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ON MEASURING BIRD HABITAT: INFLUENCE OF OBSERVER VARIABILITY AND SAMPLE SIZE[1]

WILLIAM M. BLOCK
Department of Forestry and Resource Management, 145 Mulford Hall, University of California, Berkeley, CA 94720

KIMBERLY A. WITH
Department of Biological Sciences, Northern Arizona University, Flagstaff, AZ 86011

MICHAEL L. MORRISON
Department of Forestry and Resource Management, 145 Mulford Hall, University of California, Berkeley, CA 94720

Abstract. We studied the effects of observer variability when estimating vegetation characteristics at 75 0.04-ha bird plots. Observer estimates were significantly different for 31 of 49 variables. Multivariate analyses showed significant interobserver differences for five of the seven classes of variables studied. Variable classes included the height, number, and diameter of trees, height to the first live tree branch, height and number of shrubs, and composite variables. We then compared observer estimates with measurements of the same habitat variables. Univariate and multivariate comparisons of observer estimates with actual measurements revealed no clear pattern because estimates by each observer tended to deviate unpredictably from different measured values for 21 variables. Sample size requirements for selected variables ranged from 20 to 50 for measurements and from 20 to >75 for estimates. We noted significant differences in the point estimates and associated levels of precision between the two methods. Consequently, studies that rely on ocular estimates might sacrifice accuracy in lieu of potential time and cost savings.

Key words: Bird habitiat; habitat measurement; ocular estimation; observer variability; sample size.

INTRODUCTION

A major focus of the study of bird ecology is the analysis of habitat use. Such studies assume that birds select parts of the environment that provide for certain life requisites and that these habitats share some common characteristics (Hildén 1965, Morse 1980). To determine characteristics of a bird's habitat, investigators attempt to correlate the presence of the species to certain physical and floristic attributes of where it is found (e.g., James 1971, Whitmore 1975, Gutiérrez 1980, Mannan and Meslow 1984). The investigator assumes the characteristics of the habitat studied correspond to those selected by the bird, and the description of the habitat will have some resemblance to the one used by the bird.

Underlying the study of bird habitats is the premise that they are measured both accurately and precisely (Johnson 1981a). That is, the investigator records the physical characteristics of the area as they naturally occur and with little variation due to measurement. Although biases associated with measuring vegetation have long been recognized by range ecologists (e.g., Cooper

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1957, Schultz et al. 1961), they rarely have been addressed by avian ecologists (but see Gotfryd and Hansell 1985).

The measurement of bird habitat is confounded by size and shape of sample plots, habitat characteristics to be measured, and techniques used to measure them. James and Shugart (1970) and Noon (1981) suggested standards for measuring bird habitats, but such standards are not appropriate for all situations because of the variability among habitats (Cain and Castro 1959, Johnson 1981a).

Methods for describing bird habitats have two forms: visually estimating habitat characteristics, and more objective measuring techniques. Although both methods possess inherent biases, one would expect visual estimates to require greater human judgment, and thus exhibit more potential for bias. Objective measurement techniques using instruments (e.g., diameter tape for tree diameters, clinometer for tree heights, measuring tape for distances) require less judgment. Estimation techniques to determine cover over a line intercept (Canfield 1941) or within a sampling frame (Cain and Castro 1959) entail intermediate amounts of judgment and associated biases (Schultz et al. 1961).

Another factor to consider is differences among observers in judgment. Gotfryd and Hansell (1985) found significant interobserver differences for 18 of 20 univariate habitat comparisons, and also when variables were combined in multivariate analyses. The measurement protocol used by Gotfryd and Hansell (1985) followed James and Shugart (1970), which included both measurement and estimation techniques. To date, few attempts have been made to distinguish the types and magnitudes of differences among observers who simply visually estimate habitat characteristics, and rarely have such estimates been compared with measured values (Verner 1985).

Determining adequate sample size underlies any properly designed study. Primary considerations are to obtain point estimates that are within investigator-defined ranges of precision that can be obtained within time and cost constraints. Unfortunately, many ecological data rarely are drawn from normally distributed populations (Williams 1983), and attempts to achieve accurate and precise estimates generally are precluded because of the large samples required (Noon 1981). Morrison (1984a) provided a technique for determining sample sizes based on a stability analysis. Sample size was defined by the point at which the confidence interval and the point estimate showed little variation with increasing sample sizes. In this paper we present a study to (1) compare interobserver variability in visually estimating habitat characteristics, (2) examine differences between observer estimates and objective measurements, and (3) determine sample size requirements for estimating and measuring habitat variables.

