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LANDBIRD COUNTING TECHNIQUES: CURRENT PRACTICES AND AN ALTERNATIVE

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ABSTRACT.—Counting techniques are widely used to study and monitor terrestrial birds. To assess current applications of counting techniques, we reviewed landbird studies published 1989–1998 in nine major journals and one symposium. Commonly used techniques fell into two groups: procedures that used counts of bird detections as an index to abundance (index counts), and procedures that used empirical models of detectability to estimate density. Index counts rely upon assumptions concerning detectability that are difficult or impossible to meet in most field studies, but nonetheless remain the technique of choice among ornithologists; 95% of studies we reviewed relied upon point counts, strip transects, or other index procedures. Detectability-based density estimates were rarely used and deserve wider application in landbird studies. Distance sampling is a comprehensive extension of earlier detectability-based procedures (variable-width transects, variable circular plots) and a viable alternative to index counts. We provide a conceptual overview of distance sampling, specific recommendations for applying this technique to studies of landbirds, and an introduction to analysis of distance sampling data using the program DISTANCE. *Received 19 August 1999, accepted 10 June 2001.*

RESUMEN.—Las técnicas de conteo son usadas ampliamente para estudiar y monitorear aves terrestres. Para determinar las aplicaciones actuales de las distintas técnicas de conteo, revisamos los estudios publicados en nueve revistas científicas importantes y un simposio entre 1989 y 1998. Las técnicas comúnmente utilizadas pueden separarse en dos grupos: las que utilizan conteos del número de detecciones de aves como índices de abundancia (conteos de índice) y las que emplean modelos empíricos de detectabilidad para estimar la densidad. Aunque los conteos de índice se basan en suposiciones relacionadas con la detectabilidad que son difíciles o imposibles de cumplir en estudios de campo, éstos siguen siendo los métodos más utilizados por los ornitólogos. El 95% de los estudios que revisamos emplearon conteos de punto, transectos de banda u otros procedimientos basados en índices. Por su parte, las estimaciones de la densidad basadas en la detectabilidad fueron muy poco usadas y merecen ser aplicadas con mayor frecuencia en estudios de aves terrestres. El muestreo de distancias (''distance sampling''), una extensión integral de los procedimientos previos basados en la detectabilidad (transectos de ancho variable, parcelas circulares variables), representa una alternativa viable con respecto a los conteos de índice. Presentamos una visión conceptual del muestreo de distancias incluyendo recomendaciones específicas para la aplicación de esta técnica en estudios de aves terrestres y una introducción al análisis de datos de muestreos de distancias utilizando el programa DISTANCE.

ORNITHOLOGISTS, WILDLIFE BIOLOGISTS, and resource managers have expended tremendous effort counting terrestrial birds; data that are widely used to quantify species' distribution, occurrence, habitat relationships, responses to environmental perturbations, and population trends. Count data also figure prominently in contemporary conservation planning. A notable example is the North American Breeding Bird Survey (BBS) conducted annually since 1966 (Robbins et al. 1986). Recent concerns over status of Neotropical migrants and other landbirds have spurred development of new programs that

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use counting techniques to monitor landbird populations (Leukering et al. 2000).

A variety of counting techniques have been used to count landbirds. Those techniques can be divided into two groups: (1) methods that use counts or maps of bird detections as an index to relative abundance (hereafter referred to as ''index counts''), and (2) empirical modeling techniques that directly estimate bird density. Index counts tally bird detections during one or more surveys of points, transects, or defined areas (Kendeigh 1944, Verner 1985, Bibby et al. 1992, Ralph et al. 1995). Detections are converted to an index value, for example, the total number or frequency of detections across sampling units (Verner and Ritter 1985, Hutto et al. 1986). The second group of techniques uses field procedures that are similar to index counts, but have an analytic component that models variation in species' detectability to yield direct estimates of density. Examples of those techniques include variable-distance transects (Emlen 1971, 1977; Järvinen and Väisänen 1975), variable circular-plots (Reynolds et al. 1980), and distance sampling (Burnham et al. 1980, Buckland et al. 1993).

