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A VARIABLE CIRCULAR-PLOT METHOD FOR ESTIMATING BIRD NUMBERS

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ABSTRACT.—A bird census method is presented that is designed for tall, structurally complex vegetation types, and rugged terrain. With this method the observer counts all birds seen or heard around a station, and estimates the horizontal distance from the station to each bird. Count periods at stations vary according to the avian community and structural complexity of the vegetation. The density of each species is determined by inspecting a histogram of the number of individuals per unit area in concentric bands of predetermined widths about the stations, choosing the band (with outside radius x) where the density begins to decline, and summing the number of individuals counted within the circle of radius x and dividing by the area (πx^2). Although all observations beyond radius x are rejected with this procedure, coefficients of detectability may be determined for each species using a standard fixed maximum distance.

A bird census technique that estimates the number of birds per area rather than relative abundance is desirable when the objective is to estimate the number and species of birds in a community for energetic considerations (Wiens and Nussbaum 1975), for calculating species diversity (MacArthur 1960, MacArthur and MacArthur 1961), or for elucidating the effects of habitat disturbances on bird populations (Bock and Lynch 1970). Since existing methods require different amounts of effort and give results of differing accuracy (Kendeigh 1944, Emlen 1971, Robinette et al. 1974, Best 1975, Franzreb 1976), the choice of a suitable technique should be based on the species of interest, the season of the year, time and personnel available, number and types of habitats to be censused, and accuracy of the density estimate that is required.

Territorial or spot-mapping methods (Williams 1936, Kendeigh 1944) require that the census be conducted during the breeding season and involve considerable time and effort. Both factors severely restrict the number of habitats that can be sampled (Franzreb 1976). Plots of fixed size (e.g., Fowler and McGinnes 1973, Anderson and Shugart 1974), whether traversed by transect or censused from a fixed point, are more easily censused since only bird occurrence needs to be noted. However, density estimates from a number of fixed plots in habitats that differ structurally may not be comparable because of differences in the detectability of birds. For this reason data from fixed plots are frequently reported as relative numbers rather than densities. One way of adjusting for varying detectability among species is to use small plots in dense vegetation and large plots in open habitats. Problems arise when an "optimal" plot size, in which the detectability effects are averaged across all species in the community of interest, is required. Another problem is the variance in effectiveness in which two or more observers census plots of fixed sizes (Emlen 1971).

Emlen's (1971) variable strip transect count, in which right angle distances from the transect to each observation are estimated, eliminates problems of matching plot size to habitat complexity. This is so because the area used to calculate density is determined by the distance on both sides of the transect within which all individuals of a species are seen or heard. Consequently, the area surveyed is determined by the detectability of each species and observer acuity in each habitat. Additionally, the variable strip method is rapid and relatively accurate and one person can census a variety of communities during any season. For a discussion of these points and a comparison of the variable strip count with the spot-map method see Franzreb (1976).

In our work we have found that a stationary observer spends more time searching for birds and less time watching the path of travel. This is particularly true in tall, dense vegetation and in uneven terrain. Thus, as a result of being stationary, estimates of density and of species composition should improve. We found, for example, that stationary observers have a greater probability of seeing and hearing birds high in the canopy than even slowly moving observers; standing observers have less effect on bird activity; and, because rates of travel along a transect vary with terrain, complexity of vegetation, and number of birds seen, a further advantage of being stationary is that the census periods at each station can be fixed. This aids in standardizing the time spent counting birds in each habitat. Finally, the use of stations allows more definite statements to be made concerning the relationships between the habitat variables and the abundance and occurrence of bird species.

This paper describes a variable circular-plot census technique that gives estimates of birds per unit area during all seasons. This method originated in the need for an effective technique for counting birds in mature conifer forests. As such, it represents an attempt to combine what we feel are the best attributes of existing methods for habitats of this type. Following its development and use in conifer forests, we have applied it to shrub-steppe, riparian, and semi-tropical rain forests.

