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Monitoring Bird Populations by Point Counts

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Abstract

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This volume contains in part papers presented at the Symposium on Monitoring Bird Population Trends by Point Counts, which was held November 6–7, 1991, in Beltsville, Md., in response to the need for standardization of methods to monitor bird populations by point counts. Data from various investigators working under a wide variety of conditions are presented, and various aspects of point count methodology are examined. Point counts of birds are the most widely used quantitative method and involve an observer recording birds from a single point for a standardized time period. Statistical aspects of sampling and analysis were discussed and applied to the objectives of point counts. Symposium participants agreed upon standards of point counts that should have wide applicability to a variety of habitats and terrain.

Retrieval Terms: Bird counts, bird populations, census methodology, evaluation, monitoring, point counts, sampling of populations, standards of censusing

Technical Editors:

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Birds are salient features of North American environments. Their frequent song during the summer, their bright plumages, and their visibility attract even the urbanites' attention and inspire many to pursue their study. Despite high visibility, counting bids can be a frustrating business: territorial behavior keeps populations uniformly, but thinly, distributed; dense vegetation can hamper visibility; and a myriad of songs and calls is challenging to learn.

The study of these birds is an old science, but quantification of their abundance is relatively young. Only a few enumerations of birds can be found before the 1940s. What good data occur usually involve those species of management concern, especially ducks and geese, or easily counted, highly colonial species. Smaller species of birds, often referred to as "non-game," or in a more positive sense, often known as "landbirds," include most species found in any area of the world. They are difficult to count, being dispersed, often cryptic, and small. However, much work has been done in the past 50 years to advance counting methods.

Very recently, inlerest in this subject has been heightened with the recent concern over possible decline of neotropical migratory landbids, those birds breeding in North America, and wintering to the south. Among the possible explanations for a decline is deforestation of sub-tropical and tropical America, as well as removal of large regions of the northern coniferous forest. This concern has kindled the spark of interest in landbirds into a flickering flame, known as "Partners in Flight—Aves de las Americas," an integrated program of inventory and monitoring of these many and varied species. Among the several aspects of this work, involving both population sizes, trends, and demography, is the counting of the birds.

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Many methods, and modifications thereof, have been used in the past for counting buds to estimate their relative abundance and population trends. Most of these were examined in detail in the various papers found in Ralph and Scott (1981) and by Vemer (1985) in his important evaluation. Among the methods, modifications of the unlimited distance point counts (Blondel and others 1981) often represent the best cdmpromise between economy of collection effort and precision and accuracy of the estimates of population trends or population indexes (Verner 1985).

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The Breeding Bird Survey (Bystrak 1981, Droege 1990) is basically such a point count program that has been underway throughout the United States and Southern Canada since 1966. In our deliberations we did nut exclude adopting these 3-minute, roadside counts as the recommended standard, but we found some limitations to this method. Besides the potential biases associated with roadside habitats, (the Survey is limited to roads) it was felt to be too short at 3 minutes for many purposes, and it is structured in 50 point clusters. An

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The Forest Service, U.S. Department of Agriculture, is responsible for Federal leadership in forestry It carries out this role through four main activities:

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- Cooperation with State and local governments, forest industries, and private landowners to help protect and manage non-Federal forest and associated range and watershed lands
- Participation with other agencies in human resource and community assistance programs to improve living conditions in rural areas
- Research on all aspects of forestry, rangeland management, and forest resources utilization.

The Pacific Southwest Research Station

Represents the research branch of the Forest Service in California, Hawaii, American Samoa and the western Pacific.

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Effects of Point Count Duration, Time-of-Day, and Aural Stimuli on Detectability of Migratory and Resident Bird Species in Quintana Roo, Mexico[1]

James F. Lynch[2]

Abstract: Effects of count duration, time-of-day, and aural stimuli were studied in a series of unlimited-radius point counts conducted during winter in Quintana Roo, Mexico. The rate at which new species were detected was approximately three times higher during the first 5 minutes of each 15-minute count than in the final 5 minutes. The number of individuals and species detected in 15-minute counts declined by >60 percent over the first 3 hours after sunrise. Use of aural stimuli (playbacks of prerecorded warbler "chip" notes, imitated owl calls, "spishing") offset this temporal reduction in detection rate for Nearctic migrants, but not for most permanent residents. The relative precision of occurrence rates estimated from point count data is inherently low, especially for rarely encountered species. Estimates will be more precise if the sample of points is large and especially if the probability of detecting targeted species is high. Different combinations of sample size and count duration can yield equally precise estimates of occurrence rates.

