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DISTANCE ESTIMATION AS A VARIABLE IN ESTIMATING BIRD NUMBERS FROM VOCALIZATIONS

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ABSTRACT.—The accurate measurement of distances is basic to any accurate determination of bird densities. We used field studies to determine the accuracy of distance estimates to birds heard and not seen.

Under good field conditions observers were able to estimate the distance to birds heard and not seen to within ±10% (range of averages −9.1 to +6.3%). The range of all distance estimates was one-fourth to four times the measured value with 95% falling between 4/7 and 7/4. There were significant differences between observers ($P < .025$) and species ($P < .001$).

Simulation studies were used to determine the effect of measurement errors on the accuracy of density estimates.

Suggestions for reducing the bias in density estimates resulting from measurement errors include: (1) training observers; (2) flagging known distances; (3) using range finders; (4) explaining to observers the importance of their work; (5) minimizing the responsibilities of observers; and (6) using robust methods to analyze data.

The number of birds per unit area is being estimated with increasing frequency. The methods used include: 1) counting birds within a prescribed area and 2) recording all birds heard or seen in an undefined area. The first method requires that either the area of interest be marked (Anderson and Shugart 1974), with the presence or absence of a bird within that area recorded, or that an observer make repeated judgments as to whether an animal is within an area whose limits are estimated or measured (Fowler and McGinnes 1973). Distances employed have ranged from 10 to 400 m (Anderson and Shugart 1974, Robbins and Bystrak 1974) and assumptions of coverage range from all birds in the area to some unknown percentage. The second method requires that the initial detection distance to each animal be measured or estimated. Distances can be the flushing distance (Hayne 1949), right angle distance (J. T. Emlen 1971), Gates sighting angle and distance (Robinette et al. 1974) or the horizontal distance (Reynolds et al. 1980).

The accurate measurement of distances is essential to any accurate estimate of bird density. In fact, tape measure accuracy is the suggested standard (Burnham et al. 1980). Measurement of distances is frequently used in studies of nonmoving objects: plants, nests etc. In most studies of bird populations, however, observers use a range finder or simply estimate distances (J. T. Emlen 1971).

The accuracy of range finders varies with the model and the frequency of calibration, but they are indicated as being good to approximately 1% within 30 m and ±5% at distances between 100 and 300 m. Observers vary in their ability to estimate distances to objects that can be seen, but are felt to quickly become accurate within ±10–15% when estimating distances to birds that can be seen (Emlen 1977a).

Forest birds are more frequently heard than seen. In Hawaii, for example, the vast majority of all birds detected during surveys are never seen. In a random sample of 100 station counts made by 6 observers on Maui in 1980, we found that 894 of 1100 (81%) bird detections were made on the basis of sound alone. More surprising, on 37 of these 100 eight-minute count periods *all* detections were made on the basis of call notes or song: no birds were seen, even after the initial audio detections (Scott and Kepler, unpubl. data). Judgments as to the location of these birds could be made, and the distances then measured using tapes or a range finder. In practice, however, where more than two to three birds are detected during a count period (we recorded an average of 11 birds per count period on Maui), physical measurement of the distances, however desirable, becomes impractical. In addition to physical and time constraints, the concentration required to measure each detection distance makes it impossible to scan for additional birds. This results in a serious failure to detect other individuals present, and an underestimate of numbers. Thus detection distances must be estimated or severe restrictions placed on the number of birds to be recorded (Scott and Ramsey 1981b).