STUDY SITES

The study took place at Blodgett Forest Research Station of the University of California–Berkeley, El Dorado County, California. Blodgett Forest is located in the mixed-conifer region of the central Sierra Nevada at an elevation of 1,350 m. The forest has a tree canopy dominated by Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), ponderosa pine (*Pinus ponderosa*), sugar pine (*P. lambertiana*), incense cedar (*Calocedrus decurrens*), and California black oak (*Quercus kelloggii*). The forest is divided into compartments ranging in size from 5 to 40 ha; these are subjected to various silvicultural practices. In 1985 we selected five compartments representative of the diversity of habitats found on the forest. Four were subjected to uneven-aged management practices; the fifth was designated a reserve and had not undergone any recent treatments.

METHODS

During the 1985 breeding season we followed approximately 6 km of fixed transects distributed among the five compartments to locate birds representative of three major foraging strata: the Hermit Warbler (*Dendroica occidentalis*)–upper canopy, Solitary Vireo (*Vireo solitarius*)—subcanopy, and Dark-eyed Junco (*Junco hyemalis*)—ground. We chose these species to include a large range of possible habitats used by birds. Because our sample sizes for each species (range 22–27 per species) were below the minimum suggested by Johnson (1981b) and Morrison (1984b) for analysis of habitat use, we pooled samples of all species ($n = 75$).

The location of each bird sighting corresponded to the center of a 0.04-ha circular habitat plot in which structural and floristic habitat characteristics were quantified. Vegetation characteristics at each plot were visually estimated independently by three observers (O1, O2, and O3), and then measured using established forest measurement techniques (Appendix A). The observers in this study averaged 6 years (range 3–10 years) of experience in estimating and/or measuring forest vegetation. Prior to estimating habitat variables, individuals participated in calibration exercises. These exercises were done daily prior to actual vegetation estimates and allowed observers to compare and adjust their estimates of the vegetation to measured values. Thus, by using experienced observers and by regularly checking estimates against verified measures we attempted to minimize observer error.

VEGETATION METHODS

Ocular estimates. Prior to estimating vegetation in any plot the observers discussed specific techniques for estimating the different habitat characteristics to standardize the methods used. In practice, however, each observer used different tabulation techniques while recording data. For example, when counting shrubs O1 kept a mental record, whereas O2 and O3 recorded ticks along the edge of the data sheet. Further, all observers worked in the plots simultaneously, and thus probably influenced the methods used by each other. This factor, however, probably acted further to standardize the way observers measured the plots.

Measurements. Vegetative characteristics (Appendix A) in each plot were measured by a two-person team after the ocular estimation procedure. To maximize precision associated with the measurement techniques, each task was done by the same person in all plots. Tree canopy, subcanopy, shrub, and large (>25-cm diameter) downed woody cover were estimated as the average cover over two randomly placed, perpendicular 22.6-m line intercepts (Canfield 1941). Herbaceous and small (<10-cm diameter) woody cover were estimated as the average cover within eight 1-m² sample plots (Cain and Castro 1959). Heights of all trees were measured with a clinometer; tree diameters were measured with a diameter tape. We counted the numbers of all trees by species that occurred within the plot. The numbers of shrubs by species were counted within a 7.5-m radius of plot center. Average shrub height by species was estimated by averaging the heights of up to eight shrubs of each species sampled systematically along the line intercept.

STATISTICAL ANALYSES

Univariate comparisons. Two-way analysis of variance (ANOVA) for a randomized block design (Steel and Torrie 1960) was used to compare ocular estimates of vegetation by observers. If a significant (all tests were considered significant at $P \leq 0.05$) difference was noted, we used Scheffé's comparisons to determine how observers differed (Marascuilo and McSweeney 1977). We used Levene's test (Brown and Forsythe 1974) to determine if the variances of observer estimates were significantly different. We then compared ocular estimates by each observer to the measured values using a series of two-way ANOVAs for a randomized block design (Steel and Torrie 1960). This design allowed us to partition variation attributable to plot differences from the analysis to test for differences between observer estimates and measurements.

