CALIFORNIA FORESTRY NOTE

State of California
The Resources Agency
California Department of Forestry & Fire Protection

P.O. Box 944246
Sacramento, CA 94244-2460
Phone: 916-653-7209
Web: www.fire.ca.gov

No. 115 June 2000

A Comparison of Techniques for Measuring Canopy in Watercourse and Lake Protection Zones

Timothy A. Robards, Martin W. Berbach, Peter H. Cafferata, and Bradley E. Valentine[1]

Abstract

We investigated seven methods for estimating overstory crown canopy. Subjective ocular estimates were compared with the more objective sampling tools; vertical sighting tubes and spherical densiometers. Intensive and controlled measurements allowed us to compare accuracy. We also present the time required to complete the different methods. Ocular estimates based on a walk-through of the riparian area proved sufficient for most pre-harvest evaluations. These estimates were always underestimates, which is conservative from a public trust resource perspective. Estimates that are more accurate require the use of a vertical sighting tube. We recommend the use of the vertical sighting tube to sample canopy along transects rather than plots, as the former are more efficient.

Introduction

California forest practice regulations establish minimum overstory canopy retention levels in Watercourse and Lake Protection Zones (WPLZs). Additionally, guidelines for protecting the habitat value for federally listed threatened and endangered fish species incorporate canopy retention standards as a surrogate for shade (Anon. 1997). Overstory canopy, in the context of the California Forest Practice Rules, has usually been evaluated via ocular estimation. When more objective estimates were desired, practitioners have primarily used spherical densiometers (Lemmon 1956), a curved mirror with an etched grid and bubble level. Recent literature criticizes the spherical densiometer as a tool for measuring overstory canopy cover (Bunnell and

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1 T. Robards is State Forests Research Coordinator in Sacramento with the California Department of Forestry and Fire Protection (CDF). M. Berbach, Ph.D is Environmental Specialist in Sacramento with the California Department of Fish and Game. P. Cafferata is Forest Hydrologist with CDF in Sacramento, and B. Valentine is Senior Wildlife Biologist in Santa Rosa with CDF.

Vales 1989, Ganey and Block 1994, Cook et. al. 1995). Densiometers measure cover above a conical shaped projection, and thus include both vertical and angular projections of the canopy. Formal evaluation of ocular estimation does not exist in the literature except for comparisons made to spherical densiometer estimates (Vora 1988). Due to the regulatory and resource issues surrounding canopy measurements, Berbach et. al. (1999) noted the need for clear, defensible, and efficient procedures for measuring overstory canopy cover.

The purposes of this study were to 1) identify an inexpensive method for evaluating overstory canopy cover that would be suitable for pre-harvest inspections (PHIs) and 2) identify a more accurate method that could be used on PHIs, for enforcement purposes, or for monitoring. Methods intended to satisfy the first purpose were ocular estimates. Techniques intended to satisfy the second purpose were instrument methods. We anticipated that the instrument methods would be more accurate for a given stand and assumed that a bias would be evident for the spherical densiometer. We were unaware of how the techniques would compare in their precision and relative effort. We hypothesized that the ocular and sighting tube methods would be unbiased.

We examined methods to determine their adequacy for classifying the sampled sites into categories. Harvest plan WLPZ mitigation implicitly includes a range of acceptable post-harvest overstory cover. The ability to correctly classify stands using typical categories was of interest. We also conducted a time study. Methods that provided adequate accuracy were evaluated to select the methods that required the least amount of time.

Methods

We conducted the study on the Jackson Demonstration State Forest, a 50,000-acre coastal forest between Fort Bragg and Willits in Mendocino County. All sample locations were within the Parlin Creek watershed. The stands consisted of redwood and Douglas-fir with minor amounts of other whitewoods and hardwood species. The weather for the study period consisted of calm days with a mix of clear skies and overcast conditions resulting from coastal marine layer fog.

Study sites were set up the week of September 21, 1998 when we identified and laid out the study sites. Next, we intensively measured canopy on the study sites to reliably determine the “true” value of their overstory canopies; see below for details. Test personnel estimated canopy on the study sites the following week in the sequence described below. We designed the procedures so that one person in the field could conduct them.

