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REFINING THE USE OF POINT COUNTS FOR WINTER STUDIES OF INDIVIDUAL SPECIES

KEVIN J. GUTZWILLER[1]

ABSTRACT.—I conducted 167 unlimited-distance point counts in central Texas in February 1987 and January and February 1988 to determine how count duration, time of day, site type (woodland perimeter, woodland interior), winter date (before or after 14 February), and year were related to the winter detection probabilities of 13 species. Within a species, differences in detection probability among the levels of a factor helped identify the environmental (e.g., site type) or methodological (e.g., count duration) conditions under which one could maximize both detectability and point-count sample size. Among the levels of time of day, the detectabilities of each of several species were comparable. Thus, instead of restricting censuses to the morning hours as is common in breeding-season studies, researchers could sample and obtain comparable rates of detection for one of these species throughout the day. An important benefit would be larger point-count sample sizes, which would generally improve the statistical power of subsequent analyses. Similarly, detection probabilities did not differ among 5-, 10-, and 15-min counts for several species; one could capitalize on this similarity by using 5-min counts to maximize the number of counts during a fixed time interval. Comparisons of detection probabilities among the levels of significant interaction effects demonstrated that a variety of levels, involving combinations of main-effect levels, yielded like detection probabilities. Such combinations could be scheduled to maximize simultaneously both point-count sample size and detection probabilities. Because additional point counts and improved detectability would tend to yield data that are more accurate, these strategies are likely to increase the accuracy of ecological inferences based on winter point-count data. *Received 10 Dec. 1992, accepted 25 March 1993.*

Avian ecologists often use relative abundance and occurrence (presence/absence) data to estimate turnover rates and to monitor population trends. To draw realistic inferences, researchers try to use sampling methods that maximize both statistical power and species' detection probabilities. In practice, detection probabilities are affected by numerous factors, including a species' size, color, behavior, and actual abundance, environmental conditions, and aspects of census methods. Although many of these factors are beyond one's control, potential does exist for increasing statistical power and detection probabilities through refinements of census techniques. For example, investigators can increase the number of independent samples, which typically enhances statistical power (see Sokal and Rohlf 1987:123–125), by increasing a technique's time efficiency or by sampling during more hours of the day. Detection probabilities, and therefore the accuracy of associated inferences, can be improved by identifying the optimal conditions for applying a technique.

Point counts (Verner 1985) can be used in a time-effective way (Verner

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[1] Dept. of Biology and Dept. of Environmental Studies, Baylor Univ., Waco, Texas 76798-7388.

1988) to obtain a large number of independent estimates of relative abundance and occurrence. Count duration, count-point location, and the time of day and season during which counts are conducted also can be manipulated easily to maximize species' detection probabilities. Knowledge about how to use points counts during winter is accumulating (Hutto et al. 1986, Verner and Ritter 1986, Gutzwiller 1991, Sliwa and Sherry 1992). Nevertheless, it is still unclear how researchers should use this technique during the winter to maximize simultaneously both detection probabilities and point-count sample size for individual species. Pertinent questions are: how long should unlimited-distance point counts be per station to maximize detection probabilities and the number of point counts per day?; during what time(s) of the day and winter should counts be made to maximize detection probabilities and point-count sample size?; and, at what type of site (interior or perimeter) should point counts be conducted to maximize detectability?

An additional issue here is whether different levels of count duration, time of day, site type, and winter date can be combined in a censusing scheme to yield comparable detection probabilities for a given species (see Robbins 1981a, Hutto et al. 1986, Verner and Ritter 1986). This would enable one to obtain a larger number of counts with like probabilities of detection and would thus be a strategy to improve statistical power. To determine whether such combinations are possible, a simultaneous analysis of main and interaction effects is necessary. My objectives in this paper are to show how count duration, time of day, site type (woodland interior, woodland perimeter), and winter date (before or after 14 February) are simultaneously related to detection probabilities and to describe how this information can be used in sampling protocols to increase detection probabilities and point-count sample size for individual species.

STUDY AREA AND METHODS

Point counts were completed within 50 km of Waco, Texas (31°33′N, 97°10′W), primarily in McLennan County and also in northern Bell County. Soil, vegetation, and climate details are provided in Gehlbach (1991) and Gutzwiller (1991).