Multivariate comparisons. We performed a series of multivariate analyses of variance (MANOVAs) to test first for differences among observers, and then between observer estimates and measured values. We calculated separate MANOVAs on subsets of the data by dividing the variables into seven classes: tree heights, tree numbers, shrub numbers, tree diameters, heights to the first live tree branch, cover, and a composite set of variables consisting of average tree height and diameter, tree and shrub numbers, and average height to the first live branch. Plot effects were partitioned from the analyses and MANOVAs were done on observer effects to test for significant differences as measured by Wilks' lambda statistic (Green 1978). We tested for homogeneity of dispersion matrices using Box's M statistic (SPSS 1983). MANOVAs were then done between each observer and measured values for each class of habitat variables.

SAMPLE SIZE ANALYSES

We selected the two variables from each of the variable classes that had the greatest and least variation. For each variable we randomly selected, with replacement, 10 subsamples for samples of 5, 10, 15, 20, 30, 40, 50, and 60 plots. We calculated the mean for each sample, and then calculated a mean of the means for each subset. Morrison (1984b) used the point where the mean and confidence interval stabilized to determine sample size. Stability is defined here as the point where the estimates of the mean remain within one standard deviation of subsequent estimates

TABLE 1. Comparisons among ocular estimates by observers and between observer estimates and measured values of vegetation variables within 0.04-ha circular plots.

Variable	Interobserver comparisons				Observer vs. measured comparisons		
	F-ratio[a]	O1	O2	O3	O1[b]	O2	O3
Percent cover							
Litter	36.8	A	B	A, B		**	*
Herbaceous	ns						
Dead woody material <10 cm	43.4	A	B	A	**	**	**
Dead woody material 11–25 cm	99.4	A	B	A		**	
Dead woody material >25 cm	ns						
Shrubs	28.7	A, B	A	B		**	
Sub-canopy	34.2	A	A	B			**
Canopy	ns				**	*	*
Tree diameter dbh							
Douglas-fir	ns						
White fir	3.2	A	A	A			**
Ponderosa pine	ns						
Sugar pine	ns						
Incense cedar	3.8	A	A	A			**
Black oak	ns						
Average shrub height (m)							
Douglas-fir	ns						*
White fir	ns						
Ponderosa pine	ns						
Sugar pine	3.5	A	A	A			*
Incense cedar	ns						
Black oak	9.7	A	A	A			
Average tree height (m)							
Douglas-fir	11.8	A	B	A, B			
White fir	36.7	A	B	B		**	
Ponderosa pine	11.0	A	A	A			
Sugar pine	26.8	A	B	A, B			
Incense cedar	14.2	A	B	B	*		
Black oak	ns						
Average height to live branch (m)							
Douglas-fir	3.7	A	A	A			
White fir	3.2	A	A	A			
Ponderosa pine	5.6	A	A	A			
Sugar pine	16.6	A	B	A			
Incense cedar	13.5	A	B	B		*	
Black oak	ns						
Shrub numbers [log(#/0.04 ha)]							
Douglas-fir	ns						
White fir	7.9	A	A	A		*	
Ponderosa pine	ns						
Sugar pine	6.1	A	A	A			
Incense cedar	8.5	A	A	A	*	**	
Black oak	14.7	A, B	B	A		**	
Tree numbers [log(#/0.04 ha)]							
Douglas-fir	4.6	A	A	A			
White fir	10.2	A	A	A			
Ponderosa pine	ns						
Sugar pine	ns						
Incense cedar	17.6	A	A	A	**		
Black oak	ns						

TABLE 1. Continued.

Variable	Interobserver comparisons				Observer vs. measured comparisons		
	F-ratio[a]	O1	O2	O3	O1[b]	O2	O3
Composite variables							
Total no. trees/0.04 ha	31.4	A	B	B	**		
Average tree DBH	5.6	A	A	A			
Total no. shrubs/0.04 ha	10.3	A	A	B	*	**	**
Average height to live branch	20.2	A	B	A, B	*		
Average tree height	53.4	A	B	B	**		

[a] Two-way anlaysis of variance; df = 74, 2, 148. F-ratio measures observer effects. F is significant at $P \leq 0.05$, unless noted nonsignificant (ns). Within the same row, values with the same letter are not significantly different (Scheffé's planned comparisons; $P \leq 0.05$).
[b] Two-way analysis of variance; df = 74, 1, 74; * significantly different at $P \leq 0.05$; ** significantly different at $P \leq 0.01$.

and there is little variation in the magnitude of the confidence interval. We duplicated this analysis for both the estimated and measured plots to compare the influence of sample size for ocular estimates and measurements.