The point count method is commonly used to survey breeding bird communities in temperate North America (Verner 1985), where investigators have studied the effects of count duration, radius of the count area, and time-of-day (Gutzwiller 1991; Robbins 1981; Buskirk and others, Dawson and others, Gates, Petit and others in this volume). However, there have been only two previous quantitative assessments of the point count method in the Neotropics, where a high proportion of the landbird species that breed in temperate North America spend most of the year (Blake 1992, Hutto and others 1986). Given the precarious status of some Nearctic migrants (Askins and others 1990, Hagan and Johnston 1992, Keast and Morton 1980, Rappole and others 1983), additional information on their winter distribution and ecology is urgently needed. If point counts are to be employed in such studies, several questions should be addressed: (1) Are point counts suitable for surveys of non-breeding birds in the Neotropics? (2) Which extrinsic factors influence the results of winter point counts in the Neotropics? (3) How can survey protocols be modified to increase the efficiency of winter point counts in the Neotropics?

Methods

Between 1984 and 1990, 1 conducted approximately 1200 unlimited-radius point counts of winter bird communities in the Yucatan Peninsula of Mexico, Belize, and Guatemala (Lynch 1989, 1992). Because the primary focus of my research was the distributional ecology of Nearctic migrants, I supplemented my point counts with three types of aural stimuli: (1) playbacks of prerecorded "chip" notes of the Hooded Warbler (*Wilsonia citrina*) and Kentucky Warbler (*Oporomis formosus*), (2) whistled imitation of the call of the Ferruginous Pygmy-Owl (*Glaucidium brasilianum*), a common diurnal predator of small birds, and (3) "spishing" sounds of the kind ornithologists often use to instigate approach or vocalization by birds. During the winters of 1986-87 and 1987-88, I conducted a series of experimental point counts to quantify the effects of aural stimuli, time of day, and duration of count.

This study was conducted within a 10-km radius of the coastal village of Puerto Morelos, in northeastern Quintana Roo, Mexico (lat. 20°51'N., long. 86°54'W.). Local annual rainfall is approximately 1200 mm, and a dry season extends from about November to May (Lynch 1989). Counts were restricted to the interior (>100 m from roads or clearings) of extensive tracts of relatively undisturbed medium-stature (canopy height = 12 m to 20 m), semievergreen tropical forest. Elevations of survey sites ranged from 5 m to 25 m above sea level.

I generally began conducting point counts within 15 minutes of local sunrise and continued for approximately 3 hours, by which time bird activity had declined markedly. I alternated 15-minute "unsupplemented" counts (no aural stimuli used) with 15-minute "supplemented" counts, during which I alternated playbacks of Hooded Warbler "chip" notes, imitated owl calls, "spishing" and periods of silence. No attempt was made to distinguish the individual effects of the three stimuli. Count results were tallied by 5-minute intervals, and detections made within 30 m were compiled separately. The distance between survey points was 200-300 m, and the travel time between points was 3-6 minutes (mean = 5 minutes). The term "species occurrence" refers to the detection of one or more individuals of a given species during a single point count.

At the time of year when this study was conducted (early December to mid-February), local sunrise occurred between about 0608 and 0624 c.s.t. (U.S. Department of Commerce 1990). For analysis, mornings were divided into three 1-hour count periods (0600-0659, 0700-0759, 0800-0859).

Data were subjected to multiple linear regression analysis and ANOVA, using the General Linear Models Procedure of the SAS statistical package (SAS Institute 1985).

Results

I identified 72 species of birds in 71 fifteen - minute unlimited-radius point counts. There were 673 detections of individual birds or conspecific groups, of which 595 or (88 percent) could be identified to species.

Effects of Aural Stimuli

When the data were pooled across the three time periods (0600-0900), counts supplemented by aural stimuli yielded about 11 percent more species occurrences per 15-minute

[1] An abbreviated version of this paper was presented at the Workshop on Monitoring Bird Population Trends by Point Counts, November 6-7, 1991, Beltsville, Maryland.

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count than did unsupplemented counts (*table 1*). Most of this difference was attributable to a statistically significant increase of about one species in the mean number of migratory species encountered in supplemented counts from 0800-0859. Aural stimuli had no significant effect on detection rates of migrants early in the morning (0600-0659). As a group, residents showed no consistent response to the experimental aural stimuli at any time from 0600-0900 (*fig. 1; table 2*), although a few resident taxa (e.g., several hummingbird species) reacted aggressively to the Ferruginous Pygmy-Owl call.