Data collection.—From 3–24 February 1987 and from 19 January to 25 February 1988, I recorded the number of individuals of each species detected during a two-year total of 167 20-min unlimited-distance point counts (see Gutzwiller 1991). To minimize confounding influences of seasonal changes (see Robbins 1972, Anderson et al. 1981, Best 1981, Rollfinke and Yahner 1990), I completed point counts during January and February, when species richness and abundance are essentially stable in the study area (F. R. Gehlbach, pers. comm.). Detections were recorded during four consecutive 5-min intervals within the 20-min period (Robbins 1981a). Only those individuals that I confirmed to be distinct in time and space (via visual or aural cues, or both) were recorded as separate individuals. This approach prevented me from counting the same individual more than once during a 20-min period.

I located 22 areas of woodland that were typical of those in central Texas with respect to floristic composition, areal extent, and successional stage. For each of these localities I used random starting points to define initial count sites. Subsequent sites were established by pacing along a straight line at least 200 m from the first (or previous) site and stopping at the nearest woodland perimeter (actual point where woodland abruptly adjoined pasture, fallow fields, or cropland) or woodland interior, depending on available habitat and the site type needed to obtain an equal number of site types in each locality. All count sites were established at least 200 m apart to preclude dependencies in the data from consecutive sites (see Blondel et al. 1981, Dawson 1981, Hutto et al. 1986). Most sites within a given locale were about 300 m apart. I began recording data when I reached a point 25 m from the next point-count site (at least 175 m from the previous site). This enabled me to record individuals that were present at a site but that, on my approach, stopped vocalizing or flushed without returning. Hutto et al. (1986) used this basic procedure to improve the accuracy of winter point counts.

Species that actually used woodland perimeters (N = 79 sites) or interiors (N = 88 sites), either at the time of detection or within a few seconds thereafter, are included in the present analysis. To reduce the chance for statistical dependencies among point counts, I did not include in this analysis data for several species that I frequently saw or heard at distances exceeding 200 m (waterfowl, wading birds, Turkey Vulture [*Cathartes aura*], Black Vulture [*Coragyps atratus*], Red-shouldered Hawk [*Buteo lineatus*], Red-tailed Hawk [*B. jamaicensis*], American Crow [*Corvus brachyrhynchos*]).

I completed counts when wind speed was <20 km/h (Robbins 1981b), air temperature was >0°C, no more than a light drizzle fell, and the ground was snow-free. Counts were made during one of five time periods: 07:00–09:15 (N = 35), 09:16–11:30 (N = 38), 11:31–13:45 (N = 37), 13:46–16:00 (N = 29), 16:01–18:15 (N = 28). Habitat and physical conditions varied somewhat among the 167 count sites (Gutzwiller 1991). I did not analytically remove variation in detection probabilities associated with these differences because I wanted to provide sampling recommendations that would apply to the entire range of conditions I encountered. I sampled once at 167 distinct but comparable sites to ensure that the point counts would be independent and to obtain data for a greater variety of environmental conditions than repeated censuses at fewer sites would have permitted.

Statistical analyses.—A 20-min count was conducted at each of the 167 sites, but I randomly selected sites for analysis of their 5-, 10-, or 15-min results (N = 56, 56, 55, respectively) because researchers usually use one of these three durations. Problems with shorter (2 min) and longer (20 min) durations have been documented (Fuller and Langslow 1984, Verner 1988). Detection probability was computed as the proportion of point counts during which a species was seen or heard. As defined and used here, detection probability was thus an integration of both abundance-dependent and abundance-independent observation probabilities. A measure that incorporates both types of probability is necessary because point-count results are actually influenced simultaneously by such factors.

I used logistic regression to test for differences in detection probabilities associated with count duration, time of day, site type, winter date (before 14 February, N = 107; after 14 February, N = 60), year (1987, N = 66; 1988, N = 101) and their two-way interactions. Because I was interested in whether count duration × daily period interaction effects varied with year, site type, or winter date, I also tested for the appropriate three-way interactions. Site type is not a variable that would be manipulated in a censusing protocol by a researcher studying habitat use because the distribution of individuals among various site types is the topic of interest in such a study. In contrast, site type can be chosen and, therefore, should be considered in the design of monitoring efforts, trend analyses, and turnover studies because count locations that are inappropriate for species would reduce the accuracy of abundance and occurrence data.

Analyses were implemented with BMDPLR (Dixon 1985) programs and associated maximum likelihood ratio estimators. To obtain a parsimonious description of associations and to avoid spurious relations due to overfitting or zero cell counts, I ensured that statistical assumptions were met, and I followed the modeling procedures recommended by Hosmer and Lemeshow (1989:126–133). Knowledge about main effects in the presence of interactions is valuable in some circumstances (Sokal and Rohlf 1987:198, Gutzwiller 1991). Further, the patterns exhibited by levels of the main effects are evident in the interactions I detected (see results). For these reasons, I present both main-effect and interaction-effect data. To test for differences in a species' detection probability among levels of a significant main or two-way interaction effect, I first adjusted the detection probabilities and their associated SEs for other effects in the logistic regression model. Then, I constructed simultaneous confidence intervals for the differences between adjusted detection probabilities. For the sake of brevity, differences in detection probabilities among levels of three-way interaction effects are not provided in the present paper.