We have found that observers, after gaining confidence in their ability to estimate distances, make their estimates of distance without the aid of a range finder, or only use the range finder to measure the distance to one or two prominent objects. They then rely on known distances and

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TABLE 1
OBSERVER DIFFERENCES IN MEASURED AND ESTIMATED DIFFERENCES

Observer	*N*	% Deviation
A	117	+6.3
B	32	+4.4
C	31	+3.2
D	74	+2.5
E	110	−1.8
F	103	−3.0
G	121	−3.3
H	124	−4.0
I	58	−4.1
J	143	−4.1
K	114	−4.7
L	48	−7.0
M	139	−7.6
N	111	−9.1

TABLE 2
PERCENT DEVIATION IN ESTIMATED FROM MEASURED DISTANCES FOR 15 SPECIES OF BIRDS

Species	*N*	% Deviation
Loxops coccineus coccineus	19	+9.0
Carpodacus mexicanus	50	+8.5
Vestiaria coccinea	172	+3.9
Phasianus sp.	3	+3.9
Meleagris gallopavo	4	+2.1
Himatione sanguinea sanguinea	102	−0.7
Loxops virens virens	206	−2.0
Cardinalis cardinalis	142	−2.6
Phaeornis obscurus obscurus	231	−4.5
Loxops maculatus mana	45	−5.7
Corvus tropicus	4	−6.6
Chasiempis sandwichensis sandwichensis	147	−8.7
Hemignathus wilsoni	46	−9.8
Leiothrix lutea	91	−10.1
Zosterops japonicus	63	−10.1

their own ability to estimate. With the importance placed on accurate distance measurements in the methods used to estimate bird densities (Burnham et al. 1980) and the fairly loose means by which these distances are actually estimated, we felt it was important to understand how accurately individuals can determine distances and how this accuracy might vary with distance, species, and between observers. We use this information to estimate the errors introduced in the calculation of bird densities and hence population sizes using estimated distances.

There are several possible sources of error. Distances can be mismeasured, under—or overestimated, or rounded off to convenient figures (Gates et al. 1968, Anderson and Pospahala 1970, Robinette et al. 1974). In practice all three errors are made. The extent to which they are made and their effects on accurate measures of bird abundance are the topics of this paper. In addition to observer errors, the effects of screening by vegetation, wind, rain, temperature, and background noises vary from site to site and day to day, and there are also problems created by echoes, ventriloquism, or even the direction faced by the cue-emitting bird (Witkin 1977).

METHODS

In order to determine how accurately observers estimate distances, we asked small groups of four to six experienced observers to estimate the distance to birds heard but not seen. All participants had been carefully trained in distance estimation (see Kepler and Scott 1981 and Scott et al. 1981b). All observers were at a single station. Observers were preconditioned by estimating distances to reference points prior to the estimates to birds heard and not seen. One of the observers located a singing or calling bird, then identified it to the others. All independently estimated the distance to that bird, which was then located. The actual distance was measured using a range finder or tape measure. Estimations by observers who had seen the subject bird were eliminated.

Data for the accuracy of these distance measurements consist of 1325 ($=n$) distance pairs (x, y) where x = estimated detection distance and y = measured detection distance. Included were observations on 15 species made by 14 observers.

To measure the discrepancy between estimated (x) and measured (y) distances, we considered $Z = \log (x/y)$ which best met our criteria of a) variance is unrelated to average, b) observer and species effects are additive, and c) residuals from fitted model have a symmetric unimodal distribution. The model we used is a standard two-way ANOVA Model with interactions.

$$Z_{ijk} = \mu + y_i + \tau_j + \theta_{ij} + e_{ijk} \qquad (1)$$

where μ = reference level of Z
y_i = (fixed) effect of the i^{th} observer; $I = 1, \ldots, m\ (=14)$
τ_j = (fixed) effect of j^{th} species; $j = 1, \ldots, s\ (=15)$
θ_{ij} = fixed interaction terms

and

e_{ijk} = (random) departure of Z_{ijk} from its average.

The assumptions of the model are that the e_{ijk} are independently distributed with a mean of zero and a constant variance.