RESULTS

UNIVARIATE COMPARISONS

Cover. Significant interobserver differences were found for five of the eight estimates of cover (Table 1). The only nonsignificant comparisons among observers were for herbaceous, large (>25-cm diameter), downed, woody material and tree canopy cover. In comparisons of ocular estimates with measurements, estimates by O1 differed from measures for two of the seven variables, whereas estimates by O2 and O3 differed from measurements on four and five variables, respectively. Further, although estimates of canopy cover among the observers did not differ significantly, all estimates differed from the measured values. The variances of estimates by all observers and of measurements were heterogeneous for all variables (Levene's tests, $P \leq 0.01$).

Tree dbh. Ocular estimates by observers were significantly different for only white fir and incense cedar (Table 1). In contrasts of observer estimates with measured values, only two estimates by O3 differed from measurements. The differences by O3 were attributable to underestimating the measured values. The variances of the estimates by all observers and of measurements were heterogeneous for all variables (Levene's tests, $P \leq 0.01$).

Shrub and tree heights. Ocular estimates among observers differed for sugar pine and black oak shrubs (Table 1). Estimates by O3 differed from measures of the heights of Douglas-fir and sugar pine shrubs.

Ocular estimates by observers differed significantly for heights of all tree species but black oak (Table 1). Multiple comparisons showed that O2 and O3 were not significantly different for any of the six variables, and O1 was separated from O2 and O3 on two of the six variables. O2 significantly underestimated the height of white fir; O1 overestimated the height of incense cedar.

Significant observer differences were found for estimates of height to the first live tree branch of all trees but black oak (Table 1). O1 and O3 differed from O2 in estimating branch height of sugar pine, and O3 and O2 differed from O1 in estimating branch height of incense cedar. O3 significantly underestimated the height to branches of incense cedars. The variances of the estimates by all observers and of measurements were heterogeneous for all height variables (Levene's tests, $P \leq 0.01$).

Shrub and tree numbers. Estimates of shrub numbers differed for white fir, sugar pine, incense cedar, and black oak (Table 1). Estimates by O2 differed significantly from the measured number by underestimating numbers of white fir, incense cedar, and black oak. O1 underestimated the numbers of incense cedar.

Estimates of tree numbers by observers differed for Douglas-fir, white fir, and incense cedar (Table 1). O1 underestimated the number of incense cedars. The variances of estimates by all observers and of measurements were heterogeneous for all variables (Levene's test, $P \leq 0.01$).

Composite variables. When variables from the classes were combined to derive new variables, estimates by observers were significantly different for all five variables (Table 1). O1 underestimated the numbers of shrubs and trees, and overestimated average heights of trees and first live branches. O2 and O3 underestimated the

TABLE 2. Multivariate comparisons of interobserver estimates, and observer estimated vs. measured values for seven classes of habitat variables.

			Observer vs. measured					
	Interobserver[a]		O1		O2		O3	
Variable	Wilks' lambda	Box's M	Wilks' lambda	Box's M	Wilks' lambda	Box's M	Wilks' lambda	Box's M
Tree heights	0.47**	95.06**	0.89*	46.17*	0.92	45.32*	0.97	19.38
Cover	0.19**	234.09**	0.83**	123.36**	0.35**	83.6**	0.70**	141.30**
Tree dbh	0.85*	29.78	0.95	18.04	0.95	31.28	0.90*	29.22
Height to first branch	0.64**	194.06**	0.96	72.73**	0.95	61.04*	0.94	52.03**
Tree numbers	0.69**	26.12	0.92	10.53	0.98	7.03	0.99	10.67
Shrub numbers	0.63**	62.09	0.92	27.73	0.96	16.42	0.82**	30.47
Composite variables	0.36**	339.75**	0.50**	78.06**	0.81**	128.88**	0.78**	70.94**

[a] * Significant at $P \leq 0.05$; ** significant at $P \leq 0.01$.

numbers of shrubs. Variances of the estimates by observers differed for all variables (Levene's test, $P \leq 0.01$).

MULTIVARIATE COMPARISONS

Between-observers. A series of multivariate analyses of variance (MANOVAs) done on the seven classes of variables showed significant differences between observers for all classes (Table 2). Box's M tests for homogeneity of multivariate variances among observers were significant for tree heights, cover, height to the first branch, and the composite variables.