Only those species that were detected during more than 25% of the 167 point counts were used in the present analysis. These species and the number of counts during which they were detected are Red-bellied Woodpecker (*Melanerpes carolinus*) (65); Northern Flicker (*Colaptes auratus*) (61); Blue Jay (*Cyanocitta cristata*) (69); Carolina Chickadee (*Parus carolinensis*) (110); Tufted Titmouse (*P. bicolor*) (51); Carolina Wren (*Thryothorus ludovicianus*) (70); Ruby-crowned Kinglet (*Regulus calendula*) (43); Eastern Bluebird (*Sialia sialis*) (45); American Robin (*Turdus migratorius*) (103); Northern Mockingbird (*Mimus polyglottos*) (62); Yellow-rumped Warbler (*Dendroica coronata*) (96); Northern Cardinal (*Cardinalis cardinalis*) (117); and American Goldfinch (*Carduelis tristis*) (60).

I concluded that statistically indistinguishable detection probabilities were comparable in magnitude. I did not assume these probabilities were equal or nearly equal. My interpretation was that the evidence for differences among these probabilities was not strong enough to reject the null hypothesis of no difference at alpha = 0.05. Large SEs, small sample sizes, or both can contribute to a lack of statistical significance. But the SEs for detection probabilities were small for levels that did not differ, and sample sizes within levels were adequate to detect even three-way interaction effects (see results). These conditions suggest that substantial differences in probability magnitudes were probably not obscured by sample-size or SE effects.

RESULTS

Number of effects.—Detection probabilities for each of the 13 species were tested for 18 main and interaction effects; thus 234 (13 × 18) possible effects could have been detected via the logistic regression analyses. I detected 24 significant effects (Table 1), which is two times the number expected by chance alone (0.05 × 234 = 12). In addition, the highest magnitude of attained significance for any effect was 0.022. The relations that emerged are consistent with my field observations and those of other investigators (see below), and my methods were statistically sound. These results and conditions argue that the detected effects are not spurious.

Species-specific variables.—Detection probabilities for many species were associated with unique sets of variables involving one or more of the main and interaction effects (Table 1). That is, the set of effects that was significant for one species was different from the set that was significant for most of the other 12 species. For a given species, each explanatory

TABLE 1

LOGISTIC REGRESSION STATISTICS FOR SPECIES' DETECTION PROBABILITIES (N = 167)

Species	Explanatory variable	df	χ^2 to remove (P)[a]
Red-bellied Woodpecker	Year	1	38.44 (0.000)
	Count duration × winter date	2	14.31 (0.001)
	Count duration × time of day × site type	8	31.70 (0.000)
Northern Flicker	Count duration	2	12.69 (0.002)
	Site type × year	1	10.22 (0.001)
Blue Jay	Winter date	1	26.83 (0.000)
	Time of day	4	12.08 (0.017)
Carolina Chickadee	Year	1	17.31 (0.000)
	Time of day	4	11.61 (0.021)
Tufted Titmouse	Year	1	14.20 (0.000)
Carolina Wren	Site type	1	9.23 (0.002)
	Count duration	2	7.85 (0.020)
	Year	1	14.99 (0.000)
Ruby-crowned Kinglet	Year	1	15.70 (0.000)
Eastern Bluebird	Year	1	8.81 (0.003)
American Robin	Winter date	1	22.31 (0.000)
	Site type × time of day	4	13.13 (0.011)
Northern Mockingbird	Time of day	4	12.40 (0.015)
	Count duration × time of day × site type	8	17.96 (0.022)
Yellow-rumped Warbler	Site type × year	1	7.84 (0.005)
Northern Cardinal	Time of day	4	16.98 (0.002)
	Count duration × year	2	11.52 (0.003)
American Goldfinch	Winter date	1	7.46 (0.006)
	Time of day	4	17.90 (0.001)

[a] The χ^2-to-remove statistic is a measure of association between the probability of detection and the explanatory variable after the effects of other explanatory variables in the logistic regression model have been accounted for.

variable that entered the logistic model was significantly associated with the probability of detection, even after variation in detectability associated with other variables in the model was accounted for (Table 1). When detection probabilities did not differ among the levels of a factor, that factor did not enter the logistic model.

Main effects.—The probability of detection for Carolina Wrens was higher in woodland interiors than at woodland perimeters (Table 2). Within each of the other 12 species, there were no site-type main effects.