RESULTS

FIELD STUDIES

Estimated distances ranged from ¼ the measured distance to 4 times the measured distance. These represent extremes of the rather long-

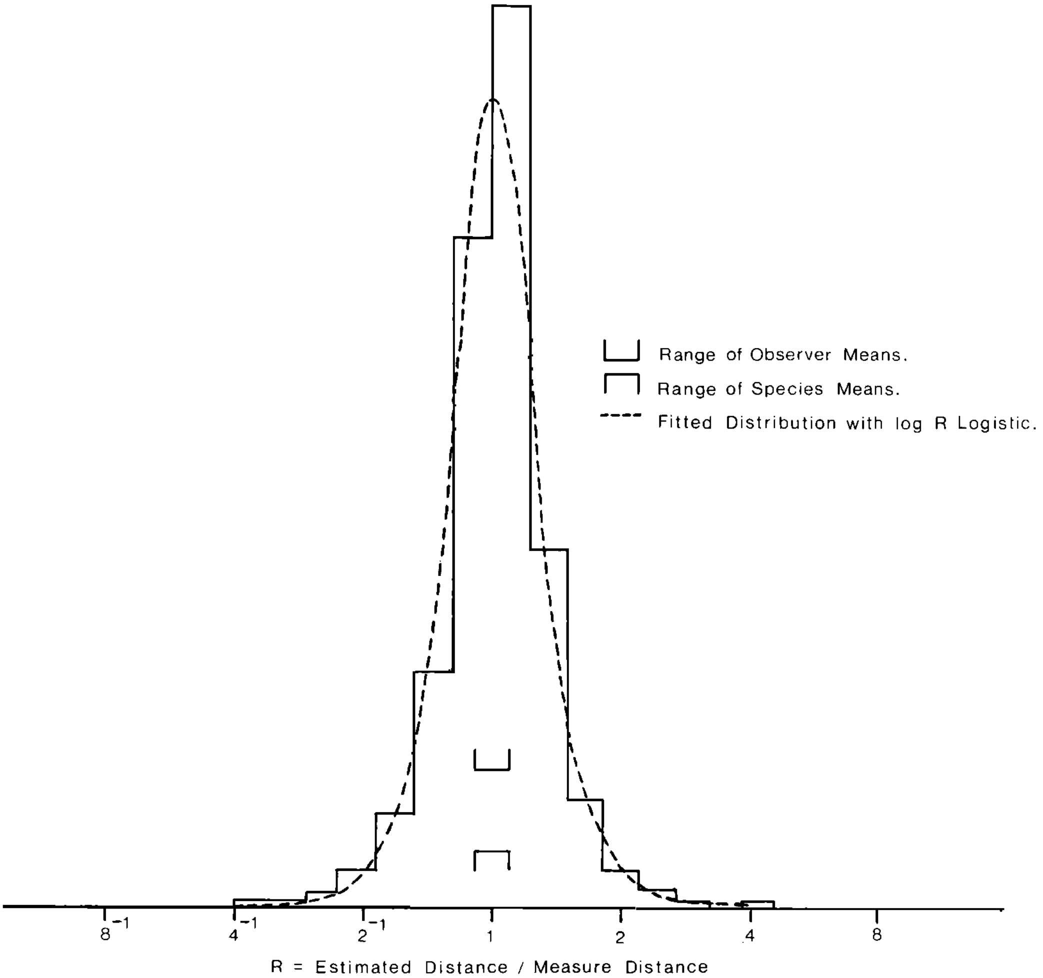

FIGURE 1. Distribution of ratios of estimated to measured distances.

tailed distribution of ratios of estimated to measured distances; 95% percent of these ratios were between 4/7 and 7/4.

There were statistically significant differences in the abilities of observers to estimate differences ($P < .025$), and the accuracy of distance estimates varied significantly with species ($P < .001$). The discrepancies are minor, however, in comparison with the overall variability of the results. Observer mean effects ranged from 9.1% below measured to 6.3% above measured, while species effects ranged from 10.1% below to 9.0% above measured distances (see Tables 1 and 2, respectively). Interactions were quite insignificant ($P > .40$). The reference level was not significantly different from zero ($P > .35$) indicating a lack of overall bias in the errors.