Because count data figure so prominently in landbird conservation, it is essential that researchers and managers use techniques that can provide ''reliable information'' (Romesburg 1981). Biases and limitations of index-counting procedures have been recognized for some time (Burnham 1981, Verner 1985, Verner and Ritter 1985, Nichols et al. 2000). Nevertheless, index counts remain popular among ornithologists and resource managers. In contrast, counting techniques based upon empirical models of detectability appear not to have been widely applied in studies of landbirds. Our objectives in this article were (1) to formally quantify use of various counting techniques in recent avian studies, (2) to promote distance sampling as a viable alternative to index counts, and (3) to provide specific recommendations on application of distance sampling to studies of landbirds.

COUNTING TECHNIQUES: CURRENT PRACTICE

We conducted an extensive literature review to quantify procedures used to collect and analyze landbird count data. The review included papers published in nine major journals (*The Auk, Biological Conservation, The Condor, Conservation Biology, Ibis, Journal of Field Ornithology, Journal of Wildlife Management, Wildlife Society Bulletin,* and *The Wilson Bulletin*) from 1989 to 1998. We also included papers published from a major symposium on ecology of Neotropical migrant landbirds (Hagan and Johnston 1992). To reduce bias resulting from multiple inclusions of the same data, we did not include papers that used previously published data, or data obtained from BBS, Christmas Bird Counts, and other long-term avian monitoring programs.

For each paper reviewed, we classified the avian counting technique that was used (area count, point count, strip transect, spot mapping, variable-distance transect, variable circular-plot, or distance sampling). We also noted whether or not variables derived from count data were accompanied by measures of dispersion or precision (standard error, standard deviation, confidence interval, or coefficient of variation). We then calculated proportion of studies that used each counting technique and proportion of studies that reported measures of dispersion or precision for count results.

We found 224 papers that used field-sampling techniques to count landbirds. Total proportions were >1.0, because many studies used more than one method. The vast majority of studies (95%) relied upon index counts (area counts, point counts, strip transects, or mapping techniques), whereas only 13% used empirical modeling techniques (variable-distance transects, variable-circular plots, or distance sampling). Point counts and strip transects were the most frequently used techniques (46 and 29%, respectively). Ten percent of the studies used area counts, 10% used mapping techniques, 6% used variable circular-plots, 4% used distance sampling, 3% used variable-distance transects, and 1% used other techniques. Count results were accompanied by measures of dispersion or precision in 41% of studies we reviewed.

The overwhelming reliance on index counts in recent avian studies is a matter of great concern. To provide reliable information, one must assume that index counts have a consistent, positive correlation with actual bird density. To meet that assumption, bird detectability must remain constant despite three types of factors that, individually or in combination with other factors, can profoundly influence avian counts. First are variables that affect an observer's ability to detect and correctly identify birds. Observer performance varies among and within individuals and is strongly influenced by training, age, experience, motivation, hearing acuity, eyesight, physical health, and fatigue level (Cyr 1981, Kepler and Scott 1981, Ramsey and Scott 1981, Sauer et al. 1994). Observer behavior and clothing color also have been reported to affect detectability (Gutzwiller and Marcum 1997). Second are environmental variables that affect bird behavior and observer efficiency. Those include wind velocity, precipitation, temperature, cloud cover, and light intensity (Anderson and Ohmart 1977, Verner 1985), as well as topography and vegetation characteristics (Dawson 1981). The third class of variables affecting detectability are physical and behavioral attributes of birds that make them more or less conspicuous to human observers. Those include body size, plumage coloration, characteristics of vocalizations (loudness, rate, sonic frequency), flight behavior, physiological status, flock size, density, age, and sex (Cohen et al. 1960, Sayre et al. 1978, Wilson and Bart 1985). When index counts are conducted on multiple occasions, one must also assume that detectability is consistent over time. However, previous studies have shown that detectability varies at multiple temporal scales (Best 1981, Robbins 1981, Skirvin 1981, Rollfinke and Yahner 1990).

To address potential problems with index counts, standardized sampling protocols have been developed (e.g. Ralph et al. 1995, Hamel et al. 1996). These protocols may reduce influence of some confounding factors; however, the critical assumption of constant detectability likely cannot be met in most studies (see Nichols et al. 2000). Measures of relative abundance derived from index counts thus represent an uncertain, confounded combination of detectability and density. Given these weaknesses, index counts should not be expected to provide reliable information or a valid basis for inference.

The fact that most studies failed to present measures of precision also is a matter of concern. By themselves, point estimates derived from count data are of little value. Without measures of precision, it is all too easy for the reader to draw incorrect conclusions concerning differences among species, sampling units, sampling periods, or other factors of interest (Thompson et al. 1998). To address that deficiency, point estimates derived from bird-count data should be accompanied by suitable measures of precision (standard error, coefficient of variation, or confidence interval) whenever possible.