The total number of species detected in point counts supplemented by aural stimuli was 19 percent higher than in unsupplemented counts (65 versus 53), but this may, in part, reflect the larger number of supplemented versus unsupplemented counts (39 versus 32).

Effect of Count Duration

On the average, 55 percent (range = 51 percent to 66 percent) and 82 percent (range = 75 percent to 85 percent) of all initial species detections occurred within the first 5 minutes and first 10 minutes, respectively, of 15-minute counts, regardless of the time of morning or the use of aural stimuli (*table 1*). The detection rate of new species in the 0- to 5-minute interval (1.02 species per minute) was three times as high as in the 10- to 15-minute interval (0.34 species per minute).

Effect of Time of Morning

The mean number of species detections per 15-minute count (supplemented and unsupplemented counts pooled) declined significantly ($P < 0.001$) from 11.5 between 0600 and 0659 to 6.6 between 0800 and 0859. This temporal decline was much steeper for unsupplemented counts (-62 percent) than for supplemented counts (-23 percent). Time of morning had no statistically significant effect on the number of migrant occurrences in counts supplemented by aural stimuli ($P < 0.05$, *table 2*). However, the number of resident detections per count showed a highly significant ($P < 0.0001$) temporal decline in both supplemented and unsupplemented counts.

Effect of Limiting the Count Radius

Unlimited-radius counts yielded 81 percent more occurrences than did counts restricted to a 30-m radius (*table 3*). However, the effect of restricting count radius was not uniform across species. Some large, highly vocal species (e.g., Plain Chachalaca (*Ortalis vetula*), Collared Forest-Falcon (*Micrastur semitorquatus*), Yellow-lored Parrot (*Amazona xantholora*), Ferruginous Pygmy-Owl, Golden-fronted Woodpecker (*Centurus aurifrons*), Brown Jay (*Cyanocorax morio*)) were rarely or never detected within 30 m of the observer, but were commonly detected at greater distances. Restricting the count radius to 30 m reduced the number of detections of such species to the point where little useful information on their occurrence was obtained. At the opposite extreme, some smaller and quieter species (e.g., American Redstart (*Setophaga ruticilla*), Black-and-white Warbler (*Mniotilta varia*), White-eyed Vireo (*Vireo griseus*), Black-throated Green Warbler (*Dendroica virens*)) were almost always detected within 30 m of the observer. Limiting the count radius had little effect on the detectability of such species.

Discussion

Utility of Winter Point Counts in the Neotropics

Most species detections of birds in forested habitats are based on vocalizations (Hayward and others 1991, Skirvin 1981). Because territorial singing by overwintering migrants is infrequent during the nonbreeding season, one might have predicted that winter point counts of migrants in tropical forest would not be effective. However, extensive survey data from the Yucatan Peninsula indicate that winter point counts in the lowland tropics can, in fact, yield useful quantitative data from both migratory and permanently resident species (Lynch 1989; 1991, 1992). Species-specific "chips" and other nonsong vocalizations are used frequently by both migrants and residents during winter in Quintana Roo, and many local residents also use territorial songs at that season. As a result, an estimated two-thirds to three-quarters of all species identifications in this study were made on the basis of aural cues.

Winter point counts in Quintana Roo do present some

Table 1--Mean number of new species detections as a function of time of morning and count interval in 71 point counts conducted during winter in Quintana Roo, Mexico. Counts were either supplemented by aural stimuli (S) or were unsupplemented controls (U)

		Count interval			Total
	n	0-5 minutes	5-10 minutes	10-15 minutes	0-15 minutes
Time	S (U)	S (U)	S (U)	S (U)	S (U)
0600-0659	12 (8)	6.1 (7.9)	2.8 (2.2)	2.2 (l.9)	11.1 (12.0)
0700-0759	16 (14)	4.9 (5.2)	3.1 (3.4)	1.7 (l.5)	9.6 (10.1)
0800-0859	11 (10)	4.3 (2.6)	2.1 (0.9)	2.2 (l.0)	8.5 (4.5)
Total (3 hours)	39 (32)	15.3 (15.7)	8(6.5)	6.1 (4.4)	29.2 (26.6)