Figure 1 displays a histogram of the residuals from a least-squares fit to equation (1). The distribution appears reasonably symmetric and unimodal, but it possesses much more in the tail regions than should be expected of a normal curve. Thus the superimposed curve represents a logistic distribution with location parameter zero and scale parameter $\sigma = .152$ (estimated by the maximum likelihood method; see Johnson and Kotz, 1970).

Figure 2 shows a scatter plot of the same residual versus the measured distances. As the slightly negative slope to the regression line indicates, there is some small tendency for observers to overestimate short distances and underestimate larger distances.

SIMULATIONS

We conducted computer simulation studies to determine how distance estimation errors of the kind encountered in the above experiment might

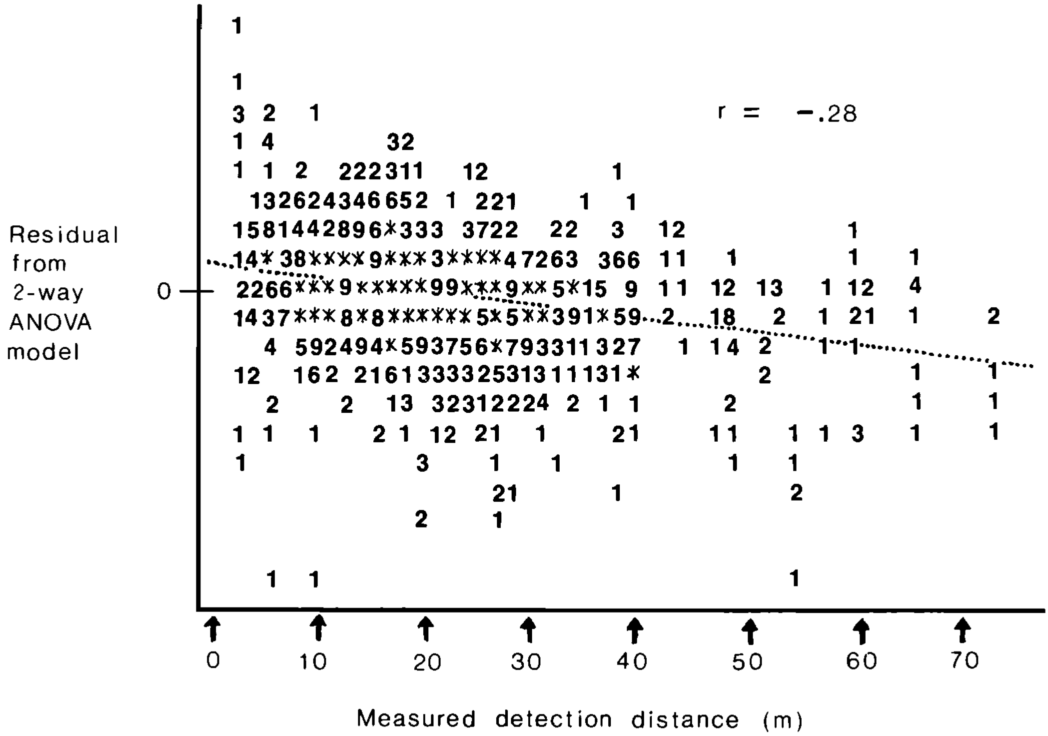

FIGURE 2. Distribution of the residuals from a least squares fit to equation (1) versus the measured distances. An asterisk indicates a cell count exceeding 9.

change estimates of density. In a typical run, "birds" are spread across a large circular region, according to a spatial Poisson process with known, constant density. The birds sing at random points in time, the "observer"—who occupies the circle's center—having a chance of detecting each call. The chance depends upon the distance separating bird and observer. (For a full explanation of the simulation model, see Ramsey, Scott and Clark, 1979). For each bird detected during a fixed observation period, we recorded its true distance, Y, from the station and then generated a random deviate, Z, from the logistic distribution with zero mean and scale σ. Then we took the estimated distance to be $X = Y \cdot \exp(Z)$.