Ocular estimates vs. measurements. All three observers differed significantly from measured values for the cover and composite variables classes (Table 2). In addition, O1's estimate of tree height differed significantly from measured values, and O3's estimates of tree dbh's and shrub numbers were significantly different from the measured values. The variance-covariance matrices of ocular estimates by all observers were significantly different from those of the measurements for the cover, height to first live branch, and composite classes of variables. Dispersion matrices for estimates by O1 and O2 differed from the dispersion matrix for measurements in the tree height class as well.

SAMPLE SIZES

Sample size analyses indicated that different samples were required for different variables, whether variables were measured or estimated. Minimum sample size requirements for measured variables ranged from 20 (average tree dbh) to 50 (average tree height), and those for estimated variables ranged from 20 (average tree diameter) to >75 plots (average height to the first live sugar pine branch). Although the means and confidence intervals of subsamples stabilized for most measured variables, samples for many estimated variables never appeared to stabilize. Further, point estimates of variables frequently differed between estimates and measurements. We describe below the influence of measurement and estimation techniques on sample sizes for different variable classes. For each class we provide a graphical example of the influence of sample size.

Cover. Ocular estimates for canopy cover did not stabilize until $n = 30$, but the mean rose slightly at $n = 60$ when the estimate of canopy closure increased from 40 to 43% (Fig. 1A). Systematic measurements stabilized at $n = 30$ at a mean value of 49%. Ocular estimates were lower than measured values for all sample sizes (Fig. 1A). Both ocular estimates and measurements for medium (11 to 25 cm diameter) woody cover stabilized at $n = 20$. Means for ocular estimates were consistently greater than measurements.

Tree dbh. Ocular estimates for the dbh of sugar pine never appeared to stabilize as the point estimate suddenly increased at $n = 60$ (Fig. 1B). Means for measurements stabilized at $n = 35$, and remained stable. Means overlapped for both techniques until $n = 15$, diverged through $n = 50$, and then converged at $n = 60$ (Fig. 1B). Both ocular estimates and measurements for the diameter of incense cedar stabilized at $n = 25$. Mean estimates were slightly less than those of measurements for all sample sizes.

Tree numbers. Measurements of the number of incense cedar stabilized at $n = 30$; however, estimates appeared to stabilize at $n = 30$, but became unstable at $n > 50$ (Fig. 1C). Mean values for estimates overlapped with measured values until $n = 10$; estimates were less than mea-