DISTANCE SAMPLING: AN ALTERNATIVE

Distance sampling is an integrated approach encompassing study design, data collection, and statistical analysis that avoids many pitfalls of index counts. When applied properly and critical assumptions are met, distance sampling provides direct estimates of bird density that are not confounded by detectability. Here, we provide a general overview of distance sampling and specific recommendations for applying that technique to studies of terrestrial birds. A comprehensive treatment of those topics is beyond the scope of this article, potential users should review theoretical, analytic, and applied aspects of distance sampling presented by Burnham et al. (1980) and Buckland et al. (1993). The latter presents detailed examples of application of distance sampling to landbird studies.

Distance sampling is based on a detection function, denoted $g(x)$ for line transects or $g(r)$ for point transects. This function is estimated from distance data and is used to compute probability of detection (p). The detection function compensates for the fact that detectability decreases with increasing distance from the observer. In the simplest case, density ($\hat{D}$) is estimated as $\hat{D} = n/a \times \hat{p}$, where n is total number of detections and a is area sampled. Models used for detection functions are ''model robust'' and can fit a wide variety of plausible shapes (Burnham et al. 1980). The probability of detecting a bird at any given perpendicular distance varies according to numerous factors, such as environmental conditions, differences among observers, and conspicuousness of the target species. Thus, the final data set may represent pooled subsets of detections corresponding to different detection curves. Models used for detection functions are ''pooling robust,'' meaning that resulting density estimates are not affected by those variations in detection probability (Burnham et al. 1980, Buckland et al. 1993).

Field procedures for distance sampling are similar to those used in index counts, consisting of one or more visits to sampling units within the area of interest. Sampling units can be either line transects or points, the latter being treated as transects of zero length and referred to as ''point transects.'' In an index count, the observer tallies total number of birds detected within a defined or unbounded area around the point or transect. When distance sampling, the observer estimates or measures distance to each bird that is detected (perpendicular distance *x* for line transects, or radial distance *r* for point transects).

SAMPLING DESIGN

The first choice faced by the investigator is whether to use line transects or point transects. Other factors being equal, the former generally are superior (Buckland et al. 1993). Line transects require less time ''deadheading'' between sampling units and thus yield more detections per unit of field time (Bollinger et al. 1988). However, point transects are preferable in several circumstances, including surveys for relatively quiet or visually inconspicuous species (T. Leukering pers. obs.), areas where terrain or vegetation make it difficult to traverse a straight line while observing birds, and when conducting multispecies studies in patchy environments (Buckland et al. 1993). In some circumstances, a combination of point and line transects may be appropriate.

Sampling units must be randomly placed if one wishes to make inference from the sample to a larger area of interest, which should be defined *a priori*. Sampling arrays should not parallel fence lines, roads, trails, or prominent features likely to yield samples unrepresentative of the surrounding area (Thompson et al. 1998). When repeated surveys are done to estimate trends in density, sampling units typically are permanently marked and reused (Buckland et al. 1993). However, if repeated visits are done in a single time period (e.g. the study encompasses only one breeding season), one may use different lines or points on each visit to maximize coverage of the study area. We refer readers to Burnham et al. (1980) and Buckland et al. (1993) for detailed information on appropriate distance-sampling designs.

FIELD PROCEDURES

Competent and well-trained observers are essential for avian surveys (Kepler and Scott 1981). When using distance sampling, investigators must also take steps to avoid violations of three critical assumptions: (1) birds on the line or point are detected with certainty; (2) birds are detected before evasive movement triggered by the observer; and (3) distances are estimated or measured accurately. Other aspects of distance-sampling theory can be considered as assumptions, but are beyond the scope of this article (see Buckland et al. 1993). Investigators should consider the following recommendations when developing field-sampling protocols.

Assumption 1: All birds on the line or point are detected.—In line transect surveys, observers should travel slowly or stop occasionally along the line to listen for vocalizations and to search dense areas of cover. Similarly, in point-transect sampling, one can increase count duration at each point, or may walk about in the immediate area near the point. The observer need not be positioned on the point, but must use it as the origin when recording distances. When using point transects, inserting a short (1–2 min) waiting period prior to initiation of the count may allow birds to settle down, thus increasing probability of detection. For some species, use of dogs, taped calls, and other devices may be useful (Buckland et al. 1993). Advanced techniques have been developed for situations where detection on the line or point is uncertain (Borchers et al. 1998a, b), but have not seen much use in studies of landbirds.