TABLE 2

DIFFERENCES AND SIMILARITIES IN WINTER DETECTION PROBABILITIES ($\hat{P}$) AMONG LEVELS OF SITE-TYPE, COUNT-DURATION, YEAR, AND WINTER-DATE MAIN EFFECTS[a]

Species	Main effect	$\hat{P}$	SE($\hat{P}$)	N
Carolina Wren	Site type			
	Woodland interior	0.413	0.056	88 A
	Woodland perimeter	0.183	0.045	79 B
Northern Flicker	Count duration			
	5 min	0.099	0.017	56 A
	10 min	0.207	0.055	56 AB
	15 min	0.382	0.066	55 B
Carolina Wren	Count duration			
	5 min	0.158	0.059	56 A
	10 min	0.336	0.066	56 AB
	15 min	0.397	0.071	55 B
Red-bellied Woodpecker	Year			
	1987	0.544	0.075	66 A
	1988	0.057	0.025	101 B
Carolina Chickadee	Year			
	1987	0.729	0.056	66 A
	1988	0.388	0.049	101 B
Tufted Titmouse	Year			
	1987	0.409	0.058	66 A
	1988	0.148	0.035	101 B
Carolina Wren	Year			
	1987	0.449	0.063	66 A
	1988	0.162	0.037	101 B
Ruby-crowned Kinglet	Year			
	1987	0.318	0.055	66 A
	1988	0.079	0.028	101 B
Eastern Bluebird	Year			
	1987	0.076	0.034	66 A
	1988	0.248	0.042	101 B
Blue Jay	Winter date			
	Before 14 February	0.479	0.052	107 A
	After 14 February	0.093	0.039	60 B
American Robin	Winter date			
	Before 14 February	0.625	0.048	107 A
	After 14 February	0.238	0.055	60 B
American Goldfinch	Winter date			
	Before 14 February	0.248	0.053	107 A
	After 14 February	0.085	0.039	60 B

[a] $\hat{P}$s and SE($\hat{P}$)s listed here are adjusted for other effects in the logistic regression models (Table 1). Level differences for the two-group comparisons are based on χ^2-to-remove tests from logistic regression analyses for each species (Table 1). Results of the three-group comparisons are based on simultaneous confidence intervals for the differences between adjusted detection probabilities; each set of three-group comparisons had an experimentwise-error rate = 0.05. Within each main effect for a given species, probabilities not marked with a common letter differed significantly.

For Northern Flickers and Carolina Wrens, 5-min counts yielded detection probabilities that were significantly lower than those associated with 15-min counts; 10- and 15-min counts yielded the highest detectabilities and were indistinguishable statistically (Table 2). None of the other 11 species exhibited count-duration main effects.

Year effects on detectability occurred for six species (Red-bellied Woodpecker, Carolina Chickadee, Tufted Titmouse, Carolina Wren, Ruby-crowned Kinglet, Eastern Bluebird); the first five were detected with a higher probability during 1987, and Eastern Bluebirds were more detectable during 1988 (Table 2). The remaining seven species (Northern Flicker, Blue Jay, American Robin, Northern Mockingbird, Yellow-rumped Warbler, Northern Cardinal, American Goldfinch) did not exhibit year main effects.

Winter-date effects for Blue Jays, American Robins, and American Goldfinches indicated they were more detectable before 14 February than after this date (Table 2). Winter-date main effects were not evident for the Red-bellied Woodpecker, Northern Flicker, Carolina Chickadee, Tufted Titmouse, Carolina Wren, Ruby-crowned Kinglet, Eastern Bluebird, Northern Mockingbird, Yellow-rumped Warbler, or Northern Cardinal.

Detection probabilities differed significantly among levels of the time-of-day main effect for Blue Jays, Carolina Chickadees, Northern Mockingbirds, Northern Cardinals, and American Goldfinches, with higher probabilities occurring primarily during 07:00–13:45 (Table 3). Within each of the other eight species (Red-bellied Woodpecker, Northern Flicker, Tufted Titmouse, Carolina Wren, Ruby-crowned Kinglet, Eastern Bluebird, American Robin, Yellow-rumped Warbler), detectabilities did not differ statistically among levels of the time-of-day main effect.