Study Sites

Sample locations were WLPZs of a width defined by the California Forest

Practice Rules (14 CCR 916.5) and of length 250 feet. We chose the length based on the Rule's requirement that at least 200 lineal feet of WLPZ must be measured to determine conformance with canopy retention standards (14 CCR 916.4(b)(2)). The side of a study site proximal to the watercourse was the transition line as defined the Forest Practice Rules, while the side distant to the watercourse was the distance required by the slope categories of the Rules.

A range of actual overstory cover and slopes were necessary to conduct the tests. Slope categories that we used (Table 1) allowed an analysis of the effect of slope on efficiency. Using the variables of slope and percent cover, we identified four categories. The 40% break-off point for slope approximates the point of substantial changes in efficiency for people or machinery. The 50% category threshold for cover was selected due to its reference by the Rules. Given these four categories, we identified four stands to ensure a balanced experimental design. We located one additional stand for training purposes.

Table 1. Criteria used in selecting study sites.

Variable	Categories
Slope	<40%, ≥40%
Percent Cover	<50%, ≥50%

Each study site required approximately one full day to find, flag, and measure intensively. We used the criteria of Table 1 to subjectively select the study sites. While replication of each of these categories was desirable, we were restricted by resources to two replications for each of the factors in Table 1.

<u>Sampling for Actual Cover</u>

Once we identified a study site and flagged it's boundaries, we sampled it intensively to establish its actual value. Design consideration regarding the ocular estimates required that we have plots of known cover. The circular plots were 1/50 acre in size (diameter of 33.3 feet) within which were five transects (Figure 1). The center transect was 32 feet in length oriented in a north-south direction. Parallel transects 7 feet and 14 feet in both directions from the center transect were 30 and 18 feet long, respectively. Points at one-foot intervals were marked on the transect rope so that a sighting tube reading was taken at every foot. This provided a total of 128 points for a plot. The transect ropes were kept horizontal and stretched tight above or through brush, slash, and trees. This method forced a systematic measurement of vertical overstory that was not influenced by vegetation, slash, or topography.

The number of plots per study site depended on the variability of the study site. The target was a confidence interval bound less than 5% of the mean with 95% confidence. We wanted the plot layout to be random but to also allow for the optimum location of plots so that the maximum number of plots could be

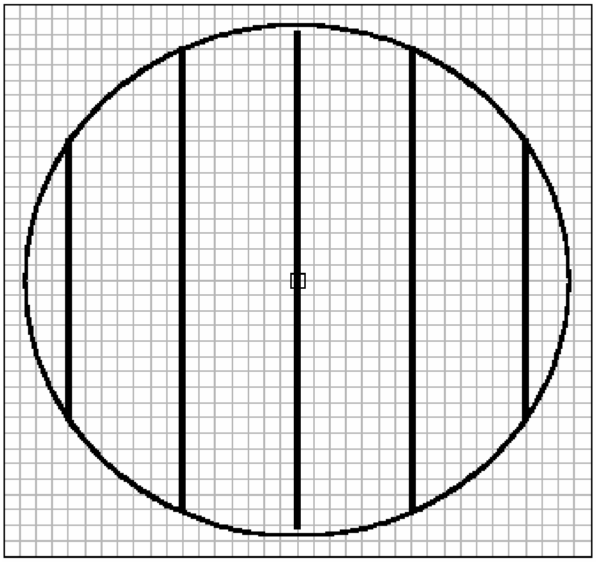

Figure 1. Layout of transects on 1/50-acre plots for intensively measuring the study sites for determining actual cover. Each cell on the grid is one square foot. A measurement was taken at each cell along the transect.

installed, if needed. Thus, the plot selection was without replacement and was pseudo-random because their locations were restricted to occur as follows. We divided the 250 foot length into seven sections of 35.7 feet each. For a 50 foot wide WLPZ, only one plot was possible per section. For the 75 foot and 100 foot wide WLPZs, two plots could be located per section. The 150 foot WLPZ could have four plots per section (Figure 2). The result was a grid of 7x4 squares into which the circular plots were centered. We installed a minimum of one plot per section, for a minimum of seven plots per study site.