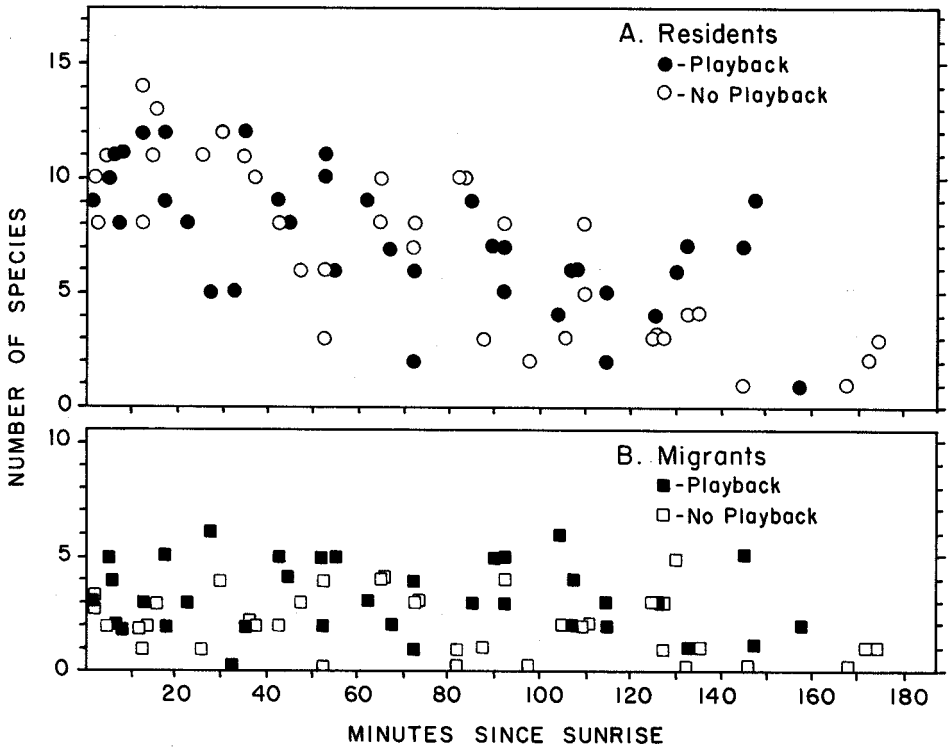

Figure 1--Effects of time of morning and the use of aural stimuli on the number of (A) resident and (B) migrant bird species detected in 15-minute unlimited-radius point counts conducted during winter in Quintana Roo, Mexico.

Table 2--*Summary of results of multiple regression analysis testing the effects of aural stimuli (AS) and time of morning (T) on the number of species detections in 71 winter point counts in Quintana Roo, Mexico*

			Coefficient		
Response variable	Mean	Intercept	AS	T	R^2
Total species/count	9.7	14.4	1.4 *	-0.06 ***	0.50 ****
Resident species/count	7.1	10.7	0.1 ns	-0.05 ***	0.52 ****
Migrant species/count	2.6	3.7	1.3 *	-0.01 ns	0.22 ***

Significance levels: ns = $P > 0.05$; * = $P < 0.05$; *** = $P < 0.001$; **** = $P < 0.0001$.

special problems. A major limitation is the relatively short period each morning during which spontaneous vocalizations are frequent enough to make point counts effective. In "standard" (i.e., unsupplemented) counts, the mean number of species detected in 15-minute counts declined by about 60 percent between 0600 and 0900. Limited data suggest that detection rates continue to decline after 0900, at least during winter. Using point counts, Blake (1992) also documented a marked diurnal decline in bird occurrences during the winter dry season in a Costa Rican lowland tropical forest. Blake suggested that point counts in such habitats should be restricted to the first 3 hours of the morning. Although Hutto and others (1986) found only a slight (and statistically nonsignificant) temporal decline in detection frequencies at a highland and lowland forest site in western Mexico, future investigators in the tropics must consider the possibility of strong diurnal variation in point count results.

Tradeoffs Between Count Duration and Travel Time

In this study, most species detections occurred within the first 5 to 10 minutes of point counts (Hamel 1984, Hutto and others 1986, Scott and Ramsey 1981). This temporal pattern might appear to favor a sampling design consisting of numerous short counts. For example, on the basis of my data from Quintana Roo, six 5-minute counts would be expected to yield about 50 percent more species occurrences than two 15-minute counts. In fact, however, the apparent advantage of short counts tends to be offset by a concomitant increase in total travel time.