Interaction effects.—Detection probabilities differed among levels of several interaction effects: site type × year (for Northern Flickers and Yellow-rumped Warblers); site type × time of day (for American Robins); count duration × year (for Northern Cardinals); and count duration × winter date (for Red-bellied Woodpeckers; Table 4). These effects indicate that the influence of the levels of one factor on detection probabilities depended on the levels of the other factor in the interaction. The count duration × time of day × site type interaction effect was significant for Red-bellied Woodpeckers and Northern Mockingbirds (Table 1), indicating that the count duration × time of day effect differed between woodland perimeters and interiors. Interaction effects did not significantly influence detection probabilities for the Blue Jay, Carolina Chickadee, Tufted Titmouse, Carolina Wren, Ruby-crowned Kinglet, Eastern Bluebird, or American Goldfinch.

TABLE 3

DIFFERENCES AND SIMILARITIES IN WINTER DETECTION PROBABILITIES ($\hat{P}$) AMONG LEVELS OF THE TIME-OF-DAY MAIN EFFECT[a]

Species	Time of day	$\hat{P}$	SE($\hat{P}$)	N
Blue Jay	07:00–09:15	0.323	0.085	35 AB
	09:16–11:30	0.432	0.090	38 A
	11:31–13:45	0.164	0.060	37 AB
	13:46–16:00	0.114	0.058	29 B
	16:01–18:15	0.225	0.084	28 AB
Carolina Chickadee	07:00–09:15	0.756	0.072	35 A
	09:16–11:30	0.580	0.080	38 AB
	11:31–13:45	0.622	0.080	37 AB
	13:46–16:00	0.529	0.093	29 AB
	16:01–18:15	0.325	0.089	28 B
Northern Mockingbird	07:00–09:15	0.248	0.082	35 AB
	09:16–11:30	0.368	0.076	38 A
	11:31–13:45	0.250	0.081	37 AB
	13:46–16:00	0.071	0.058	29 B
	16:01–18:15	0.074	0.069	28 B
Northern Cardinal	07:00–09:15	0.826	0.066	35 A
	09:16–11:30	0.687	0.075	38 AB
	11:31–13:45	0.614	0.079	37 AB
	13:46–16:00	0.398	0.090	29 B
	16:01–18:15	0.407	0.091	28 B
American Goldfinch	07:00–09:15	0.397	0.086	35 A
	09:16–11:30	0.202	0.065	38 AB
	11:31–13:45	0.239	0.070	37 AB
	13:46–16:00	0.085	0.055	29 B
	16:01–18:15	0.033	0.050	28 B

[a] $\hat{P}$s and SE($\hat{P}$)s listed here are adjusted for other effects in the logistic regression models (Table 1). Level differences are based on simultaneous confidence intervals for the differences between adjusted detection probabilities; each set of comparisons for a given species had an experimentwise-error rate = 0.05. Within each time-of-day effect for a given species, probabilities not marked with a common letter differed significantly.

DISCUSSION

Criteria for identifying comparable probabilities. — For probabilities that are found to be statistically indistinguishable among the levels of a factor, some researchers, in deciding which factor levels to use during sampling, may want the magnitudes of these probabilities to be very similar (e.g., $\leq 5\%$ actual difference). This ideal can at least be approached by increasing alpha. In the absence of sample size changes, a larger alpha would reduce the Type II error rate (beta) and increase statistical power (1 − beta) (the ability to detect a difference when one exists) (Zar 1984:44). Probabilities

TABLE 4

DIFFERENCES AND SIMILARITIES IN WINTER DETECTION PROBABILITIES ($\hat{P}$) AMONG LEVELS OF THE SITE TYPE × YEAR, SITE TYPE × TIME OF DAY, COUNT DURATION × YEAR, AND COUNT DURATION × WINTER DATE INTERACTION EFFECTS[a]

Species	Interaction effect	$\hat{P}$	SE($\hat{P}$)	N
Northern Flicker	Site type × year			
	Woodland interior, 1987	0.328	0.055	33 A
	Woodland interior, 1988	0.123	0.036	55 B
	Woodland perimeter, 1987	0.123	0.036	33 B
	Woodland perimeter, 1988	0.328	0.055	46 A
Yellow-rumped Warbler	Site type × year			
	Woodland interior, 1987	0.342	0.052	33 A
	Woodland interior, 1988	0.557	0.051	55 B
	Woodland perimeter, 1987	0.557	0.051	33 B
	Woodland perimeter, 1988	0.342	0.052	46 A
American Robin	Site type × time of day			
	Woodland interior, 07:00–09:15	0.408	0.087	17 ABC
	Woodland interior, 09:16–11:30	0.204	0.067	16 AC
	Woodland interior, 11:31–13:45	0.586	0.084	21 BD
	Woodland interior, 13:46–16:00	0.554	0.088	20 ABC
	Woodland interior, 16:01–18:15	0.387	0.094	14 ABC
	Woodland perimeter, 07:00–09:15	0.431	0.086	18 ABC
	Woodland perimeter, 09:16–11:30	0.670	0.078	22 B
	Woodland perimeter, 11:31–13:45	0.269	0.074	16 CD
	Woodland perimeter, 13:46–16:00	0.296	0.087	9 ABC
	Woodland perimeter, 16:01–18:15	0.453	0.093	14 ABC