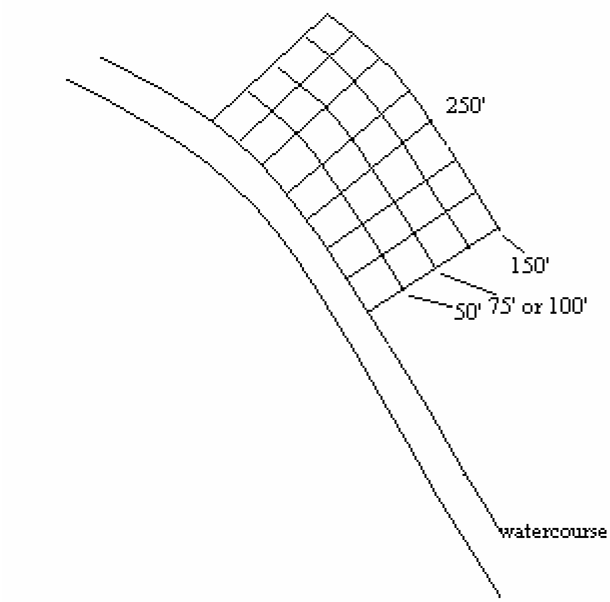

Figure 2. Layout of plots on a WLPZ for intensively measuring a study site. The 1/50-acre circular plots fit within each square. For a 50' width WLPZ there were 7 possible plots, 14 possible plots for 75' or 100' width WLPZ, and 28 plots possible for a 150' width WLPZ.

We selected a random integer in the range of one to one, two, or four depending on WLPZ width. This random number determined the location of the plot in the section. The process was repeated if additional plots were needed. Points already selected were not available again. Plot centers were monumented with a wooden stake labeled with the plot number.

The vertical sighting tube we used was the GRS Densitometer™, an instrument consisting of two pieces of PVC pipe joined into a "T" shape enclosing a mirror, two bubble levels, and two windows. The orientation of the two levels assures a true vertical view (Figure 3). On the window closest to the eye is an etched circle and on the window pointing up is an etched dot. After centering both levels, the canopy was measured by viewing through the small dot when it was centered within the larger circle. A hit was recorded when the dot intercepted vegetation.

The dripline of a tree was the deciding factor in evaluating if a sample was a hit or a miss. Rather than simply recording a hit or miss of a piece of vegetation, a view through the crown of a tree represented a hit. This made the measurement consistent with other canopy estimation techniques such as aerial photo interpretation or crown models predicted from tree attributes. Aerial photo interpretation does not generally account for intra-crown openings. In addition, crown models consider the entire crown cross-sectional area as a solid (Biging and Wensel 1990, Uzoh and Ritchie 1996). The regulatory definition of overstory (14 CCR 895.1) is given as "…that portion of the trees, in a forest of more than one story, forming the upper canopy layers." This definition does not lend itself to a strict quantitative evaluation. We defined overstory using the general silvicultural definition of dominant or codominant trees, as defined by the microsite (Smith 1962).

The test crews began their inventories after we intensively sampled the study sites. Their data provided the means to evaluate the different combinations of sampling design and instruments. Each crew consisted of one person or "estimator." Four of the five estimators were California Registered Professional Foresters with extensive field experience, but with variable experience in overstory crown estimation. Table 2 provides a summary of the methods described below.

Table 2. Summary of methods.

Identifier	Instrument	Layout	Comments
1	Ocular	Unstructured walk-through	Before training
2	Ocular	1/50 Acre plots	Same plot centers as “actual” plots; before training
3	Ocular	Unstructured walk-through	After training
4	Ocular	1/50 Acre plots	Same plot centers as “actual” plots; after training
5	Concave spherical densiometer	Plots	Variable sample size, same plot centers as #6
6	Vertical sighting tube	Plots	Variable sample size, same plot centers as #5
7	Vertical sighting tube	Grid of points	Variable sample size

Ocular Estimation Methods

Ocular estimation consisted of two experience levels: a "without training" and a "with training". The canopies were estimated "without training" first because we wished to re-use the same study sites. Within a study site, canopy was estimated by ocular techniques in two portions: 1) the entire site based on a walk-through and 2) at each plot center, from which we calculated an average. Estimators did not take part in study site establishment so they had no prior knowledge of the study sites. Their walk-throughs were not structured; rather they roamed about the study site, as they deemed appropriate. The plot-based method used the same plot centers as were established for estimating actual.