DESCRIPTION OF THE METHOD

In the variable circular-plot method, stations (points) are established within a plant community either at equal intervals along a transect or scattered (avoiding edges) in such a manner as to minimize the probability of observing the same bird from several stations. Thus, the distance between stations depends (in part) on how far away the birds can be detected and how fast they move; it will vary with vegetation and the behavior of the birds (see below). Each bird seen or heard during a fixed time period around a station is counted and the horizontal distance to its location when first observed is estimated. We adjust the time counting at stations to match the structural characteristics of the vegetation and the number of bird species in the plant community being censused. Our strategy is to select the time required to count all birds within an effective detection distance (see below) but to keep the time short enough so that the probability of counting the same bird more than once or of counting birds that move into the area being sampled is minimized. For conifer forests, 10 min at each station following a 1-min "rest period" for equilibration of bird activity after arrival at each station, appears to be sufficient. For the closed canopy rain forests of Hawaii, 8 min is sufficient (J. M. Scott and J. L. Sincock, unpubl. data). For more open habitats (e.g., shrub-steppe) less time is required. With the variable circular-plot method no maximum distance restrictions are placed on any observation. We count only those birds actively using the census area. For example, gulls flying over a stand of cottonwoods are not counted. Peregrine Falcons (*Falco peregrinus*) soaring over the same area are included because they may capture prey therein. Birds that are flushed while approaching a station are recorded using the distance from the station to where they were first observed as the detection distance. Species that commonly do this are quail, grouse, hawks and owls.

In the analysis, we determine the distance from the stations where the number of birds observed begins to decline (the point of inflection) by plotting for each species the number of individuals seen in concentric bands around all stations in each type of habitat. Since the area in each consecutively larger band around the stations is greater (see below) the number of birds observed in each band cannot be plotted directly. Thus, we plot the number of birds per area per band and convert the density in each to a standard of birds/km^2. The number of birds in the habitat is then determined by summing the number of individuals counted within the circle of radius x (the inflection point), dividing by the area (π^2) and converting the resultant density to a standard area (birds/km^2). With this procedure, we reject all observations outside of the circle of radius x. However, coefficients of detectability (CDs) may be calculated from these data using a standard fixed maximum distance for all species as described by Emlen (1971).

For example, we plot the density (birds/km^2) of Apapane (*Himatione s. sanguinea*) in each band with 5-m widths from 0 to 100-m, and 10-m widths from 100-m to 200-m from the stations (Fig. 1). Since the density of birds recorded in the bands may vary, we established the following criteria to provide consistency in estimating the point of inflection: choose the distance to the outermost edge of the band where the density of individuals per km^2 in the next outermost band is less than 50% of the previous band, with the specified condition that the number of individuals per km^2 in any one of the

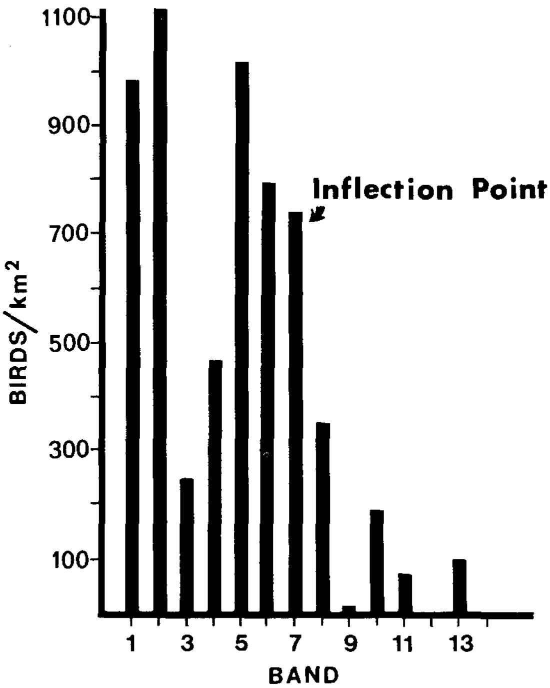

FIGURE 1. An example of a plot of the number of birds (Apapane) per km² per band in ohia forests in Hawaii. A total of 372 birds were counted. By the criteria outlined in the text, the inflection point occurs at the seventh band (35-m). Band 1, 0–5m; 2, 5–10 m; 3, 10–15 m; 4, 15–20 m, etc.