Typically, a run produced 200–250 detections. We estimated density using both the true and estimated distances, grouped into distance classes. The method of estimating density (see Ramsey and Scott, 1979) is a variant of Emlen's (1971) technique for line transect data. Different runs were produced for different values of the scale factor, σ. Thus with σ small, there is very little estimation error in distances, while larger σ-values indicate larger magnitude errors. The model does not incorporate bias in the errors, nor does it feature a dependence of the relative error on the true detection distance.

Figure 3 contains the results of our simulations. Each run is represented by an arrow *from* the density estimate using true distances *to* the density estimate using estimated distances. These estimates are displayed relative to the actual density.

As should be anticipated, the density estimates become more severely corrupted as the magnitude of distance estimation errors increases. In most cases, because of a bias toward underestimation the result is to inflate the density estimate from its value using true distances (only 3 of the 32 arrows go down). The reason for this is traceable to the type of survey performed and to the density estimation procedure. The procedure, like most others, is quite sensitive to density of detections in strips "close to" the observer. With a variable circular plot design, the expected *numbers* of detections in concentric strips of equal radial increment increase dramatically with distance from the observer. Thus the very modest fraction of a large number of detections at intermediate distances which are

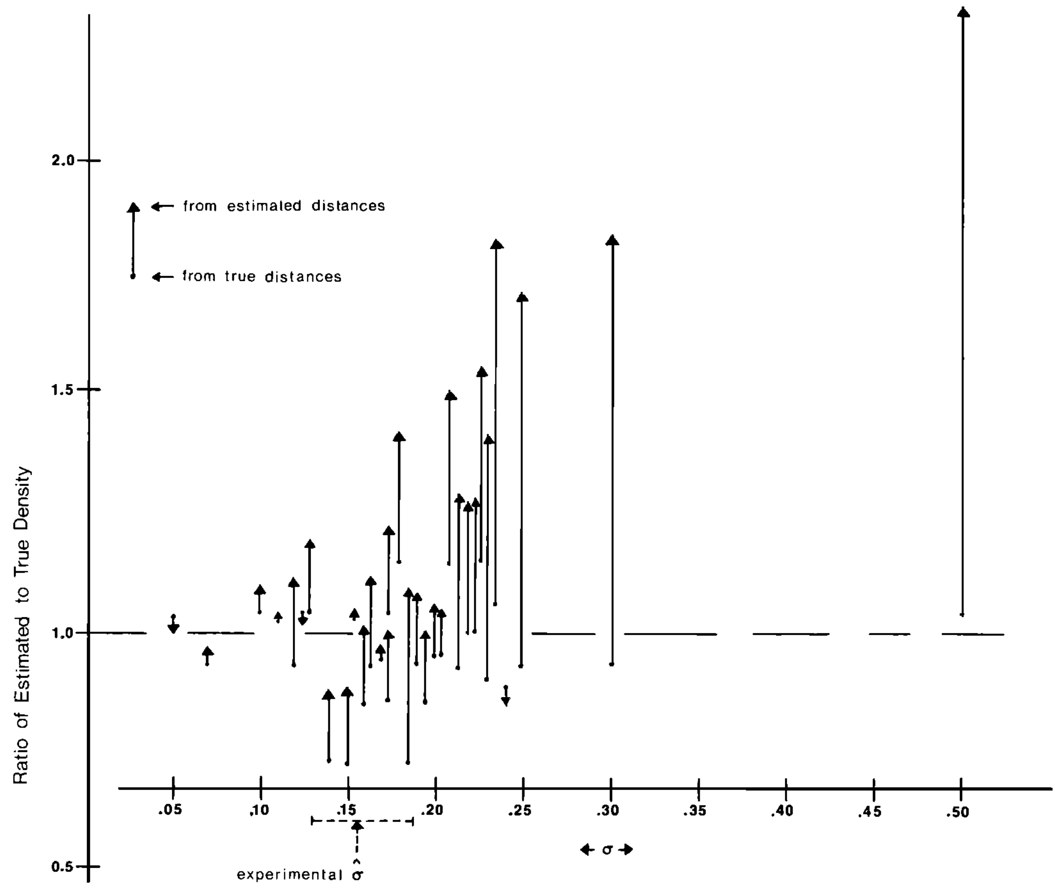

FIGURE 3. The effect on density estimation of errors in estimating distance. Data is from simulations with log-logistic error.

underestimated by the observer may comprise a substantial fraction of the total detections which the observer records as being close in. This effect is illustrated in Figure 4, where the $\sigma = .225$ run with 232 detections is displayed. The density versus radial distance class is plotted for the true and estimated distances. Nearly 50% of all detections were made of birds from 80–130 meters from the observer; less than 10% were from 0–50 meters. The few of the more distant birds whose detection distances have been underestimated substantially inflated the density in the near-observer region. Whether this is a severe practical problem is not clear nor is the extent that these biasis may be compensated for by birds that are completely missed (Mayfield 1981).

Returning to Figure 3, note that the experimentally determined scale factor of $\hat{\sigma} = .152$ is indicated along with a 95% confidence interval. Runs with σ in that interval typically had density estimates inflated by 20% as a result of the errors in distance estimation. However, in only one of these 14 runs did this create a density estimate more than 30% from the true density.

DISCUSSION

The ability of observers to estimate distances under the conditions of our experimental field trials was quite good. The range of observed accuracies is well within the 10 to 15% suggested by Emlen (1971; 1977). However, it is unknown to what degree observers may increase the error of their distance estimates under nonexperimental conditions. Variables that decrease this accuracy include the following: large number of birds and subsequent short time (0–20 seconds) to make distance estimates; often only one call or song (vs. several in experiment); and finally, birds heard when the observer is looking in a

