Comparison of three canopy cover estimation techniques in Long Island Central Pine Barrens

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Abstract

Light availability controlled by forest canopy openness has a causal relationship with understory plant growth and tree species recruitment into forest canopy, thus plant and forest community composition. Understanding changes in light availability in forest understories is important for forest managers to produce appropriate management strategies. At a subset of 28 permanent forest health monitoring (FHM) plots established in 2005-2006, we characterized canopy cover in 2019 using the following three independent methods that varied in complexity, time required for each reading, and cost: (1) hemispherical photography (HP), (2) spherical crown densiometer (convex mirror), and (3) the AccuPAR LP-80 ceptometer. We conducted a three-way ANOVA and simple regression analyses to determine that no statistically significant differences existed amongst canopy openness measurements provided by the three different tools. The results of this study support the accuracy of these widely used methods, allowing researchers to choose the most appropriate and cost-effective tool and forest stewards to develop the best management plans for the sustainability of natural resources in pine barren forests. Importantly, our analyses suggest that forest managers can save costs by avoiding using the costliest of the methods (e.g., AccuPAR ceptometer) when tools that are orders of magnitude cheaper (convex mirror, HP) may suffice in the open ecosystem of pine barrens.

Introduction

Light availability has a causal relationship with understory plant species growth and tree recruitment and often determines forest composition. Canopy openness (CO) is a major driver of light availability and is defined as the fraction of unobscured sky [1]. Estimates of CO are useful in numerous types of forest research and management including silviculture, wildlife management and understory diversity restoration [2–4]. As a result of the diversity in CO applications, many tools and techniques have been developed.

Canopy openness measurements can fall into one of two categories: direct or indirect. Direct measurements (tree canopy allometry) are often time consuming and destructive, in which trees must be logged or other large samples must be taken from the forest [5–7]. To avoid any destructive effect on the forest and improve efficiency, indirect techniques of estimating canopy openness tend to be widely used. One method employs direct light measurements, for example, using AccuPAR LP-80 which contain sensors that measure photosynthetically active radiation [8]. This tool has been shown to minimize bias due to random clumping of leaves and other plant material in the canopy and it also minimizes observer bias [9]. In comparison, the spherical crown densiometer, designed in 1956 by Paul Lemmon, is a cheap, lightweight, and easy-to-use tool. The portability and small-form-factor makes it quick to take measurements in a diversity of settings, but the general skill-level of an operator may cause inaccuracies in the data [10,11].

Another relatively new technique, hemispherical photography (HP), has become much more accessible in recent years. Traditionally, HP has required the use of a Digital Single Lens Reflex (DSLR) camera with a fish-eye lens attachment to take sky-ward photographs for post-processing in image analysis software such as Gap Light Analyzer (GLA) [9,12,13]. However, image analysis can also be accomplished with ImageJ software with the Hemispherical 2.0 package for batch processing, which is faster and more user-friendly than GLA [14]. Advancing technology has made it possible to take hemispherical photographs with a smartphone and very cheap clip-on fish-eye lens [15]. This method is faster and requires simpler protocols compared to the traditional hemispherical photography [16]. Some bias has been reported, but nothing affecting its reliability as a suitable replacement to traditional and more cumbersome photography techniques [17].

The spherical crown densiometer, hemispherical photography, and AccuPAR have varying price ranges, operating time, and post-processing time. which should be considered when selecting a tool for a project [18] (Table 1). Our objective in this paper is to compare three indirect methods of measuring canopy openness in order to determine which is the most reliable and accurate in the pine barren ecosystem where canopy openness is highly variable (including often relatively open canopies). In addition, we aim to decide if cheaper methods (HP and convex mirror) are equally as accurate. We hypothesize that hemispherical photography and the AccuPAR ceptometer will tend to find relatively higher canopy openness due to the “clumping” effect of canopy structure where leaves and branches overlap and create larger gaps [19]. Pine needles group in such a way that does not typically fit the gap-fraction model and thus tends to increase clumping [6]. The spherical crown densiometer is predicted to be less susceptible to these effects.