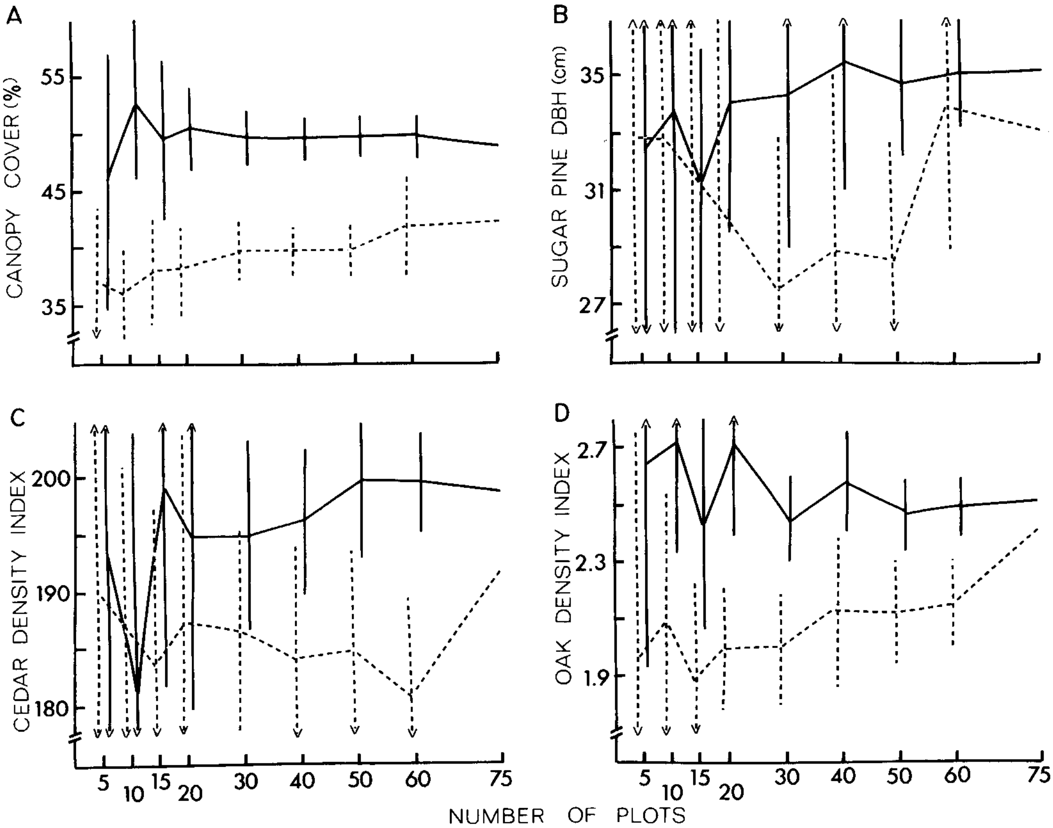

FIGURE 1. Influence of sample size on the stability of estimates (dashed horizontal lines) and measurements (solid horizontal lines) of bird habitat characteristics. Dashed or solid vertical lines represent 1 SD from point estimates for estimates and measurements, respectively. Variables shown are (A) percent tree canopy cover, (B) diameter at breast height for sugar pine, (C) 100 × $\log_{10}$ of the average number of incense cedar trees within sample plots, (D) $\log_{10}$ of the average number of black oak shrubs within sample plots.

sures for all $n > 10$. Means for ocular estimates and measurements of the number of ponderosa pine overlapped for all sample sizes. Measurements stabilized at $n = 50$, but estimates never appeared to stabilize.

Shrub numbers. The mean and confidence interval for the number of shrub-sized black oak stabilized at $n = 30$ for measurements; however, estimates appeared stable at $n = 20$ but became unstable at $n > 60$ (Fig. 1D). The estimated number of black oak shrubs was less than the number measured.

Tree heights. The mean and confidence interval for the height of sugar pine stabilized at $n = 20$ for measurements, but never stabilized for estimates (Fig. 2A). Observer estimates tended to be lower than measured heights.

Ocular estimates for height to the first live branch on sugar pine stabilized at $n = 20$ for the measurements, but never stabilized for estimates (Fig. 2B). Mean estimates and measurements, however, overlapped for most sample sizes.

Composite variables. The mean and confidence intervals for total shrub numbers stabilized at $n = 30$ for ocular estimates and $n = 40$ for measurements (Fig. 2C). There was a noticeable difference between the number of shrubs that were estimated compared to the number counted. A similar relationship appeared for the average number of trees per plot, as the number estimated was consistently less than the number counted (Fig. 2D). The ocular estimates and measurements stabilized at $n = 30$ and $n = 40$, respectively.

