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SAMPLING CONSIDERATIONS FOR ESTIMATING DENSITY OF PASSERINES IN GRASSLANDS

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Abstract. Researchers often use fixed-radius point counts to estimate density (absolute or relative) of territorial male grassland birds, but in doing so they must assume that detectability of birds is constant (or nearly so) among habitats, years, and/or species. If the assumption is violated, comparisons of density among species and/or habitats are invalid because counts are confounded by changes in both detectability and density. Recent advances in the theory and methods of distance sampling allow biologists to estimate detection probabilities and may provide more accurate estimates of density than other techniques. We conducted 450 point counts at 150 points in Lostwood National Wildlife Refuge, North Dakota, in 1994, estimated the distance to each male detected aurally, and estimated density for the 10 most abundant species with two methods: (1) using data from 50- or 75-meter-radius plots (estimates based on the average number of males heard per point count) and (2) using program DISTANCE and a maximum detection distance of 400 meters (estimates based on number of males heard and the detectability of males). We felt we were able to meet the assumptions of distance sampling and reliably estimate absolute density. Results generated by program DISTANCE suggested that males of some species went undetected on 50- and/or 75-meter plots. Density estimates from the two analysis methods were similar, however, and did not differ for any species ($P > 0.05$). Estimates from fixed-radius point counts in our study thus appeared to provide valid estimates of density (absolute and relative). In other habitats or for other species, the problem of undetected males may be more pronounced. In such cases, distance-sampling techniques may provide an important alternative for collecting and analyzing density data if adequate samples are obtained and unbiased distance data can be collected.

CONSIDERACIONES PARA LA TOMA DE MUESTRA DE LAS ESTIMACIONES DE LA DENSIDAD DE AVES PASERIFORMES EN PASTIZALES

Sinopsis. A menudo los investigadores utilizan conteos desde un punto y por un radio fijo para estimar la densidad (absoluta o relativa) de machos territoriales de aves de pastizal, pero al hacerlo tienen que presumir que la posibilidad de detectar aves es constante (o prácticamente constante) entre hábitats, años y/o especies. Si la suposición no es correcta, las comparaciones de densidad entre especies y/o hábitats son inválidas porque los cambios de la posibilidad de detección y de la densidad confunden los conteos. Recientes avances en la teoría y en los métodos de la toma de muestra a distancias diferentes permiten que los biólogos estimen las probabilidades de detección y también pueden proveer estimaciones de densidad más precisas que otras técnicas. En 1994, en el Refugio Nacional de Fauna Lostwood, Dakota del Norte, hicimos 450 conteos desde 150 puntos, estimamos la distancia a cada macho detectado auditivamente, y estimamos la densidad para las 10 especies más abundantes con dos métodos: (1) utilizando datos de parcelas de 50 ó 75 metros de radio (estimaciones basadas en el número promedio de machos oídos por conteo) y (2) utilizando el programa DISTANCE y una distancia de detección máxima de 400 metros (estimaciones basadas en el número de machos oídos y en la posibilidad de detección de los machos). Pensamos que logramos satisfacer las suposiciones de la toma de muestra a distancias diferentes y estimar fidedignamente la densidad absoluta. Los resultados que produjo el programa DISTANCE indicaron que no se hallaron los machos de algunas especies en parcelas de 50 y/o 75 metros. Sin embargo, las estimaciones de densidad hechas con los dos métodos de análisis fueron similares, y no se diferenciaron para ninguna especie ($P > 0{,}05$). Así parecía que las estimaciones de los conteos desde un punto y por un radio fijo en nuestro estudio entregaron estimaciones válidas de densidad (absoluta y relativa). En otros hábitats o para otras especies, el problema de machos no detectados puede ser mayor. En esos casos, las técnicas de toma de muestra a distancias diferentes pueden proporcionar una alternativa importante para la recolección y el análisis de datos de densidad si se obtienen muestras adecuadas y se recolectan datos imparciales de distancia.

Key Words: density estimation; detectability; grasslands; point counts.