Assumption 2: Birds are detected prior to evasive movement.—Distance sampling obtains an instantaneous ''snapshot'' of birds around the line or point. However, an observer walking a transect or approaching a point may cause evasive movements, for example, nearby birds may be flushed but are not detected until they have flown for some distance. Ground-dwelling birds such as quail may run a considerable distance before flushing and being detected. Other species, particularly corvids, may instead be attracted to the observer (S. S. Rosenstock pers. obs.). Potential bias resulting from evasive movements is far greater with point transects, because surveyed area increases quadratically with increasing distance from the point. Keeping count duration as short as possible (e.g. ≤5 min per point) will reduce potential influence of evasive movements (Scott and Ramsey 1981). Distance sampling theory allows imperfect detection away from the line or point, thus questionable detections in those regions may be discarded without biasing estimates of density. In contrast, movements affecting detection on the line or point are problematic, potentially violating assumption 1.

Assumption 3: Distances are measured accurately.—When using point transects, the observer measures or estimates radial distance (r) from the point to the bird. With line transects, however, one estimates perpendicular distance (x) from the line to the bird. If a perpendicular measurement is impossible, the observer records radial distance (r) and sighting angle (θ). Perpendicular distance is then calculated as $x = r \sin(\theta)$. Angles must be measured accurately to avoid rounding errors that may adversely affect density estimates. Buckland et al. (1993) provide detailed recommendations to avoid such problems. Distances must not be rounded to convenient units (i.e. units of 5 or 10), because the resulting ''heaping'' makes it difficult to fit a detection function. That is particularly true for observations close to the line or point. Many landbirds commonly occur in ''clusters,'' that is, flocks or breeding pairs. Individuals within a cluster are not independent observations, thus the sample unit is the cluster, not individual birds within the cluster. When sampling clustered birds, the observer records distance to the center of the cluster as well as number of individuals present in the cluster.

Accuracy of distance measurements can be greatly improved by proper training of observers, placing visible markers at known distances from transects or points, and by using range finders (Scott et al. 1981). Rugged, lightweight laser range finder units accurate to ±1 m can be purchased for ~$250 and are ideal for this purpose. One also may mark locations of individual detections and return later to measure distance from the line or point. If detection distance for a particular observation is unknown or uncertain (bird is in flight, etc.) then it should not be recorded. As long as those missing data do not occur on the line or point, density estimates will not be biased.

In densely vegetated areas, distances often must be estimated rather than measured. For example, >85% of bird detections in Arizona and Colorado conifer forests were auditory and did not include a visual observation (Rosenstock 1996; T. Leukering unpubl. data). Distance estimation to unseen birds is difficult, because attenuation of bird vocalizations is affected by vegetation type and physiognomy, position of the bird relative to the observer, and song or call pitch (Waide and Narins 1988). Under those circumstances, it often is preferable to collect data in intervals (''grouped data'') instead of continuous distance estimates. Here, the assumption concerning measurement accuracy is relaxed and one assumes only that observations are placed into the correct interval (Buckland et al. 1993). Using distance intervals greatly increases accuracy and consistency among and within observers (S. S. Rosenstock pers. obs.). As a general recommendation, interval width should increase with increasing distance from the line or point, and total number of intervals should be between four and eight. Using too many intervals makes classification of objects into the correct distance interval more time-consuming and error-prone, whereas using too few intervals results in loss of precision when estimating $g(x)$ or $g(r)$. The final interval should have no upper bound to avoid incorrect heaping of detections actually located farther away. For example, a suitable approach would be to use intervals bounded at 10, 25, 50, 100, 200, and >200 m. Additional guidelines for defining intervals are given by Buckland et al. (1993). Where distance estimation is particularly difficult, one may use binomial methods that place detections into one of two distance categories (Järvinen and Väisänen 1975, line transects; Buckland 1987, point transects).

SAMPLE SIZE

An adequate sample size of bird detections (n) is essential to obtain reasonably precise density estimates. For example, to obtain estimates with a coefficient of variation of 0.15, an n of 60–100 observations per species often is required. Because a greater proportion of observations occur at distances where detection probability is low, point transects require a larger n than do line transects to obtain comparable precision. Buckland et al. (1993) provide formulae to estimate required sample sizes for given levels of precision. The calculations require estimates of encounter rates, which may be obtained from pilot studies or prior, comparable surveys.