Ocular estimation with training followed the same approach as that without training, except that estimators were trained. At one study site with a range of conditions, we facilitated calibration of estimators’ by telling them the "true" values at each plot, as well as for the total of the study site after they had estimated the canopy.

Instrument Sampling

We evaluated canopy measures using two instruments, the vertical sighting tube and the concave spherical densiometer. Both were used jointly on one sampling scheme, while only the vertical sighting tube was used on another.

Figure 3. The concave spherical densiometer with tape for Strickler's modification is on the left and the vertical sighting tube is on the right.

Sighting Tube Systematic - Plotless

The "sighting tube systematic – plotless" method used a grid of sample points based on a random start. Sample size (the number of points per grid) was determined using the ocular estimate of percent cover following the guidelines of Table 3. This table assumes a 5% acceptable error and is not a function of the size of the area sampled. The binary data that results from using the vertical sighting tube follows a binomial distribution; the source for Table 3.

Table 3. Sample size necessary to meet 5% error at 95% confidence.

Estimated % Cover:	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Estimated Sample Size:	0	36	64	84	96	100	96	84	64	36	0

The plot sheet included a table that specified the distances between points given the sample size and WLPZ width. The initial point was randomly located by starting at a WLPZ corner. A random number table provided the distances to the initial starting point based on a distance parallel and then a distance perpendicular to the watercourse. The offsets were restricted to a range between zero and the distance between points.

Sighting Tube - Plots

Each 1/50-acre circular plot consisted of nine points (Figure 4). The points were laid-out in a 3x3 grid with the center point on the plot center. A spacing of 9'10" was used between points so that each point represented an equal area. The grids were oriented approximately perpendicular to the watercourse. The number of plots sampled was a function of the size of the study site and the variability between plots. Tables 4-7 were used to determine the sample size as a function of the WLPZ width and estimated coefficient of variation (CV).

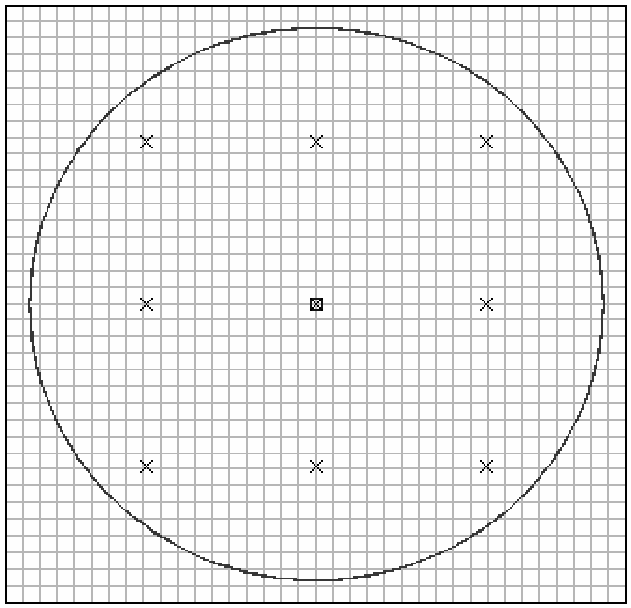

Figure 4. Plot layout of nine sample points for vertical sighting tube measure. Plot is 1/50 acre and distance between sample points is 9’10”.

We laid out the plots in the same manner as for the actual (intensive) measurements described above. Plot locations were monumented with a stake, so that we could collect spherical densiometer measurements from the same plot centers.

Table 4. Sample size necessary to meet 5% error for a 50' WLPZ 250' long.