Density of passerines and numerous other landbirds is most commonly estimated from point-based counts of birds on fixed-radius plots (Hutto et al. 1986; Ralph et al. 1993, 1995). Because point counts may provide incomplete counts of birds present on survey plots (e.g., Burnham 1981, Hutto et al. 1986, Barker and Sauer 1995), point counts are typically considered estimates of relative density (Hutto et al. 1986). Because researchers do not usually estimate the proportion of birds counted (i.e., bird detectability; Barker and Sauer 1995), however, point counts provide an untested index that may be unreliable (Burnham 1981, Rotella and Ratti 1986). In particular, factors other than density (e.g., observers, habitat) can affect counts (see numerous articles *in* Ralph and Scott 1981), and thus variation in counts among habitats, years, and/or species may represent variation in detectability rather than variation in actual density (Pendleton 1995).

Although survey conditions are typically constrained to reduce variation in detectability among counts, it is unlikely that all factors influencing detectability can be controlled (Burnham 1981, Pendleton 1995). Consequently, Burnham (1981) concluded that it is necessary to adjust point counts by detection probabilities if reliable estimates of density are desired. Similarly, Johnson (1995:123) stated that "we need to better understand the role of the detection probabilities if we are to draw inferences from the counts about bird populations."

Distance sampling, which has recently undergone important advances in estimation methods, provides a rigorous means of estimating detection probabilities (Buckland 1987, Buckland et al. 1993). Although the technique requires that distances to detected birds be estimated, distances can be recorded in categories. Furthermore, "provided distance estimation is unbiased on average, measurement errors must be large to be problematic" (Buckland et al. 1993:171). In distance sampling, the distance from the sampling point to each bird detected (seen and/or heard, depending on the study) is recorded; distances are analyzed to estimate the detectability of birds as a function of the distance from the sampling point to a bird; and the detection function (based on distance data) is used to correct for birds that went undetected. Using distance sampling, it is possible to produce unbiased maximum likelihood estimates of density and variance despite missing the majority of the birds on a plot if the following assumptions are met: (1) birds on points (distance = 0) are always detected; (2) birds are detected at their initial locations before any movement is made in response to observers; and (3) distances are accurately measured or assigned to the correct distance category (Buckland et al. 1993). Because detection functions can be estimated for each species and habitat type, valid comparisons of density can be made among species and/or habitats even though detectability may vary.

Although distance sampling has been used effectively to estimate density of numerous inanimate objects (e.g., bird nests, burrows) and vertebrates (e.g., birds, terrestrial and marine mammals; Buckland et al. 1993), it has not been used or evaluated in studies of grassland birds. Although others have commented on the logistical difficulties of estimating detection probabilities (e.g., Hutto et al. 1986, Pendleton 1995), we suspected we could meet the assumptions of distance sampling in open grassland habitat. Furthermore, distance sampling may more efficiently sample grassland birds than do fixed-radius plots. Because birds often occur at lower densities in grasslands than in structurally complex habitats (Cody 1985), point counts of grassland birds often yield small sample sizes. Distance sampling precludes the need to constrain plot sizes such that all birds on a plot can be detected and thus can sample a larger area per point than can fixed-radius plots.

We designed this study to evaluate the feasibility of using distance-sampling techniques and, if distance sampling proved effective, to test the validity of estimating density (absolute or relative) from fixed-radius point counts. To meet these objectives, we simultaneously collected data using fixed-radius point counts and distance sampling and estimated passerine density with both methods. Our study was conducted as part of a larger study investigating fire management and habitat ecology of grassland birds in North Dakota (Madden 1996).

STUDY AREA

We conducted bird sampling at Lostwood National Wildlife Refuge (NWR) in Mountrail and Burke Counties, North Dakota (48°37′ N, 102°27′ W). Lostwood NWR is 109 km^2 of undulating mixed-grass prairie interspersed with more than 4,000 wetland basins and many clumps of quaking aspen (*Populus tremuloides*). Major vegetation is a needlegrass (*Stipa* spp.)/wheatgrass (*Agropyron* spp.) association (Coupland 1950) with diverse forbs and scattered shrubs. Since the 1970s, the U.S. Fish and Wildlife Service has used prescribed fire and short-duration grazing to reduce woody vegetation and restore natural diversity of successional stages to Lostwood NWR.