Methods

Study area and design

The Long Island Pine Barrens comprises 105,000 acres in the central and eastern areas of the island. The Pine Barrens host a multitude of rare, endangered, and threatened species and is the largest natural area used for recreational activities and groundwater recharge on Long Island [20,21]. FHM studies are aimed at quantifying changes within the forest to guide management strategies and preserve the health of these forests and the many supporting, provisioning, regulating, and cultural ecosystem services [20].

From a total of 95 plots established in 2005-2006 as a part of the Forest Health Monitoring network in the Long Island Central Pine Barrens, we used 28 plots that were located by stratified random plot placement based on forest types (each received a number of plots in proportion of its area on LI) using GIS [22]. All plots established within public lands of the Pine Barrens were at least 50 meters from any other plot, and any land altered by human use. These plots are classified by forest community type summarized in Table 2 [22].

Within each plot (16 x 25 m), five points were established for canopy openness measurements (marked M, A, B, C, and D) using pink flags (Fig. 1A). Point M corresponded to the center mark of each plot located at the rebar and cap with the "CM" engraving. Points A and C are 4 m away from M and run perpendicular to each 25 m plot boundary. Points B and D are 6 m away from M and run perpendicular to each 16 m plot boundary. Readings from each tool were taken at each marked point on the grid in the order of M, A, B, C, D. A similar grid was laid out in an open area outside of each plot as a control for the "open sky" (full light) conditions. A random point was selected in this area as a center mark and four measurements were taken 2 m from this center mark in the cardinal directions. Measurements were only taken under an overcast sky or a clear sky with few clouds and all measurements were taken at a vertical height of 1.3 m.

Measurements

<u>*PAR Ceptometer*</u>

The AccuPAR LP-80 measures total photosynthetically active radiation (PAR; $\mu mol \cdot m^2 \cdot s^{-1}$) along an 80 cm wand with 80 individual sensors. This tool is designed for use in agricultural systems, so adjustments to data collection were developed for the forest ecosystem [8]. To emulate above canopy-below canopy comparisons, we made outside and inside plot comparisons where: a) outside-plot measurements were taken reasonably close to inside-plot measurements (*i.e.* within the same community type), and b) outside plots have as little canopy cover as possible to represent above-canopy conditions.

Two sets of outside-plot measurements were taken; the first set preceding and the second set succeeding inside-plot measurements to best characterize outside light conditions. Inside and outside measurements are averaged, and canopy openness is calculated using Equation 1.

$$Mean_{inside} \div (Mean_{inside} + Mean_{outside}) \cdot 100 \quad \textbf{(1)}$$

<u>*Spherical Crown Densiometer (Convex)*</u>

Having been used in forest environments for more than half a century, the spherical crown densiometer is an established tool for estimating canopy openness [23]. The densiometer has 24 quarter-inch squares in a gridded pattern on a convex mirror. Each square has 4 imaginary dots in the corners creating a total of 96 “dots” on the grid. The number of dots not covered by canopy is recorded. At each established 2 x 2 m grid outside the plot and 4 x 6 m grid inside the plot, densiometer measurements were taken facing north and south at each point.

Measurements taken outside of the plot were not taken since they are not necessary for determining percent canopy openness (but may be helpful as a control and for finding discrepancies in future analyses). Mean dot-values were taken for each corresponding north- and south-facing measurement inside the plot (*i.e.* Inside_CM_north/south through Inside_D_north/south). These five values were averaged to find a mean dot-value representative of the entire plot. Finally, this total mean value was multiplied by 1.04 to find percent canopy openness [24].