more distant bands does not exceed 50% of the mean number of birds per km² per band over all preceding bands. Using these criteria the inflection point in our example occurs between bands 7 and 8, or 35 m from the stations. These criteria do not always work (consider a distribution that decreases at 45% per band) and one must frequently use common sense in determining the effective detection distance. Emlen (1971) determined this distance by inspecting similar frequency histograms but he did not suggest any standardizing criteria for doing so. Anderson and Pospahala (1970), who examined properties of line transects similar to Emlen's, fitted regression lines to the 100% density level and the proportion of objects that were missed within the range of attempted coverage. Several other methods for determining the point of inflection are presented by Ramsey and Scott (1979).

In our experience up to 80% of the birds in dense, mature coniferous forests and 90% or more of the individuals of certain species in semitropical rain forests are heard and not seen. Estimating the distances to the sources (base of tree or perch) of bird vocalizations results in a greater error than estimating the distances to birds located visually. We attempt to reduce the "aural" distance error by recording the distance to each bird when first located by sound, and subsequently attempt to locate these visually and confirm the distance. We have found an intensive two-week training period to be effective in minimizing the "aural" error. During training we practice estimating distances to singing or calling birds whose actual distances are subsequently determined by pacing or with a range finder. When repeatedly done for each species and for each call or song, the distance estimates become considerably more accurate.

TABLE 1. Number of stations necessary to determine a given percentage variation around a mean density estimate. The number of stations indicated are for two (same day) 8-min count periods at each station.

	Birds/km²				
Percent variation in density	Apapane[a] 1,776	Iiwi[b] 537	Amakihi[c] 448	Omao[c] 305	Akiapoláau[d] 11
	Number of stations				
±50	6	10	14	5	107
40	10	15	21	8	161
30	17	27	28	14	321
25	24	38	54	20	459
20	37	60	84	31	642
15	65	105	149	55	1,070
10	145	233	336	115	3,210
5	580	943	1,341	494	10,700

[a] Abundant but variably distributed.
[b] Common but variably distributed.
[c] Common and uniformly distributed.
[d] Rare and variably distributed.

The number of stations required to establish the abundance of a species varies with the spatial distribution of individuals within a population, their abundance, and their conspicuousness in each season and habitat. We present a table of the number of stations required to estimate density values ranging from ±5 to ±50% of the mean density (determined over a large number of stations) for five Hawaiian birds of differing conspicuousness and abundance in ohia (*Metrosideros collina*) and ohia koa (*Acacia koa*) forests with 60% canopy closure and an average height of 10-m (Table 1). The estimate of the number of stations was derived from Stein's (1945) two-sample test. The procedure is to compute the density over all stations, estimate the cumulative variance, and compute the number of stations necessary for a given percent confidence. The density estimates were derived from 64 stations (sampled twice daily) for four species in ohia forests and 114 stations for the Akiapoláau (*Hemignathus wilsoni*) in ohia koa forests. The relative conspicuousness of the five species decreases in the following order: Omao (Hawaiian Thrush; *Phaeornis o. obscurus*), Akiapoláau, Apapane, Iiwi (*Vestiaria c. coccinea*), Amakihi (*Loxops v. virens*). For each species except the Akiapoláau, density estimates of ±30% of mean density can be obtained by sampling 28 stations or less. For rarer or less conspicuous species more stations are required. We strive for ±50% of the mean density for rare and ±20% for common species.