METHODS

BIRD SAMPLING

We randomly selected 150 sampling points from a grid of 265 potential points that encompassed the study area. Grid points were 250 m or more apart to provide statistical independence (Hutto et al. 1986, Ralph et al. 1993). Selected points met the following criteria: (1) located in "upland prairie" as delineated by the National Wetland Inventory (NWI) map of cover types of Lostwood NWR (NWI Project 1989); (2) more than 100 m from aspen trees; (3) more than 100 m from roads or firebreaks; (4) more than 50 m from any seasonally flooded wetland zone; and (5) ungrazed by livestock in 1994.

We conducted three replicate bird counts at each sampling point between 26 May and 24 June 1994. During each point count, an observer stood at a point for 10 min and recorded the distance to each bird heard singing. Distance to each bird when first detected was categorized as 0–14.9 m, 15–29.9 m, 30–49.9 m, 50–74.9 m, or more than 75 m. We chose these categories so we could compare detectability in different bands (see "Data Analysis," below) and could test whether the probability of detecting a singing male declined in outer portions (30–49.9 m and/or 50–74.9 m) of 50- or 75-m-radius plots typically used for point counts or varied among species. We did not count birds we saw fly on to plots during counts.

To meet critical assumptions of distance sampling (Buckland et al. 1993:30–37), we spent 2 wk prior to the field season practicing bird identification by song, point-count techniques, and distance measurements (Reynolds et al. 1980), with emphasis on estimating distances to aurally detected birds; we observed each point from 100–200 m away and recorded distance categories for birds detected within 75 m of the point before approaching the point; and we used flagging placed 30, 50, and 75 m from each point in cardinal directions to ensure accurate distance estimation. When assignment to a distance category was uncertain, we confirmed distances by pacing to observed locations after the 10-min count was completed.

Point counts were conducted only on mornings when weather conditions did not impede detection of birds (i.e., no rain, fog, or wind >15 km/hr). Counts began 30 min before sunrise and continued until 0900 central daylight time. Assignment of observers (E. Madden and one technician) to points and the order in which points were surveyed were rotated among replicate counts to minimize sampling bias. We recorded data only for passerines and upland-nesting shorebirds.

DATA ANALYSIS

For species detected 10 or more times within 50 m of sampling points, we estimated density of territorial males (males/100 ha) using a fixed-radius method (Hutto et al. 1986) and distance-sampling methods (Buckland et al. 1983). Hutto et al. (1986) reviewed two commonly used methods of analyzing data from fixed-radius point counts: (1) calculating the average number of birds detected per point count (relative density) and (2) calculating the average number of birds detected per unit area censused by each point count (converting relative density to absolute density). We used the second method to calculate estimates of territorial males per 100 ha for each of two plot sizes; we calculated the average number of territorial males detected per point count (based on three replicate surveys of 150 50- or 75-m-radius plots) and divided the average count by the area of each plot (0.79 ha for 50-m plots, 1.77 ha for 75-m plots). Brown-headed Cowbirds (*Molothrus ater*) were treated differently because male cowbirds do not sing and defend territories in the same manner as other passerines. For cowbirds, we divided the number of male and female detections (aural and visual) per point count by two to estimate the number of breeding males detected. We note that Hutto et al. (1986) cautioned that presenting average detections per unit area of each fixed-radius plot may be misleading because the effective area sampled by each point count is unknown. Accordingly, most recent studies only present relative density. We made the conversion to detections per unit area, however, so that comparisons with density estimates from distance sampling, which are estimated on a per-unit-area basis, could be made using estimates presented on the same scale.

To estimate density from distance data, we used program DISTANCE (Laake et al. 1993) and the methods of Buckland et al. (1993) as reviewed above. Program DISTANCE requires an entry for maximum detection distance for each species. Therefore, we set the maximum detection distance to 400 m for all species, which we felt encompassed all detections. We note that distance sampling does not assume that birds are only counted from one point (Buckland et al. 1993). Thus, 400 m was an appropriate distance despite points being within 250 m of each other. Also, more than 90% of birds were detected less than 250 m from points. Accuracy of the maximum distance was not critical because estimates from program DISTANCE are not highly sensitive to data in the most distant category (J. Laake, pers. comm.). To verify this, we conducted analyses using a maximum distance of 1,000 versus 400 m and, as expected, found that the two analyses generated virtually identical density estimates.