Hemispherical Photography and Image Processing

This method of measuring canopy openness utilizes a fish-eye lens attachment to a camera. In our case, a smartphone and clip-on 180° lens were used as a cheaper and faster alternative to a camera and tripod. The camera was leveled, and pictures were taken at an estimated zenith. To calculate canopy openness, the software program ImageJ was used to convert pictures into black-and-white images [14]. Pixels were counted as either open or closed canopy and canopy openness was calculated as in Equation 2.

$$Pixels_{open} \div (Pixels_{open} + Pixels_{closed}) \quad \textbf{(2)}$$

Statistical Analyses

To determine a difference in canopy openness amongst different canopy openness tools, we used a one-way ANOVA and simple linear regression plots using R [25] (See appendix).

Results

Our results showed that the three tools do not measure CO differently from one another (F=0.4838, p=0.6182) (Fig. 1). HP tended to provide higher CO estimates, particularly relative to AccuPAR. AccuPAR provided measurements with the most variability. A Bartlett's test suggested homoscedasticity amongst CO measurements (Bartlett's K-squared = 1.8092, df = 2, p-value = 0.4047). There was high positive correlation between HP and the Densiometer (r=0.81). There was a moderately positive correlation between HP and AccuPAR and between Densiometer and AccuPAR (r=0.73 and r=0.72, respectively) (Fig. 2).

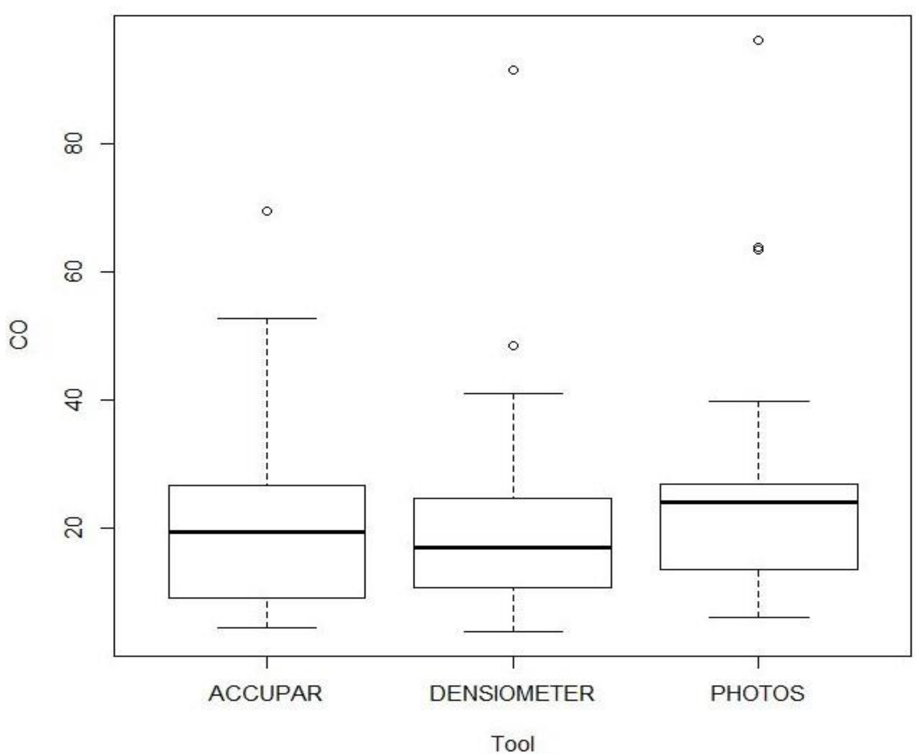

Fig. 1. Evaluating CO estimates between tools. With 28 samples for each tool, we saw no significant difference amongst measurements. "Photos" are HP measurements. This graph shows the variability in measurements amongst tools.

