs increased, although spherical densiometer canopy closure has a wider range of observed values than did canopy closure estimated from photographs even after calibration of the photographs.

Table 2—Models relating canopy closure measured by a spherical densiometer to stocking, basal area, density, and canopy closure calculated from a photograph

Models		*F*-value	AIC[a]	R^2
X = Stocking (%)	41.8335 log10 (1.2077 + X)	738.99[b]	370.0	0.91
X = Basal area (square feet per acre)	39.0443 log10 (1.2270 + X)	677.72	374.0	0.97
X = Density (trees per acre)	38.6471 log10 (1.2300 + X)	755.81	368.9	0.97
X = Canopy closure (photograph, %)	–13.7544 + 1.4415 X	476.22	356.1	0.97

[a] AIC = lowest Akaike's information criterion value was used to determine if the linear or exponential model was the better fit given the model complexity.

[b] *F*-values for all models were significant ($P < 0.00001$).

and Kabrick 2002). A primary goal of stand alteration is to decrease competition for growth resources. PAR in the understory is a key growth resource increased by stand management practices. Establishment and growth of reproduction has been linked to stand metrics, and light requirements are known for some species. Models presented here provide a link between stand metrics and relative light in the understory PAR of stands following clearcut, seed tree, and light and heavy shelterwood treatments.

Canopy closure measured with Lemmon's convex spherical densiometer was the better individual predictor of understory PAR because it is the more direct measure of sky obstruction. Sky obstruction is the primary cause of decreased sunlight (Jennings and others 1999, Oliver and Larson 1996). Canopy closure also integrates the height of the surrounding overstory as well as horizontal area of the canopy opening (Jennings and others 1999). Stocking, basal area, and density are measures of overstory structure, but do not take into account the height of the overstory.

Hemispherical photographs may be used to track changes in canopy closure over time for continuous forest inventory plots, but are less practical than other methods for estimating PAR due to the data entry and data processing required in the office (Lhotka and Loewenstein 2006). Understory PAR was better predicted by canopy closure measured with Lemmon's convex spherical densiometer than by hemispherical canopy photographs as analyzed here. Further techniques may be applied to improve the usefulness of hemispherical canopy photographs (Lhotka and Loewenstein 2006).

CONCLUSIONS

Single-variable stand metric models were successful in modeling the percent of above canopy diurnal PAR that reached the understory given the constraint implicit in the fact that seed tree and shelterwood regeneration methods attempt to leave uniformly spaced mature trees with healthy crowns. Mean percent of above canopy diurnal PAR that reaches the understory is controlled primarily by canopy closure. Canopy closure measured with a spherical densiometer was a better indicator of diurnal understory PAR than canopy closure from hemispherical photographs. As spherical densiometer canopy closure was a better predictor of understory PAR, it would be reasonable to consider additional photograph analysis techniques that mimic spherical densiometer estimates. Stocking and density in these stands were good indicators of spherical densiometer canopy closure.

Incorporating canopy closure measured with a convex spherical densiometer with stocking, basal area, or density may increase the reliability of the estimate of understory PAR. Stands with greater variability or denser midstory and understories may require more complex models (Guo and Shelton 1998; Lhotka and Loewenstein 2006, 2008; Motsinger and others 2010). Additional variables may include height to live crown and total height of the stand and of each canopy layer.

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