Like Emlen (1971) we record "singing males" and "all other observations" separately during the breeding season. The number of singing males is then doubled to account for the females of the territorial males. However, for the variable strip count, Franzreb (1976) suggested using whatever gives the higher density value—the number of singing males times two or "all other observations" plus the number of singing males. In areas where breeding seasons are prolonged and it is not known whether both males and females sing, nor the percentage of paired singing males, we make no corrections.

ASSUMPTIONS AND PROBLEMS

As with most other bird census methods, an assumption of the variable circular plot method is that all birds have an equal likelihood of occurring anywhere within the habitat being censused. In addition, it is assumed all birds seen or heard are in the exact position they occupied when the station was first occupied, and that all individuals actually in the area bounded by the point of inflection are detected.

Emlen's transect method, as well as the variable circular-plot, is sensitive to uncommon species because the only area limits are those dictated by the observer's acuity. Thus, because a larger area is surveyed (though much of it incompletely) the opportunity for recording the rarer species is increased. However, the number of observations of uncommon species may not be sufficient to accurately determine the point of inflection in their frequency distribution. This may be overcome by using the effective detection distance of species with similar detectabilities.

The selection of the "best" distance between stations and the "best" counting period at each station is a complex problem. In choosing the distance between stations we attempt to keep the stations statistically independent; that is, to minimize the probability of counting the same bird at two or more stations. However, any interval will be a compromise because the distance will vary among species and between sexes. For example, with a distance between stations selected on the basis of the loudness of male pheasant calls, female pheasants may be seriously undersampled. A strategy we have adopted is to place our transects much farther apart (1–3 km) than our stations (100–250 m) whenever possible. The "best" counting period will vary with species, reproductive status, sex, and age of the birds as well as time of day, season, weather, and the vegetational complexity of the habitat. As an aid in the selection of a counting time we plot the number of species against time spent counting for several preliminary 30-min sampling periods in each habitat. We use as our counting period the time at which the addition of new species begins to level off.

Many vegetative stands are not large enough to hold the number of stations required by a given confidence level of a density estimate. In these situations we establish as many stations as allowed by the minimal distance between stations and sample each twice daily. Since the two samples are not statistically independent, an average density is obtained. The question of the number of times a station should be sampled may be considered separate from the question of the number of stations required per habitat. This distinction depends upon the distribution of the individuals of the species of interest; the extent of patchiness would dictate the number of transects (stations) required, whereas rarity would dictate the number of times each station should be sampled.

Birds in tall forests may be as much as 75-m above the observer. While these may actually occur in a cylindrical projection of the first concentric circle they may be missed because of intervening foliage (they may be beyond the effective detection distance). This source of error will, of course, result in an underestimate of the true density. We note, however, that this problem is also inherent in other census techniques when used in tall forests.

Finally, because the area in each concentric band increases with increasing distance from the observer, the effect of erring in a distance estimate (placing an individual in one or an adjacent band) significantly alters the frequency plot of birds per area per band. However, the "area effect" decreases with increasing distance from stations. This effect presents a problem with species that are attracted to or repelled from an observer. If, for example, birds move from distant to closer bands before being observed, the density in the closer bands will be overestimated. If birds are repelled, the density in the closer bands will be underestimated. Observers should be aware of these problems.

Accurately determining the effective detection distance (point of inflection) requires that bands be relatively narrow. Since the area effect increases with shorter band increments, our choice of 5-m increments from 0 to 100-m, 10-m increments from 100 to 200-m, and 20-m increments at distances of 200-m or greater, resulted from attempts to keep the distance increments small while minimizing the area effect.

In summary, we believe the variable circular-plot method offers the following advantages over the variable strip count: (1) it frees the observer from worries of personal safety during count periods; (2) because the observer is stationary, canopy birds are more accurately censused; (3) because the area censused is centered on fixed points and constitutes smaller, more discrete areas than usually occur along a transect, habitat correlates at each station can be more accurately related to species abundance or absence; and (4) the sampling effort can be more accurately determined. However, we emphasize that the strip count frequently allows coverage of larger areas per unit time, a trade-off that has increased attractiveness as vegetation and bird communities become less complex.

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