TABLE 4
CONTINUED

Species	Interaction effect	$\hat{P}$	SE($\hat{P}$)	N
Northern Cardinal	Count duration × year			
	5 min, 1987	0.768	0.053	26 A
	5 min, 1988	0.404	0.071	30 B
	10 min, 1987	0.554	0.071	22 AB
	10 min, 1988	0.644	0.066	34 AB
	15 min, 1987	0.450	0.073	18 B
	15 min, 1988	0.733	0.058	37 A
Red-bellied Woodpecker	Count duration × winter date			
	5 min, before 14 February	0.073	0.038	38 A
	5 min, after 14 February	0.473	0.093	18 B
	10 min, before 14 February	0.234	0.077	35 AB
	10 min, after 14 February	0.190	0.063	21 AB
	15 min, before 14 February	0.440	0.087	34 B
	15 min, after 14 February	0.083	0.042	21 A

[a] $\hat{P}$s and SE($\hat{P}$)s listed here are adjusted for other effects in the logistic regression models (Table 1). Level differences are based on simultaneous confidence intervals for the differences between adjusted detection probabilities; experimentwise-error rate = 0.05. Within each interaction effect for a given species, probabilities not marked with a common letter differed significantly.

judged not to differ at the higher alpha level would tend to be more similar in magnitude, all else being equal. By increasing alpha, however, one would run a greater risk of incorrectly rejecting the null hypothesis and inferring that two or more probabilities were different (Type I error rate would be higher). I used the conventional level of alpha (0.05) to minimize both Type I and Type II errors (see Zar 1984:44) and to illustrate my approach for identifying point-count variables that either were or were not influential under winter conditions. Higher alpha levels could be used if desired. Or, an alpha of 0.05 could be used to capitalize on the advantages mentioned above, and investigators could use only those levels of a factor (significant or nonsignificant) that yield magnitudes of probabilities that satisfy their criteria for similarity.

Species-specific variables.—Species' detectabilities were influenced by different environmental or methodological factors or both; these results underscore the need to tailor census designs to individual species when relative abundances are to be compared or when population trends for particular species are of special interest. Otherwise, less accurate inferences regarding these topics could be drawn because the optimal conditions for using point counts to census one species may not be optimal for another species. When many species are to be studied, censuses designed specifically for individual species will be difficult to implement simultaneously and will require additional time and effort. One option in this situation is to identify the environmental and method-related aspects of using point counts that simultaneously maximize both detectability and point-count sample size for a group of species of special concern (perhaps an assemblage of neotropical migrants, for example) or for most species. This can be accomplished by determining the factors that affect detectability and point-count sample size for each species individually and then identifying common results. Applying this approach to count duration, time of day, site type, and winter date for the present analysis, 10-min counts during 07:00–13:45 in woodland interiors before 14 February would maximize both detection probabilities and point-count sample size for the set of 13 species as a whole (cf. Tables 2–4).

Main and interaction effects.—Among the levels of main and interaction effects involving site type, detectabilities were similar within each of the following species: Blue Jay, Carolina Chickadee, Tufted Titmouse, Ruby-crowned Kinglet, Eastern Bluebird, Northern Cardinal, and American Goldfinch. Thus, one could census these species at woodland perimeters and in woodland interiors, and a large area containing both site types could be sampled more effectively. An important advantage of such a scheme is that point-count sample size would be increased substantially, which would generally improve the statistical power of subsequent analyses (see Zar 1984, Hanowski et al. 1990). For species whose detectability is influenced by site type (e.g., Carolina Wren, Table 2), point-count stations can be randomly placed within site types that maximize detection. This strategy would not be appropriate for research in which habitat associations are being studied, but it would be crucial for monitoring trends in bird populations (e.g., Verner 1988, Verner and Milne 1989) and for studies of turnover.

For main and interaction effects involving count duration, detection probabilities did not differ significantly for eight species (Table 1), which suggests that within each of these species, individuals would be detected with like probabilities for all three levels of count duration. One could capitalize on this similarity by using 5-min counts, in lieu of 10- or 15-min counts, to increase the number of samples that could be obtained during a set time interval. Within some species, 10- and 15-min counts yielded comparable detection probabilities (Table 2). To maximize both detectability and point-count sample size, 10-min counts would be optimal (see also Fuller and Langslow 1984, Verner 1988) because 15-min counts require more time. Maximizing the number of point counts can help one census an area in less time. This is an important concern when many different areas must be censused during a fixed period or when the number of days spent sampling must be minimized to avoid the effects of changing environmental conditions (e.g., temperature, precipitation, bird community composition).