Estimated % CV:	5	10	15	20	25	30	35	40	45	50
Estimated Sample Size:	3	8	10	12	13	13	13	14	14	14

Table 5. Sample size necessary to meet 5% error for a 75' WLPZ 250' long.

Estimated % CV:	5	10	15	20	25	30	35	40	45	50
Estimated Sample Size:	3	9	13	16	18	19	19	20	20	20

Table 6. Sample size necessary to meet 5% error for a 100' WLPZ 250' long.

Estimated % CV:	5	10	15	20	25	30	35	40	45	50
Estimated Sample Size:	4	10	16	20	22	24	25	26	26	27

Table 7. Sample size necessary to meet 5% error for a 150' WLPZ 250' long.

Estimated % CV:	5	10	15	20	25	30	35	40	45	50
Estimated Sample Size:	4	12	20	26	30	33	35	37	38	39

Spherical Densiometer

We tested concave spherical densiometers at the same plot centers used for the sighting tube-plots. Using Strickler's (1959) modification eliminated overlap in view when sampling the four cardinal directions from the plot center. This method required that we sample 17 points in four directions for a total of 68 points per plot. Dividing the number of hits by 68 derived a single value of canopy for each plot. Overstory was not differentiated from understory with this instrument, as the curved mirror reflection does not allow such discrimination.

Experimental Design

Sampling order of the methods was important. The untrained ocular methods necessarily preceded all other methods. The trained ocular methods preceded the instrumented methods in order to assess the specific training provided and not confound the results with experience gained from the instrument methods. Finally, we randomized the order of the remaining methods to avoid any unwanted effects in the cover or time measurements. This entailed three trips to each study site after the "actual" canopy had been measured.

Results

Summaries of the actual attributes of the five study sites are presented in Table 8. We used study site 3 as the training site and therefore did not include it in the report of results. Site 3 had been harvested recently. It provided a diverse training site because within it were a lower slope strip with relatively high canopy cover and an upper slope strip with relatively low cover. Within each strip, the canopy cover was uniform. The two sites with the steepest slopes, sites 1 and 4, also had the most slash. The coefficient of variation (CV) for the canopy cover indicated that the most variation was in the sites with the lowest cover. Plots often fell either within a clump of trees or in the open, thus producing a high variation between plots.

Table 8. Study site statistics from "actual" sampling.

Study Site	Width (ft)	Slope (%)	No. of Plots	Average Cover (%)	CV(%)	Average Basal Area (sq ft/acre)	Notes
1	100	50	9	64	13	124	Slash
2	75	5	7	97	4	357	
3	75	22	11	62	23	238	Training
4	75	45	10	24	68	48	Slash
5	75	5	9	24	72	84	

The combination of instruments and sampling schemes are compared using the difference between the actual percent cover for a study site and the estimated percent cover. A zero value means the actual and estimated values agree completely, a negative value indicates an overestimation, and a positive value shows an underestimation. Within a training regime, the ocular methods with plots were better than the walk-throughs (Figure 5), but only on the study sites that were relatively flat and free of slash.