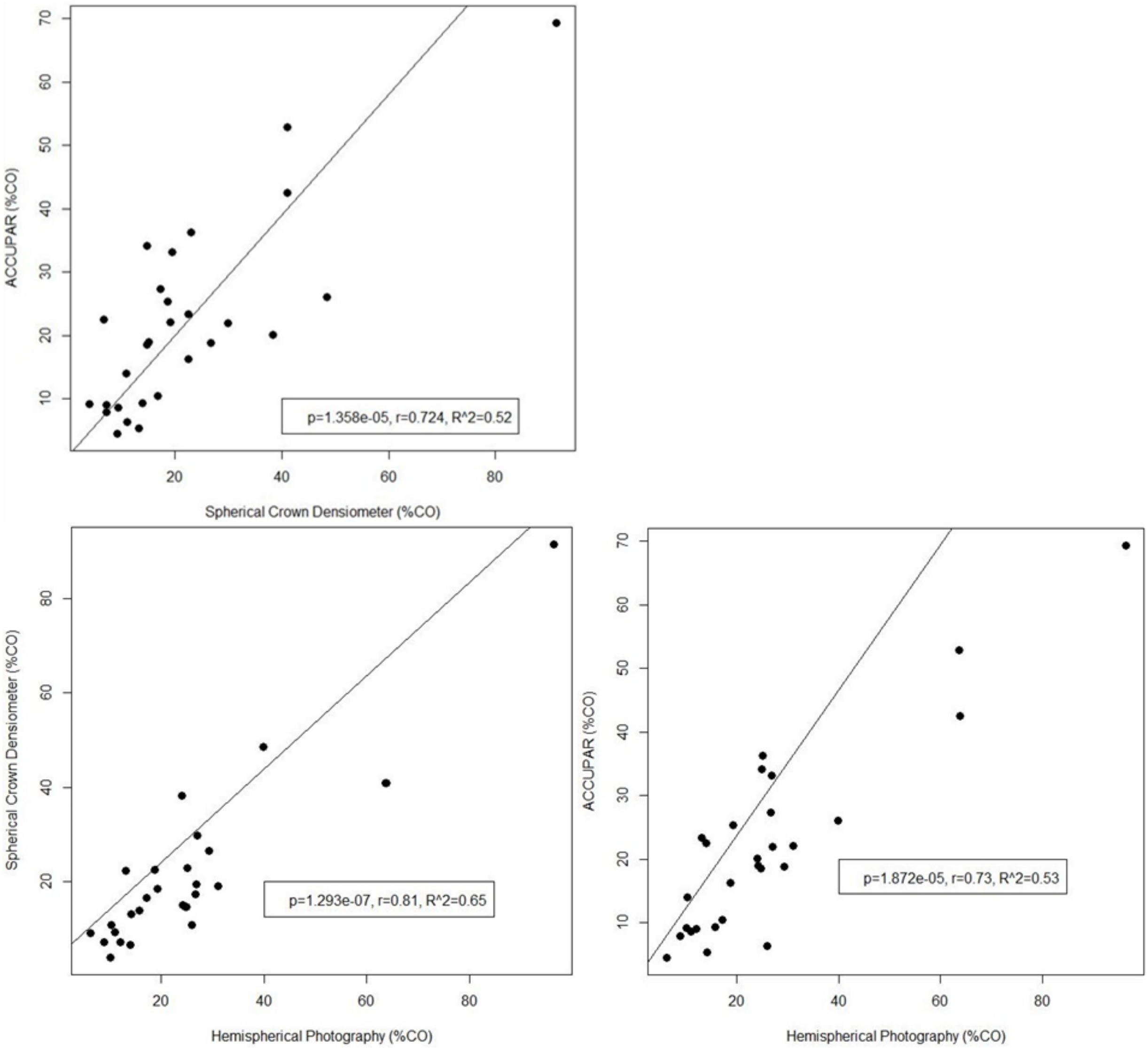

Fig. 2. Individual comparisons of CO instruments. Simple linear regression lines, p-values, and R2 values, and Spearman Correlation coefficients (r) are shown.

Discussion

We expected HP and the AccuPAR ceptometer to measure larger values of canopy openness with respect to the crown densiometer due to "clumping" effects [26]. However, we found that there was no significant difference amongst CO values produced by the instruments. One possible explanation for these observed results may come from the small subset of data used for analysis (n=28). In addition, several forest types are known to exist within the Pine Barrens ecosystem, some with dense canopy (such as Oak-Pine) and others with very little canopy (such as Dwarf Pine). Instruments such as the densiometer were commonly tested within pine forests, and may produce bias in hardwood-dominated forests [27]. Additionally, it is debated whether gaps within tree crowns ought to be counted as open canopy which leads to differing results amongst operators [28].