In pilot studies to determine which variables influence detection probabilities, annual differences in detectability (e.g., Table 2) should be assessed and, if significant, controlled for in statistical analyses (cf. Smith 1984). Annual differences were accounted for in the present study by including year in the logistic model when necessary. This approach enabled me to remove confounding variation associated with year, use all 167 counts for a given model, and thereby obtain a clearer assessment of the influence of the other independent variables.

Considering both main and interaction effects, the detectability of nine species did not differ significantly between winter dates (Table 1), indicating that within each of these species the probability of detection was similar from mid-January through late February. The number of comparable independent point counts could be maximized for these species by sampling until late February. The winter-date influences on detectabilities of Blue Jays, American Robins, and American Goldfinches (Table 2) support earlier recommendations that for some species winter censusing should be conducted before mid-February (Kolb 1965, Dickson 1978, Conner and Dickson 1980).

I did not find differences in detection probabilities among the levels of main or interaction effects involving time of day for six species. These results indicate that instead of sampling just during the morning hours, as is common for breeding-season censuses, researchers could sample for one of these species throughout the day and expect comparable rates of detection among the five times of day for that species. Of course, some times of day would yield probabilities that were higher or more similar than what other times may provide, and investigators could decide which times to use on the basis of desired magnitude and similarity. The more similar the probabilities from various factor levels are, the less chance there is of introducing variance into point-count results. For species that are sampled during the entire day, observer fatigue also could introduce variation into the results. Scheduling a single observer for no more than 4 or 5 hours of counting per day would help avoid this problem.

For some species certain times of day were optimal for censusing and all periods did not yield comparable detection probabilities (Table 3). To maximize both detectability and sample size, counts for Northern Cardinals, for example, could be conducted during 07:00–13:45. Another option would be to sample Northern Cardinals just during 09:16–13:45 because, by using levels that yielded detection probabilities that were more similar, the variance of resulting point-count data would be minimized. Other investigators have found differences in detectability associated with time of day during the winter for various species (see Robbins 1972, Shields 1977, Verner and Ritter 1986, Rollfinke and Yahner 1990). Rollfinke and Yahner (1990) suggested that counts conducted after 14:00 may lead to underestimates of the abundances of some species. In the present study, counts conducted from 13:46–18:15 did indeed yield significantly lower detection probabilities than earlier times for some species (Table 3). This pattern was not evident for most of the species I studied. General recommendations about when to sample during the day in winter may be inappropriate because there is considerable variation among species in detectability during the day, even in the same study area (see Table 3 and the references cited immediately above). A more valid approach would be to conduct area-specific analyses to identify optimal sampling times for the species or group of species of interest.

Knowledge about interaction effects (e.g., Table 4) can be valuable in designing census plans. The site type × time of day interaction for American Robins, for instance, could be used to identify a variety of site type-time of day combinations that would yield comparable detectabilities. One could use the combinations to maximize sample size, detectability, or both. For example, one could maximize both sample size and detectability for American Robins by using all combinations that yielded probabilities that did not differ significantly from the highest detection probability ($\hat{P}$ = 0.670 for woodland perimeter, 09:16–11:30); only two combinations (woodland interior, 09:16–11:30 and woodland perimeter, 11:31–13:45) yielded significantly lower probabilities (Table 4). Interaction effects may be important indicators of problems to avoid, such as habitat shifts between years that may be associated with site type × year interactions. Any interaction involving year indicates that the differences in detectability among levels of the other factor in the interaction were not the same each year. To maintain the accuracy and precision of point counts, investigators should base sampling protocols on relations that do not differ among years. The count duration × time of day interaction differed between site types for Red-bellied Woodpeckers and Northern Mockingbirds, which indicates that census schemes involving combinations of various count durations and times of day would not yield detection probabilities that would be comparable between site types for these species.

My specific results will be most relevant for winter researchers working with the same species that I studied. But the present analysis also has broader significance in that it demonstrates how investigators can increase both point-count sample size and detectabilities. Although estimates of detection probabilities presented herein for certain species may be broadly applicable, a study of how to use point counts in the area of interest is likely to provide more refined and effective recommendations. Factors beyond the scope of analysis here—effects of observer skill (Smith 1984, Verner and Milne 1989) and observer fatigue, for example—also deserve attention in pilot studies. The additional effort required for such analyses is warranted because it can help investigators determine how to increase point-count sample size and detection probabilities which should in turn improve the accuracy of ecological inferences.