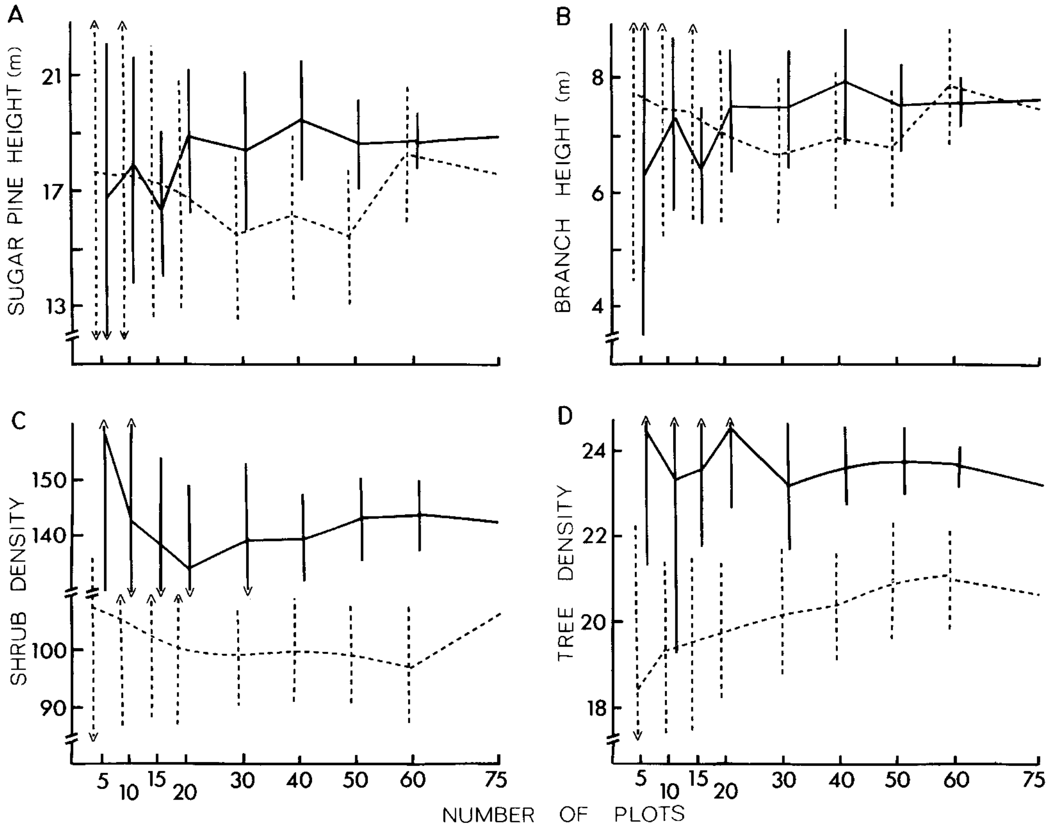

FIGURE 2. Influence of sample size on the stability of estimates (dashed horizontal lines) and measurements (solid horizontal lines) of bird-habitat characteristics. Dashed or solid vertical lines represent 1 SD from point estimates for estimates and measurements, respectively. Variables shown are (A) average height of sugar pine, (B) average height to the first live branch of sugar pine, (C) average number of shrubs within sample plots, and (D) average number of trees within sample plots.

DISCUSSION

INTEROBSERVER VARIABILITY

Ocular estimates by the three observers differed for 31 of the 49 variables used in our study. In contrast, Gotfryd and Hansell (1985) found significant differences among observers for 18 of 20 variables. We believe the discrepancy between the results of Gotfryd and Hansell and this study can be explained as follows. Both studies used standardization procedures to calibrate methods used by observers. The actual techniques used by each study, however, differed. Gotfryd and Hansell used the James and Shugart (1970) method to measure habitat variables, whereas we used more biased ocular estimation techniques. Gotfryd and Hansell's (1985) study occured at only eight different sampling points, which were measured four times each by four different observers. In contrast, our habitat measurements were done at 75 independent points and probably included greater habitat variation. Thus, given that our study entailed more biased observer estimates and probably included greater habitat variation than Gotfryd and Hansell's (1985) study, we would have expected our observers to differ more often than those in their study. It is notable, however, that the observers in this study averaged six years of experience, and between them had measured >4,000 habitat plots. Gotfryd and Hansell (1985) reported that each of their four observers had previously measured at least 70 plots, about 1,000 plots totally (Gotfryd, pers. comm.). Further, the two studies occurred within different habitats which likely differed in structure and composition of the vegetation. Thus, we suggest that the different results of the two studies might be attributable to differences in experience by observers and/or differences in habitats.

Perhaps the most confounding aspect of using estimates by multiple observers is unpredictable interobserver variation. Multiple comparisons of estimates for the 31 significant variables resulted in all possible combinations of groupings of observers. For instance, O1 was grouped separately from the other two observers for five variables, O2 differed from O1 and O3 for three variables, and O3 differed from O1 and O2 for two variables. Thus, when samples from different observers are pooled, observer variation increases. Further, we found significant observer differences for all of the seven variable classes we analyzed by MANOVA. It is conceivable that multivariate ordinations to describe habitats of species would result in different ecological gradients and consequently, different interpretations of species' habitats. Thus, our results support Gotfryd and Hansell's (1985) conclusions that the interpretations of multivariate axes can vary depending on the person who collects the field data.

OBSERVER ESTIMATES VS. MEASUREMENTS

Comparisons of observer estimates and measurements further demonstrate differences among observer estimates. Estimates by at least one observer differed from measurements for 21 of the 49 variables. All observers underestimated measurements for small (< 10-cm diameter) downed woody cover, tree canopy cover, and total shrub numbers. Estimates by two observers differed from measurements for litter cover and number of incense cedar shrubs. Both observers consistently overestimated litter cover and underestimated the number of incense cedar shrubs. Estimates by one observer were significantly different from measurements for 16 variables. Observers tended to underestimate tree diameters, tree and shrub numbers, heights to first live tree branches, and canopy cover, and overestimate tree heights (except for black oak) and ground cover.