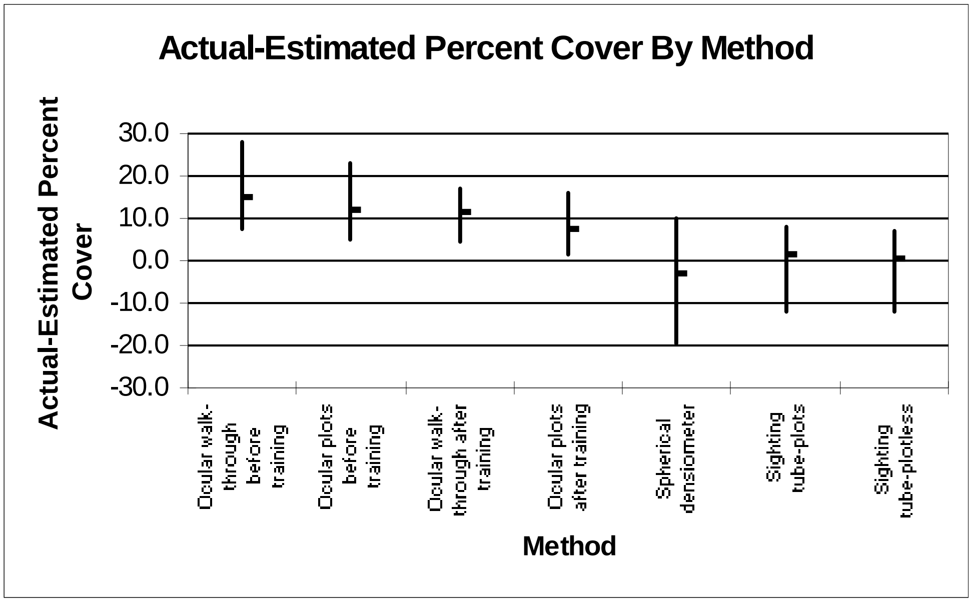

Figure 5. Actual minus estimated percent cover by method. Lines represent high and low figures and tick marks are the average.

Training produced an improvement of 3.3% and 4.4% for the ocular walk-throughs and ocular plots, respectively. Estimators always underestimated the overstory canopy present when using ocular judgement.

The range of estimates was largest for the spherical densiometer (Figure 5). The largest deviation occurred in study site 5 which was relatively open, but surrounded by mature stands. The more severe overestimation of the spherical densiometer is probably due to the angle of view of the instrument incorporating the surrounding dense canopy. Similarly, the largest positive deviation of the instruments occurred with the spherical densiometer on study site 2. This stand was very dense, but there was an opening just outside the WLPZ. Due to the densiometer's measurement angle, these openings were measured. A plot by plot comparison of the sighting tube and spherical densiometer estimates shows how the spherical densiometer frequently overestimates cover (Figure 6).

A categorical approach to presenting the results is to consider the practical applications regarding California forest practice regulations and other regulatory constraints. Three classes were examined with a cutoff of 50% to correspond to the Forest Practice Rules (14 CCR 916.5(e)(G-I)) and a commonly applied cutoff of 75% to address concerns for the endangered coho salmon. Classifying relatively sparse or dense stands does not appear to be an issue with any of the methods (Table 9). The 50-75% range does appear to be affected by method, with the "sighting tube-plotless" method (7) being the most accurate. However, because the actual canopy values (Table 8) were all more than 20% away from the category bounds in the sparse and dense stands, we cannot say from this analysis if the same finding would be true as the actual values approach the bounds.

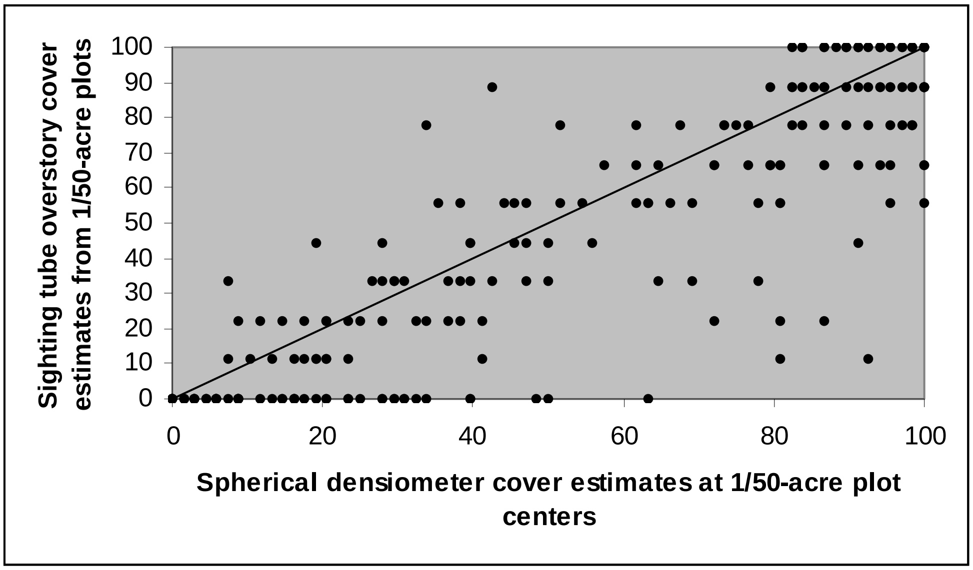

Figure 6. Sighting tube-plot overstory estimates versus concave spherical densiometer estimates of cover.