We modeled the probability of detecting territorial males as a function of the distance from the sampling point to a male and estimated density using the model to adjust for undetected males. The probability of detecting each species was modeled using one of the following functions: uniform model with cosine adjustment terms, uniform model with polynomial adjustment terms, half-normal model with hermite polynomial adjustment terms, hazard-rate model with cosine adjustment terms, or a negative-exponential model (Buckland et al. 1993:46–49). We determined the number of adjustment terms to add to each function type based on the results of likelihood ratio tests between sequential versions of each function type, e.g., uniform model with and without a cosine adjustment term. We then chose among models using Akaike's Information Criterion (AIC; Akaike 1973, Burnham and Anderson 1992). Finally, we calculated the χ^2 goodness-of-fit statistic for the chosen model and visually inspected histograms of the distance data and the fit of detection function, with special emphasis on model fit for birds near sampling points. If an adequate fit was not achieved for any model for a given species, we pooled data from two adjacent distance categories and reanalyzed the data for that species. We chose which categories to pool based on visual inspection of distance data as suggested by Buckland et al. 1993. Standard errors were estimated using 399 bootstrap samples (Buckland et al. 1993). The detection-function model for each species was used to estimate the probability of detecting territorial males of each species that were 50 or 75 m from sampling points.

We tested whether the probability of detecting territorial males that were 50 or 75 m from sampling points was less than 1.0 for any species or differed among species by examining 95% confidence intervals for detection probabilities. We tested for a difference between estimates generated by the two analysis methods across all species with the Wilcoxon signed-ranks test (Conover 1980:280–283). This method considered density estimates from the two methods as species-specific matched pairs. We also tested whether the two methods produced different density estimates for any species using z-tests (z = [DISTANCE estimate—

TABLE 1. DENSITY (TERRITORIAL MALES/100 HA) OF GRASSLAND BIRDS AT LOSTWOOD NWR, NORTH DAKOTA, ESTIMATED FROM POINT COUNTS CONDUCTED MAY–JUNE 1994

			50-m-radius plot		75-m-radius plot		Distance sampling	
Species	N (50)[a]	N (400)[b]	D[c]	SE	D	SE	D	SE
Sprague's Pipit	11	81	3.1	0.9	2.6	0.6	3.1	0.9
Common Yellowthroat	24	601	6.8	1.7	7.3	1.2	7.6	1.1
Clay-colored Sparrow	271	1,149	76.7	6.2	71.9	4.2	72.1	4.4
Savannah Sparrow	223	1,226	63.1	4.2	60.5	3.0	60.5	9.1
Baird's Sparrow	28	424	10.2	2.0	11.8	1.7	11.8	1.4
Grasshopper Sparrow	65	336	18.4	2.8	15.3	1.8	19.0	2.3
Le Conte's Sparrow	15	58	4.2	1.1	2.8	0.7	3.6	1.0
Bobolink	48	609	13.6	2.3	15.3	1.8	17.0	1.9
Western Meadowlark	14	808	4.0	1.2	4.0	0.8	3.6	0.7
Brown-headed Cowbird	30	350	4.2	1.4	4.9	1.0	6.7	2.1

Note: Density was estimated from three replicate counts at 150 sampling points using (1) numbers detected on 50-m-radius plots, (2) numbers detected on 75-m-radius plots, and (3) birds detected out to 400 m. For distance sampling, program DISTANCE (Laake et al. 1993) and distances to birds on 400-m-radius plots were used to estimate density.

[a] Total number of singing males detected on 450 counts on 50-m-radius plots.

[b] Total number of singing males detected on 450 counts on 400-m-radius plots.

[c] Density of territorial males/100 ha.

fixed-radius estimate]/[SE of DISTANCE estimate]; Steel and Torrie 1980).