Although estimates by one or more observers may have differed from measurements, values obtained by objective measurement techniques are not without inherent biases. Plant ecologists have long recognized differences among techniques and have compared values obtained for particular variables using various techniques (Cooper 1957, Lindsey et al. 1958, Schultz et al. 1961, Hatton et al. 1986). The objective of using measurement techniques is to reduce the magnitude of human error, and although these methods contain their own biases, it is expected that they are more accurate than ocular estimates (Schultz et al. 1961). Further, we know of no study that addresses biases of particular measurement techniques (e.g., actually measuring tree height with a tape to compare with values obtained using a clinometer, or tagging all trees or shrubs to be certain of an exact count). Until such biases are determined we can only assume that measurements are more accurate than estimates.

SAMPLE SIZES

We found it possible to obtain stable point estimates for most variables when measured. Conversely, we were unable to determine stability for many variables when estimated. The implications of adequate sample sizes are well documented in the statistical literature (Cochran 1963). Adequate samples are required to provide precise point estimates for the variables of interest. Most habitat studies of vertebrates entail the quantification of a set of habitat characteristics, which are used to describe consistent features in the habitat used by the organism. Consequently, the total number of samples required should be no less than the greatest sample size required for any one variable. In this study, minimum sample sizes would be 50 and >75 for measurements and estimates, respectively.

Morrison (1984b) found that a minimum of 35 samples was needed for discriminant analyses of the habitats of the birds he studied. He worked in clearcut areas that exhibited less vegetative complexity than our areas and could probably be estimated with greater accuracy. Morrison (1984b) noted that many studies included inadequate samples. Our results indicated that even larger samples were required in forested habitats and consequently the minimum sample proposed by Morrison (1984b) appears too small for some types of habitats.

Lindsey et al. (1958) proposed a measure of efficiency for different forest sampling methods based on the effort required to achieve a specified precision of the estimates. We found that, on average, less than one-third the time was required to estimate plots compared to measuring them (17.3 ± 2.6 [SD] vs. 56.8 ± 18.8 min). If we consider the time required to obtain stable means and confidence intervals, then estimation is more efficient, in the sense of Lindsey et al. (1958), than measurements for the variables that stabilized at ≤75 plots. These estimates, however, may never be as accurate as measurements, e.g., canopy cover (Fig. 1), tree and shrub density (Fig. 2).

Our results and those of Gotfryd and Hansell (1985) clearly show significant differences among the estimates of different observers. We also found significant differences between observer estimates and measurements for many variables. Further, the curves resulting from our sample size analyses never stabilized for some variables when estimated, whereas the curves stabilized for measurements of the same variables. These results strongly suggest that investigators reconsider using estimation techniques for quantifying habitat characteristics until the magnitude and effects of observer variability are understood more fully.

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APPENDIX A

Vegetation characteristics estimated and measured within 75 0.04-ha circular plots at Blodgett Forest Research Station, El Dorado County, California.

Litter cover. Average percent litter cover within eight 1-m^2 sampling frames.

Herbaceous cover. Average percent herbaceous cover within eight 1-m^2 sampling frames.

Small (<10 cm diameter) downed woody cover. Average percent small downed woody cover within eight 1-m^2 sampling frames.

Medium (11–25 cm diameter) downed woody cover. Average percent of medium downed woody cover over two perpendicular 22.6-m line intercepts.

Large (>25 cm diameter) downed woody cover. Average percent of large downed woody cover over two perpendicular 22.6-m line intercepts.

Shrub cover. Average percent shrub cover over two perpendicular 22.6-m line intercepts.

Sub-canopy. Average percent sub-canopy tree cover over two perpendicular 22.6-m line intercepts.

Tree canopy cover. Average percent of tree canopy cover over two perpendicular 22.6-m line intercepts.

Average diameters of trees by species. Average diameter of each tree species measured using a diameter tape.

Number of trees by species. Number of trees counted within the plot for each species.

Number of shrubs by species. Number of shrubs of each species counted within a 7.5-m radius of plot center.

Average shrub height by species. Average height of one to eight shrubs per species within the plot. Shrubs were sampled systematically along the two line-intercepts and were measured with a ruler.

Average tree height by species. Average height by species of trees found within the plot. Tree heights were measured with a clinometer.

Average height to first live tree branch. Average height by species of trees found within the plot. Branch heights were measured with a ruler or a clinometer.