Our results indicate that HP tends to overestimate CO with respect to the other two methods. This likely stems from software mechanics and light phenomena. Within the ImageJ software, images are automatically thresholded, which distinguishes objects within an image by converting it to a grayscale. A forest canopy is usually discontinuous containing many openings of varying shapes and sizes. When light passes through small openings in the canopy, a glow often results around the perimeter of the opening known as the "pinhole effect." When this glow is sensed by processing software, the thresholding function may render a canopy opening that is bigger than it truly is causing some bias in CO readings [29,30]. Additionally, when CO is low, it is suspected that the observed thresholding bias will have a greater influence on CO measurements.

AccuPAR LP-80 and other ceptometers use gap-fraction models to quantify CO which assume a random spatial aggregation of plant material. The presence of pine needles also weakens the accuracy and effectiveness of ceptometers for measuring CO due to increased penumbral effect in coniferous forests [31].

Future studies should focus on a larger sample size in each forest type within the pine barrens to determine which have more open or closed canopies. This may allow for a clearer picture when assessing if an instrument under- or overestimates in more dense canopies. Understanding how these instruments operate in broadleaf versus coniferous forest types may be also useful in deciding which methods perform best. The numerous methods available to estimate CO differ in cost, required time to take measurements, and appropriateness for different forest types, and choosing the best tool for a certain forest is key.

Conclusions

Our results indicate that all three methods for measuring CO are suitable to be used in the Central Pine Barrens system. More expensive methods, such as the ACCUPAR, are not necessary to provide similar results. This may help future Central Pine Barrens researchers to cut down on costs or apply their savings to other aspects of their studies. Further research should focus on increasing sample size to balance out statistical noise. Additionally, future studies should examine broadleaf and coniferous forests individually to pinpoint subtleties in measurement methods for canopy openness.

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Appendix

Table 1: Cost of Canopy Openness Measurement Tools

Spherical Crown Densiometer	AccuPAR	Hemispherical Photography
$104.50[1]	$4,500.00[2]	$2.99[3]

[1]Forestry Suppliers, [2]Meter Environment, [3]Walmart (excludes the cost of a smartphone)

Table 2. Summary of Subtarget (Forest Type) Characteristics[4]

Subtarget	Community Type	Canopy Cover	Presence of Pitch Pine	Presence of Scrub Oak	Presence of Blueberry & Huckleberry
Coastal Oak	Forest	≥60%	≤10%	None	Continuous
Oak-Pine	Forest	≥60%	11-49%	Scattered	Continuous
Pine-Oak	Forest	≥60%	50-89%	Scattered	Nearly Continuous
Pitch Pine	Forest	≥60%	≥90%	Continuous	Scattered
Pitch Pine Scrub	Shrub land	<60%, open	Primarily Pitch Pine with some Tree Oaks	Continuous	Scattered
Dwarf Pine Plain	Shrub Land		Pitch Pine, Dwarf Pine	Nearly Continuous	

[4]*Taken from Forest Health Monitoring Protocols for the Long Island Central Pine Barrens*