RESULTS

DENSITY ESTIMATES

Ten species were detected 10 or more times within 50 m of sampling points and were used to compare density estimates from different analysis methods: Sprague's Pipit (*Anthus spragueii*), Common Yellowthroat (*Geothlypis trichas*), Clay-colored Sparrow (*Spizella pallida*), Savannah Sparrow (*Passerculus sandwichensis*), Baird's Sparrow (*Ammodramus bairdii*), Grasshopper Sparrow (*A. savannarum*), Le Conte's Sparrow (*A. leconteii*), Bobolink (*Dolichonyx oryzivorus*), Western Meadowlark (*Sturnella neglecta*), and Brown-headed Cowbird (Table 1).

We felt we were able to meet the assumptions of distance sampling (discussed above) for all species except Clay-colored Sparrow. Program DISTANCE successfully fit models to the distance data for nine species and marginally fit a model for Clay-colored Sparrow (Table 2, Fig. 1). We pooled data from two distance categories for 3 of 10 species to achieve acceptable model fit (Table 2). Clay-colored Sparrows apparently moved away from points in response to observers before we detected them (Fig. 1). Hence, the best model marginally fit the distance data for this species ($P = 0.04$), and the density estimate is likely biased low. Bibby and Buckland (1987) calculated that the bias in density estimates would be −30 and −55% if birds moved 20 and 40 m, respectively, before being detected. Such fleeing distances seem reasonable for Clay-colored Sparrows based on inspection of histograms of the distance data.

COMPARISON OF ESTIMATES FROM DIFFERENT ANALYSES

Analysis of distance data indicated that the probability of detecting all territorial males present was less than 1.0 at 50 and 75 m for 6 of 10 species (Table 2); i.e., we did not detect all males of all species on 50- and 75-m plots. Despite this problem, the fixed-radius method of analyzing data from 50-m plots did not yield different density or standard-error estimates than program DISTANCE ($P = 0.68$; Table 1). The fixed-radius method of analyzing data from 75-m plots, however, tended to yield smaller estimates of density and standard error than program DISTANCE ($P = 0.04$ and 0.02, respectively), although differences between the estimate types were relatively small (mean differences for density and standard error were 0.86 and 1.13 males/100 ha, respectively).

Single-species comparisons of density estimates also indicated that the two analysis methods produce consistent results. Point estimates of density from fixed-radius methods of analysis (50- or 75-m plots) and program DISTANCE differed by 27–60% but were not significantly different for any species ($z < 1.8$, $P > 0.07$). Percentage differences between the two estimate types were greatest for Brown-headed Cowbirds, but estimates were not significantly different because of the large standard error produced by the negative-exponential model used.

DISCUSSION

Based on our field experiences, we felt we were able to meet the assumptions of distance sampling for 9 of 10 grassland species that were common on our study area. Accordingly, we be-

TABLE 2. DENSITY OF 10 SPECIES OF GRASSLAND BIRDS AT LOSTWOOD NWR, NORTH DAKOTA, ESTIMATED FROM DISTANCE SAMPLES, 1994

					Density (males/100 ha)		Probability of detection ($\bar{X}$)[a]	
Species	N	Pooled categories[b]	Estimator[c]	G-O-F ($P > \chi^2$)[d]	$\bar{X}$	SE[e]	50 m	75 m
Sprague's Pipit	81	none	HN (0)	0.12	3.1	0.9	0.87*	0.74*
Common Yellowthroat	601	none	UN (1)	0.85	7.6	1.1	0.96*	0.91*
Clay-colored Sparrow	1,149	3 & 4	HZ (0)	0.04	72.1	4.4*	1.00	1.00
Savannah Sparrow	1,226	2 & 3	HZ (0)	0.21	60.5	9.1*	1.00	1.00
Baird's Sparrow	424	none	HZ (0)	0.14	11.8	1.4	1.00	1.00
Grasshopper Sparrow	3636	none	HN (0)	0.10	19.0	2.3	0.82*	0.64*
Le Conte's Sparrow	58	none	HN (0)	0.24	3.6	1.0	0.80*	0.61*
Bobolink	609	none	HN (0)	0.06	17.0	1.9	0.91*	0.80*
Western Meadowlark	808	none	UN (0)	0.12	3.6	0.7*	1.00	1.00
Brown-headed Cowbird	350	3 & 4	NE (0)	0.51	6.7	2.1*	0.73*	0.63*

Note: Density was estimated from three replicates of 150 point-centered distance samples.