Table 9. The percentage of estimates that are correctly classified when the actual value is within the given range.

Method	***<50% Canopy***	***50-75% Canopy***	***>75% Canopy***
1-Ocular, walk-through before training	100.0%	0.0%	100.0%
2-Ocular, plots before training	100.0%	0.0%	100.0%
3-Ocular, walk-through after training	100.0%	20.0%	100.0%
4-Ocular, plots after training	100.0%	60.0%	100.0%
5-Spherical densiometer	100.0%	40.0%	100.0%
6-Vertical sighting tube, plots	100.0%	40.0%	100.0%
7-Vertical sighting tube, plotless	100.0%	80.0%	100.0%

Because the ocular estimation without training performed the least satisfactorily in the 50-75% category, we examined the nature of the misclassifications. The actual values were compared with the estimated classifications for methods 1 and 2 only (Table 10). A perfect classification would show numbers only on the diagonal. Untrained ocular estimation appears to result in categorizing the 50-75% class into the less than 50% category. This is also suggested in Figure 5, which also suggests the same to be true for methods 3 and 4. A scatter diagram of cover values for the actual values for the 1/50-acre plots versus post-training ocular estimation illustrates the misclassification in the mid-range of values (Figure 7).

Table 10. Error matrix for methods 1 and 2, untrained ocular estimation.

	Actual			
Estimated	*<50%*	*50-75%*	*>75%*	***Total***
<50%	20	10	0	30
50-75%	0	0	0	0
>75%	0	0	10	10
Total	20	10	10	40

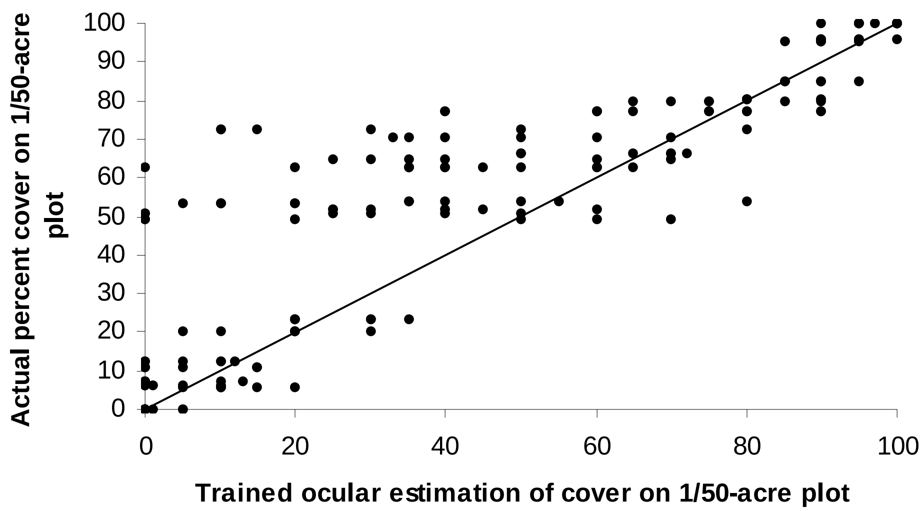

Figure 7. Actual versus trained ocular estimates of overstory cover on 1/50-acre circular plots over all study sites.

We present the times required to obtain the accuracy described above for two classes of measurement difficulty, based on slope and the amount of slash (Table 11). Study sites 2 and 5 provided relatively easy mobility (easy) and sites 1 and 4 were considered more difficult (hard). The walk-through required the least amount of effort of all of the methods. Considering only methods that use instruments (5-7), the “sighting tube-plotless” method using grid points was found to be the most efficient.

Table 11. Time required to a conduct survey for a study site and time per plot or point.