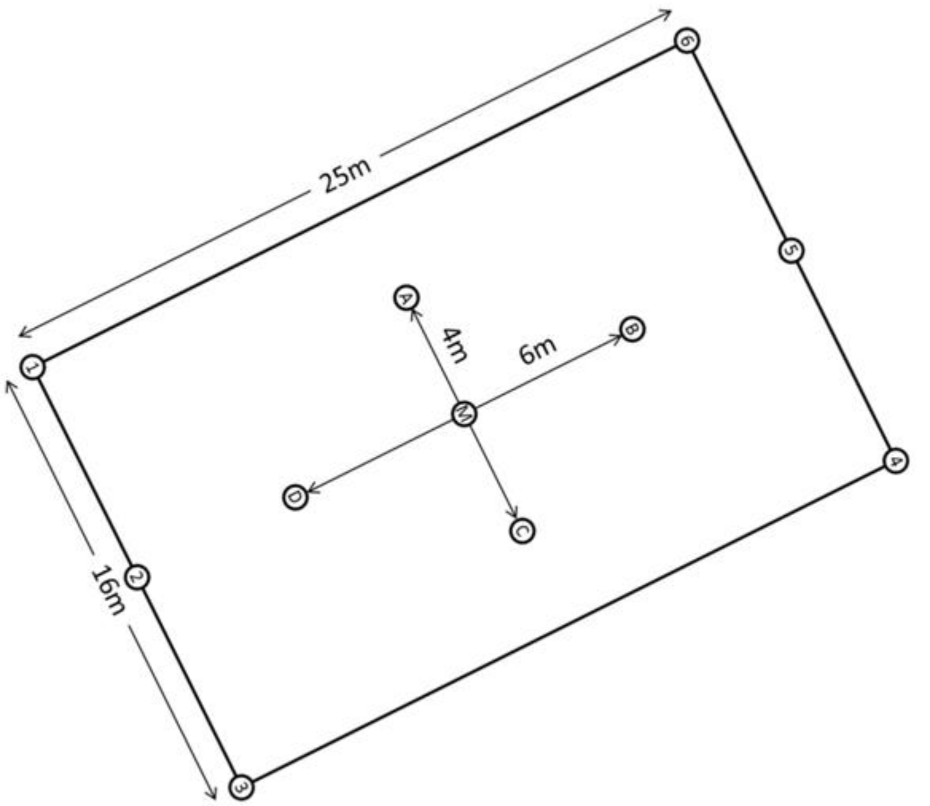

Fig. 1A. Plot dimensions and inside-plot grid layout

R Code:

```
> lai <- read.csv(file.choose(),header=T)
> lai
> cor.test(lai$CO_PHOTO, lai$CO_DENSIOMETER, method="spearman")
> cor.test(lai$CO_PHOTO, lai$CO_ACCUPAR, method="spearman")
> cor.test(lai$CO_DENSIOMETER, lai$ACCUPAR, method="spearman")
> cor.test(lai$CO_DENSIOMETER, lai$CO_ACCUPAR, method="spearman")
> plot(lai$CO_DENSIOMETER, lai$CO_ACCUPAR, pch=16, cex=1.3, col="black",
xlab="Spherical Crown Densiometer (%CO)", ylab="ACCUPAR (%CO)")
> lm(lai$CO_DENSIOMETER~lai$CO_ACCUPAR)
> abline(0.9476,0.9525)
> plot(lai$CO_PHOTO, lai$CO_ACCUPAR, pch=16, cex=1.3, col="black",
xlab="Hemispherical Photography (%CO)", ylab="ACCUPAR (%CO)")
> lm(lai$CO_PHOTO~lai$CO_ACCUPAR)
> abline(0.709,1.148)
```

```
> legend(40,20, legend=c("p=1.872e-05, r=0.73, R^2=0.53"))
> plot(lai$CO_PHOTO, lai$CO_DENSIOMETER, pch=16, cex=1.3, col="black",
xlab="Hemispherical Photography (%CO)", ylab="Spherical Crown Densiometer (%CO)")
> lm(lai$CO_PHOTO~lai$CO_DENSIOMETER)
> abline(4.2622,0.9902)
> legend(40,20,legend=c("p=1.293e-07, r=0.81, R^2=0.65"))
> lai2 <- read.csv(file.choose(),header=T)
> lai2
> myaov <- aov(CO~Tool, data=lai2)
> summary(myaov)
> mylm <- lm(CO~Tool,data=lai2)
> summary(mylm)
> bartlett.test(CO~Tool,data=lai2)
```

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