[a] Estimated probability of detecting a singing male exactly 50 or 75 m away from a sampling point. Probabilities marked with an asterisk differed ($P < 0.05$) from 1.0 based on z tests. Upper and lower 95% confidence limits for probabilities that were different from 1.0 at 50 and 75 m, respectively, are Sprague's Pipit (0.91–0.80; 0.81–0.61), Common Yellowthroat (0.97–0.94; 0.93–0.87), Grasshopper Sparrow (0.84–0.78; 0.68–0.58), Le Conte's Sparrow (0.86–0.71; 0.71–0.46), Bobolink (0.92–0.89; 0.83–0.77), and Brown-headed Cowbird (0.78–0.68; 0.68–0.56).

[b] Categories used to estimate the distance from sampling points to singing males were (1) 0–14.9 m, (2) 15–29.9 m, (3) 30–49.9 m, (4) 50–74.9, and (5) 75–400 m. During analysis, pooling of data from distance categories 1 and 2, 2 and 3, or 3 and 4 was conducted based on examination of histograms of the distance data that were generated by program DISTANCE (Laake et al. 1993) as suggested by Buckland et al. 1993.

[c] The estimator with the lowest Akaike Information Criteria value was used for density estimation. Estimators considered were UN (uniform model with cosine adjustment terms), HN (half-normal model with hermite polynomial adjustment terms), HZ (hazard rate model with cosine adjustment terms), and NE (negative-exponential model; Buckland et al. 1993). Numbers in parentheses represent the number of adjustment terms, if any, that were added to the model.

[d] Goodness-of-fit tests were conducted to determine how well the best model fit the observed data (Buckland et al. 1993).

[e] Standard errors marked with an asterisk were generated with bootstrapping techniques (Buckland et al. 1993) and represent cases where standard errors generated by program DISTANCE were underestimates.

lieve that distance sampling produced reliable estimates of absolute density for 9 of 10 species. Our distance data show that point counts did not detect all males of all species on 50- or 75-m plots and that detectability varied by species. Most males on 50-m plots were detected, however, and undetected males did not cause estimates from fixed-radius plots to differ significantly from estimates generated from distance sampling. Thus, it appears that the typical plot size used for point counts of grassland birds (50 m; Ralph et al. 1993) provides reasonable density estimates (absolute or relative). The greater percentage of males undetected on 75-m plots caused a slight negative bias in density estimates. Thus, when estimates of absolute density are desired, we caution against using analysis of fixed-radius data on plot sizes larger than 50 m in radius without examining species detectability as a function of distance. If the trade-off between plot size and number of detections per plot causes researchers to choose larger plots (smaller plots yield fewer detections/plot, and their use may necessitate sampling large numbers of plots to detect rare species), investigators should realize that average detections per point on plots larger than those evaluated here represent an untested index of relative density and should consider the potential problems of using such an index (Burnham 1981, Rotella and Ratti 1986).

It is important to note that we only worked on one study area in one year. Other species/habitat combinations may have steeper detection functions, i.e., detection probability drops off more quickly with increasing distance from sampling points. For example, detection functions for House Wrens (*Troglodytes aedon*) in Colorado were quite steep and indicated that only a small percentage of individuals present were detected beyond 25 m (Buckland et al. 1993:396–403). Steeper detection functions will cause fixed-radius analyses to underestimate density and may occur in habitats with denser vegetation or for species with subtle songs. Thus, we recommend that researchers collect distance data, examine detection functions, and consider whether estimates are biased by birds that flee before detection or are difficult to detect within 50 m of a point. This recommendation is especially important for researchers intending to compare density estimates among species/habitat combinations that may have different detection functions. Under such circumstances, using the average number of birds detected per point count as an index to density is "neither scientifically sound nor reliable" (Burnham 1981: 325).