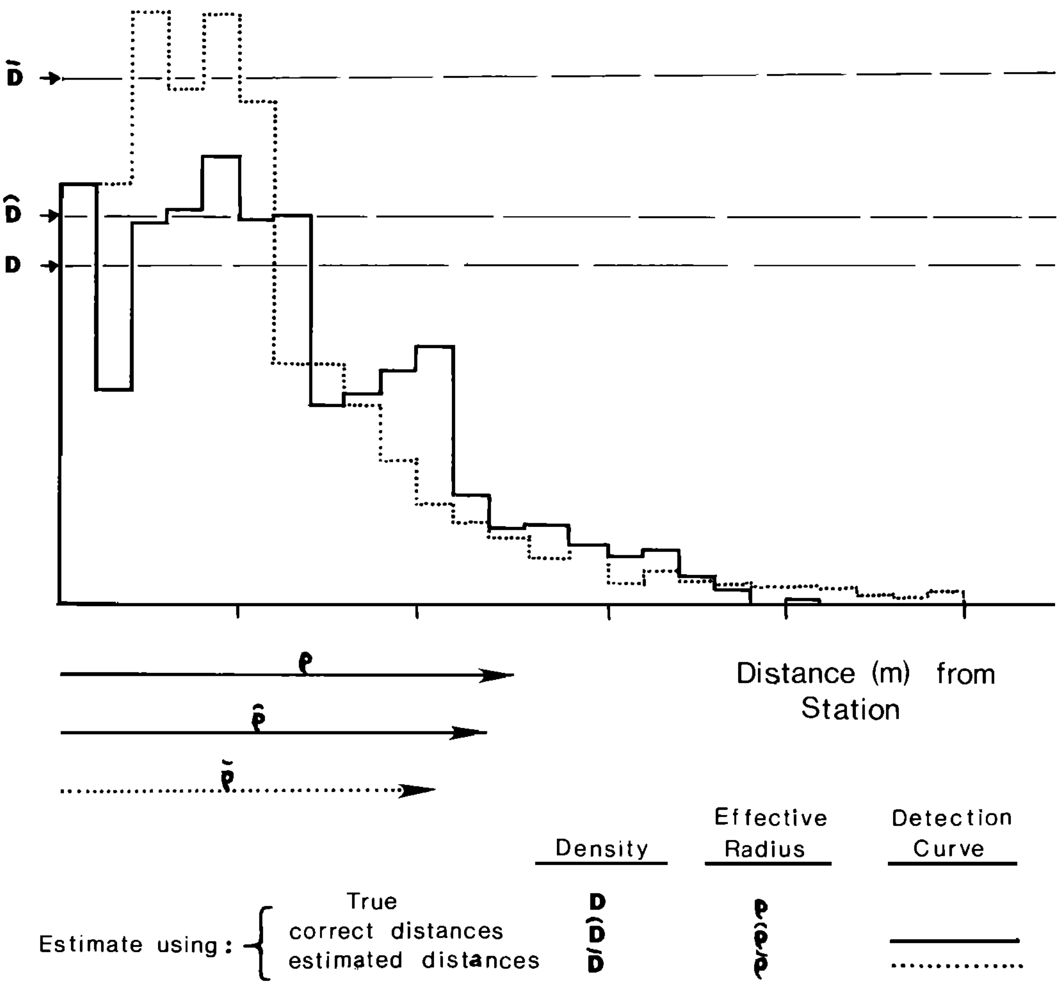

FIGURE 4. The effects of errors in distance estimation. Simulation with $\sigma = .225$ ($n = 232$ detections).

different direction. The degree to which this happens must be in part a function of the motivation of the observer to obtain reliable information. Use of distance references in the field and highly trained observers should help to reduce this source of error. The conditions under which we tested the reliability of distance estimates were very competitive.

We made no attempt to determine differences in ability to estimate distances to calls or songs of different types. Because of differences in the attenuation of sounds of varying quality (Richards 1981), the accuracy with which an observer estimates the distance to the bird giving a vocalization may vary with the type of vocalization given. (This aspect of the problem needs to be studied).

The increased percentage of underestimated distances within 18 m of the observers was interesting. Recent work has shown that for at least some calls of the Black-capped Chickadee (*Parus atricapillus*), the sound is not omnidirectional and is greatest to the front of the bird (Witkin 1977). The same was found to be true for the drumming of Ruffed Grouse (*Bonasa umbellus*), again with the highest intensity of sound being found in front of the bird (Archibald 1974). The assumption of our model is that birds are randomly oriented with regard to the observer. If in fact they are not, and those within 18 m tend to face the observer, then this could account for the tendency to underestimate these distances. The calls and songs would be louder and thus perceived as being closer. This hypothesis can be tested by comparing the accuracy of distance estimates for directional and omnidirectional vocalizations as a function of distance from the observer.

The error introduced in the area surveyed as a result of 10% errors in distance estimation is approximately 20% for circular plots and 10% for line transects.

RECOMMENDATIONS

In order to minimize the error introduced by distance estimation, we offer the following advice:

(1) Train all observers by having them estimate distances to objects, then verify the distances. Start with objects that can be seen, and work up to birds heard but not seen. Tape recording may also be used.

(2) Flag objects at known distances from sampling points and have observers use these as reference points.

(3) Use range finders to measure distances to additional reference points at each sampling point.

(4) Make measurements in feet (smaller rounding errors).

(5) Use robust methods to analyze data: (a) Lump distance estimates (categories may vary with species, season, and vegetation type); (b) Make certain that the limits of the lumping categories coincide with the natural rounding tendencies of observers (e.g., 50, 100, 150, 200 m etc.).

(6) Convince observers of the importance of obtaining accurate measurements, with the corollary of reinforcing their confidence in their abilities to do so.

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