Method	**Difficulty**	***Average Time(min.)***	***Avg. Points/Plots***	***Time per Point/Plot(min.)***
1-Ocular, walk-through	Easy	6.50	na	na
	Hard	12.33	na	na
2-Ocular, plots	Easy	10.17	10.20	1.00
	Hard	20.58	11.40	1.81
3-Ocular, walk-through	Easy	6.00	na	na
	Hard	8.00	na	na
4-Ocular, plots	Easy	9.33	10.20	0.92
	Hard	15.67	11.40	1.37
5-Spherical densiometer	Easy	29.00	10.20	2.84
	Hard	42.08	13.10	3.21
6-Sighting tube, plots	Easy	29.83	10.20	2.92
	Hard	46.33	13.10	3.54
7-Sighting tube, plotless	Easy	21.75	53.50	0.41
	Hard	33.67	58.80	0.57

Discussion

The objectives of this project were to identify: 1) a method of measuring overstory canopy appropriate for PHIs, and 2) a more accurate method for enforcement or monitoring. The California Forest Practice Rules define overstory (14 CCR 895) as "…that portion of the trees, in a forest of more than one story, forming the upper canopy layers." Further, the rules list a variety of functions and processes that are to be protected by WLPZs, including water temperature, streambed and flow modifications by large woody debris, filtration of organic and inorganic material, vertical vegetation diversity, microclimate, snags, and surface cover. If water temperature, and hence shade, were the only factor of interest then a measure of angular shade canopy and relationship to the path of the sun would be of direct interest. A Solar Pathfinder® would be the most appropriate tool to answer that question. Because of the angle of sunlight, the sampling universe would be shifted northward for measuring shade canopy relative to one directly beneath the trees for measuring a vertical projection of canopy. The Forest Practice Rules imply that vertical overstory canopy closure is the parameter of interest.

Ocular estimation appears to be a biased method, although training and experience may reduce the magnitude of the bias. Our field crew consisted of experienced forestry personnel, and training only improved their estimates by less than five percent. The direction of the bias in our field crew of five was always an underestimation. If universally true, this underestimation would protect against harvesting below the standard. If this holds true for a larger population of persons applying the method, this makes the ocular estimation method appropriate for PHIs. The ocular plot method did not provide a substantial improvement in estimation over the walk-through method. The ocular plot method was also more time consuming and therefore we do not recommend it for our stated purposes. Ocular plots would be useful if a measure of variance were needed or as the auxiliary variable in a double sampling scheme.

The use of the vertical sighting tube on a systematic grid is the preferred method for more accurate estimation. This method is also the most efficient for any terrain. Analyses of the spherical densiometer as a tool for measuring vertical overstory canopy cover reveals that the sample collected does not enable an inference to the population and is biased (Bunnell and Vales 1990, Ganey and Block 1994, Cook et al. 1995, Robards 1998). This study is consistent with those conclusions. Other researchers (Nuttle 1997, Jennings et.al. 1999) have correctly pointed out that this instrument is by design not intended to measure canopy cover, but rather canopy density.

Having a clear definition of overstory is critical. Should the overstory be considered in the context of the entire WLPZ area being sampled or based on the particular position of the subject tree relative to its immediate neighbors? Based on the benefits larger trees provide within riparian areas, it seems plausible that the most conservative definition would be the former.

This study was not designed to determine whether experience with estimating canopy using instruments will improve an estimator's ability to ocularly estimate overstory canopy, although that is not an unreasonable hypothesis that could be explored further. Practitioners can improve their confidence in their estimates by always estimating ocularly before sampling with instruments until their ocular estimates are consistently within a desired difference of the instrument technique. Then, only infrequent calibration would be necessary.

Acknowledgements

The authors gratefully acknowledge the field assistance of CDF staff Clay Brandow, Helge Eng, Chris Keithley, Darla Mills, Jesse Rios, Allen Robertson, and Larry Ryan.

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Andrea E. Tuttle

Director

California Department of Forestry and Fire Protection

California Department of Forestry &
Fire Protection
P.O. Box 944246
Sacramento, CA 94244-2460