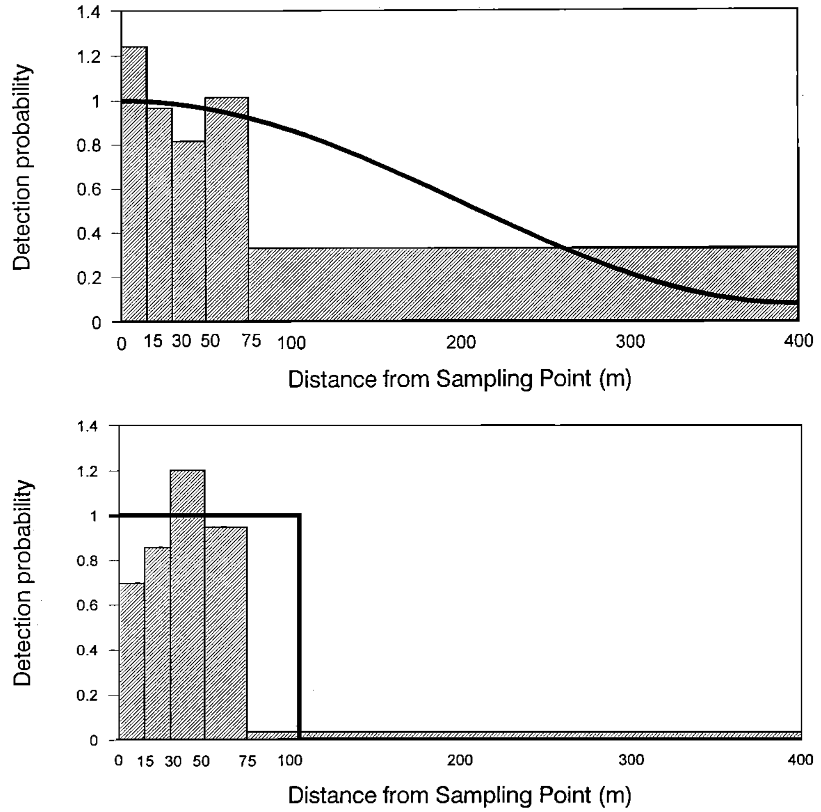

FIGURE 1. Histograms of distance data and fitted models for the detection function g(x) for point-count data collected at Lostwood NWR, 1994. Top: uniform model with one cosine term fitted to data for Common Yellowthroat showing an acceptable fit ($P = 0.85$) and slight decline in detectability within 75 m. Bottom: hazard function model with no adjustment terms fitted to data for Clay-colored Sparrow showing a marginal fit ($P = 0.04$) and evidence of movement away from sampling points before detection.

Based on our experience and recommendations in Buckland et al. 1993, we believe that the following distance categories are appropriate for grassland work: 0–20 m, 20–30 m, 30–40 m, 40–50 m, 50–65 m, 65–100 m, and more than 100 m. These intervals are likely to have equal sample sizes in each category and to allow for data truncation, which may occasionally be necessary to achieve adequate fit of detection functions to the data (Buckland et al. 1993). If researchers are uncomfortable assigning birds to categories that are 10 m wide, they can establish larger categories following guidelines in Buckland et al. 1993.

Although the methods of Buckland et al. (1993) seem to provide an excellent alternative for estimating density from point-count data, distance sampling will not reliably allow density estimation in all situations. Not all species will be detected frequently enough to provide adequate sample sizes in each stratum for which estimates are desired. Buckland et al. (1993: 301–308) suggest that 75–100 detections are needed to produce reliable estimates. Furthermore, the behavior of some species will cause assumptions of distance sampling to be violated. For example, despite our efforts to the contrary, Clay-colored Sparrows apparently fled from points before being detected, which probably caused our estimate to be biased low. Similar problems with fleeing from or being attracted toward observers before detection have been discussed by others (e.g., Hutto and Mosconi 1981, Bibby and Buckland 1987). Simulations, as conducted by Bibby and Buckland (1987), can be used to estimate the bias resulting from assumption violations and can be used to adjust estimates.

We caution that we did not know true density for any species. Future studies should estimate true density from work with banded birds and should validate estimates from point counts and distance sampling. It will be extremely difficult, however, to band adequate samples of multiple species at spatial scales of interest to most studies.

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