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LITERATURE CITED

ANDERSON, B. W., R. D. OHMART, AND J. RICE. 1981. Seasonal changes in avian densities and diversities. Pp. 262–264 *in* Estimating numbers of terrestrial birds (C. J. Ralph and J. M. Scott, eds.). Stud. Avian Biol. 6.

BEST, L. B. 1981. Seasonal changes in detection of individual bird species. Pp. 252–261 *in* Estimating numbers of terrestrial birds (C. J. Ralph and J. M. Scott, eds.). Stud. Avian Biol. 6.

BLONDEL, J., C. FERRY, AND B. FROCHOT. 1981. Point counts with unlimited distance. Pp. 414–420 *in* Estimating numbers of terrestrial birds (C. J. Ralph and J. M. Scott, eds.). Stud. Avian Biol. 6.

CONNER, R. N. AND J. G. DICKSON. 1980. Strip transect sampling and analysis for avian habitat studies. Wildl. Soc. Bull. 8:4–10.

DAWSON, D. G. 1981. Counting birds for a relative measure (index) of density. Pp. 12–16 *in* Estimating numbers of terrestrial birds (C. J. Ralph and J. M. Scott, eds.). Stud. Avian Biol. 6.

DICKSON, J. G. 1978. Seasonal bird populations in a south central Louisiana bottomland hardwood forest. J. Wildl. Manage. 42:875–883.

DIXON, W. J. (ed.). 1985. BMDP statistical software: 1985 printing. Univ. California Press, Berkeley, California.

FULLER, R. J. AND D. R. LANGSLOW. 1984. Estimating numbers of birds by point counts: how long should counts last? Bird Study 31:195–202.

GEHLBACH, F. R. 1991. The east-west transition zone of terrestrial vertebrates in central Texas: a biogeographical analysis. Texas J. Sci. 43:415–427.

GUTZWILLER, K. J. 1991. Estimating winter species richness with unlimited-distance point counts. Auk 108:853–862.

HANOWSKI, J. M., G. J. NIEMI, AND J. G. BLAKE. 1990. Statistical perspectives and experimental design when counting birds on line transects. Condor 92:326–335.

HOSMER, D. W., JR. AND S. LEMESHOW. 1989. Applied logistic regression. John Wiley and Sons, New York, New York.

HUTTO, R. L., S. M. PLETSCHET, AND P. HENDRICKS. 1986. A fixed-radius point count method for nonbreeding and breeding season use. Auk 103:593–602.

KOLB, H. 1965. The Audubon winter bird-population study. Audubon Field Notes 19: 432–434.

ROBBINS, C. S. 1972. An appraisal of the winter bird-population study technique. Am. Birds 26:688–692.

———. 1981a. Effect of time of day on bird activity. Pp. 275–286 *in* Estimating numbers of terrestrial birds (C. J. Ralph and J. M. Scott, eds.). Stud. Avian Biol. 6.

———. 1981b. Bird activity levels related to weather. Pp. 301–310 *in* Estimating numbers of terrestrial birds (C. J. Ralph and J. M. Scott, eds.). Stud. Avian Biol. 6.

ROLLFINKE, F. B. AND R. H. YAHNER. 1990. Effects of time of day and season on winter bird counts. Condor 92:215–219.

SHIELDS, W. M. 1977. The effect of time of day on avian census results. Auk 94:380–383.

SLIWA, A. AND T. W. SHERRY. 1992. Surveying winter warbler populations in Jamaica: point counts with and without broadcast vocalizations. Condor 94:924–936.

SMITH, P. G. R. 1984. Observer and annual variation in winter bird population studies. Wilson Bull. 96:561–574.

SOKAL, R. R. AND F. J. ROHLF. 1987. Introduction to biostatistics. W. H. Freeman, New York, New York.

VERNER, J. 1985. Assessment of counting techniques. Pp. 247–302 *in* Current ornithology, vol. 2 (R. F. Johnston, ed.). Plenum Press, New York, New York.

———. 1988. Optimizing the duration of point counts for monitoring trends in bird populations. Res. Note PSW-395. Pacific Southwest For. Range Exp. Sta., Berkeley, California.

——— and K. A. Milne. 1989. Coping with sources of variability when monitoring population trends. Ann. Zool. Fennici 26:191–199.

——— and L. V. Ritter. 1986. Hourly variation in morning point counts of birds. Auk 103:117–124.

ZAR, J. H. 1984. Biostatistical analysis, 2nd edition. Prentice-Hall, Englewood Cliffs, New Jersey.

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