Repeated sampling is a suitable means to increase *n* and common practice in avian studies using distance sampling. Repeated observations of the same individual on multiple visits or during the same visit do not violate the assumption of independence, as long as individuals are not detected more than one time from the same line or point in a given survey. In practice, however, double-counting generally is of little consequence (Buckland et al. 1993), particularly if such events are relatively infrequent. When a single estimate will be derived from multiple sampling visits, the sampling period should be constrained in time, such that density of the target species remains more or less constant.

Another option for rare or uncommon species is to use a detection function derived from a more common ''surrogate species.'' However, use of surrogate species is not well studied and must be approached with caution. The surrogate must be sympatric with uncommon species of interest and should be similar with respect to characteristics affecting detectability, for example, size, behavior, vocalization type and pattern, and microhabitat use. When sampling avian communities, it may be impossible to estimate densities of all species in the study area. Like all techniques, distance sampling has limitations that must be understood and respected. We encourage investigators to be realistic when designing landbird studies and surveys.

ANALYSIS OF DISTANCE DATA

Distance sampling data can be managed and analyzed using the program DISTANCE (Thomas et al. 1998), a comprehensive software package for Microsoft Windows™ available free of charge online (see Acknowledgements). The website also contains reference information and other software useful to users of distance sampling. Proper analysis requires working knowledge of distance-sampling theory and analytic options provided by DISTANCE; one can easily obtain incorrect results if data or analysis are structured improperly. We refer readers to Buckland et al. (1993) and DISTANCE program documentation for detailed information.

Analysis of distance data consists of three steps: exploratory analysis, model fitting and selection, and model inference. Exploratory graphical analysis (frequency histograms, box-and-whisker plots) of raw detection data will illustrate overall detection patterns and can identify potential problems such as evasive movements, heaping, and outliers (Buckland et al. 1993). Such analyses are particularly useful to examine variation among subunits of the data corresponding to different locations, time periods, or observers.

Distance data can be modeled globally (entire data set), by strata established in the sampling design (''stratification''), or by data subsets defined *post hoc* (''post-stratification''). Models used by program DISTANCE are ''pooling robust'' to variation in detection probability; however, stratification will improve precision and reduce bias of estimates when detection patterns vary substantially among subunits of the data (Buckland et al. 1993). Data sets containing clustered observations are modeled differently than are data sets consisting of single birds (Buckland et al. 1993); DISTANCE provides extensive diagnostic and analytic options for handling clustered data.

Modeling distance data is an iterative process that uses a key function (half-normal, uniform, or hazard rate) followed by parameter adjustments (cosine or polynomial) to improve model fit. Typically, one begins by fitting an initial model (the half-normal model with simple polynomial adjustment often is a good starting point for landbird data). Goodness-of-fit tests and detection-function plots produced by DISTANCE are used to assess model fit and may suggest changes in analytic strategy, such as data truncation (Buckland et al. 1993), *post hoc* grouping of continuous distances (Buckland et al. 1993), or use of a different key function (Buckland et al. 1993). Note that when binomial distance-sampling methods (Buckland 1987) are used, one can only fit a single-parameter model and goodness-of-fit cannot be tested (Buckland et al. 1993). After evaluating the initial model, one may develop, fit, and evaluate additional candidate models. Akaike's Information Criterion (AIC) values calculated by DISTANCE provide an objective means to select among competing models; the model with lowest AIC value provides the most parsimonious and best approximation of information contained in the data (Burnham and Anderson 1998). It is important to note that AIC can only be used to assess competing models' fit to the same data. For example, one cannot compare AIC values for truncated versus untruncated, or grouped versus ungrouped observations derived from a common data set. If the data meet key assumptions, competing models typically yield similar estimates, but vary in their precision. However, if estimates vary greatly, this can indicate fundamental problems with the data that may not be resolved by further manipulation or analytic procedures.

The final step in distance analysis is model inference. At this point, a ''best'' model will have been selected, with which to make inferences concerning bird density, abundance, or detectability. When interpreting results of distance sampling, the scope of inference should be appropriate to the sampling design, spatial and temporal extent of the data, and precision of parameter estimates. The current version of DISTANCE supports inference only from a single model, however, a forthcoming version will allow inference from multiple models or ''model averaging'' (Burnham and Anderson 1998).

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