Given the 5-minute travel time recorded in the present study, one could actually perform 18 (not 36) 5-minute counts, or 12 (not 18) 10-minute counts, or 9 (not 12) 15-minute counts in a 3-hour field session. Without the use of aural stimuli, these three sampling designs would be expected to yield approximately 94, 89, and 80 species occurrences per

Table 3-*Most frequently detected species (>10 occurrences) arranged in increasing order of their tendency to be detected >30 m from the observer in 71 winter point counts conducted in Quintana Roo. Common names follow the American Ornithologists' Union (A.O.U.) Check-list (1983).*

Species	Occurrences (maximum =71)			Percent occurrences
	<30 m	>30 m	Total	>30 m
White-eyed Vireo*	11	0	11	0
Black-throated Green Warbler*	10	0	10	0
Black-and-white Warbler*	12	0	10	0
American Redstart*	24	1	25	4
Red-throated Ant-Tanager	21	1	22	5
White-throated Spadebill	20	2	22	9
Magnolia Warbler*	29	5	34	15
Northern Bentbill	14	3	17	18
Lesser Greenlet	12	4	16	25
Hooded Warbler*	33	13	46	28
Dusky-capped Flycatcher	8	5	13	38
Wood Thrush*	10	10	20	50
Carolina Wren	5	5	10	50
Keel-billed Toucan	7	15	22	68
Bright-rumped Attila	4	12	16	75
Pale-billed Woodpecker	3	10	13	77
Brown Jay	11	41	52	79
Golden-fronted Woodpecker	2	11	13	85
Yellow-lored Parrot	2	12	14	86
Collared Forest-Falcon	0	10	10	100
Plain Chachalaca	0	14	14	100
Ferruginous Pygmy-Owl	0	19	19	100

* Species marked with an asterisk (*) are Nearctic migrants.

morning, respectively, per 3-hour session (*table 4*). However, if aural stimuli are used, all three sampling designs would yield similar results (92 versus 93 versus 88 occurrences, respectively). For unsupplemented counts, doubling travel time to 10 minutes results in essentially identical expected numbers of detections for either 12 10-minute counts (68) or 9 15-minute counts (67), but fewer detections (62) for a sampling strategy consisting of 9 5-minute counts. If travel time is 15 minutes, then 15-minute unsupplemented counts yield more occurrences per morning than either 5-minute or 10-minute counts. These particular numerical values may reflect conditions that prevail during winter in Quintana Roo but, as a rule, longer travel time favors longer count durations.

Tradeoffs Between Statistical Precision, Count Duration, and the Magnitude of Occurrence Rates

The presence or absence data of point counts conform to a binomial distribution and are conveniently expressed as percent occurrences. For sample sizes up to several hundred counts, the confidence limits around observed percentages are so broad that only gross differences can be confirmed statistically (Rohlf and Sokal 1969). The *relative* (but not absolute) confidence limits around an observed occurrence rate shrink as either the sample size of points or the magnitude of the occurrence rate increases (Petit and others 1990), but the latter effect is proportionately much greater. For a sample of 100 counts, the 95 percent confidence limits around a 4 percent observed occurrence rate overlap with those around a nearly four-fold higher occurrence rate of 15 percent (Rohlf and Sokal 1969). Even if the sampling intensity is doubled (n = 200 points), one still cannot statistically differentiate a 4 percent observed occurrence rate from a nearly three-fold higher rate of 11 percent. In contrast, if the observed occurrence rate is 50 percent, a relative change of as little as 30 percent (i.e., an occurrence rate of 65 percent) can be statistically verified in two samples of 200 points. Thompson and Schwalbach (this volume) estimated that as many as 30,000 point counts might be required to detect a 20 percent relative change in the occurrence rates of the rarer bird species in their Indiana study area.

Table 5 provides concrete examples of sample size and point count duration on the reliability of observed occurrence rates observed in Quintana Roo, assuming that (1) diel changes in the detection rates for individual species mirror community trends, (2) counts are conducted between 0600 and 0900, (3) total field time is held constant, and (4) travel time is 5 minutes. These computations indicate that uncommon species occurring in less than 10 percent of 15-minute point counts (e.g., Yellow-throated Vireo (*Vireo flavifrons*) would be more precisely sampled by employing large numbers of short (i.e., 5-minute) counts. For species that occur in 10 percent to 20 percent of 15-minute counts (e.g., Black-throated Green Warbler), 5-minute counts and 15-minute counts

Table 4--*The total number of species detections expected per hour of field time in supplemented (S) and unsupplemented (U) point counts as a function of count duration and time of morning. Travel time between points is assumed to remain constant at 5 minutes.*

	Duration (and number/hour) of counts		
	5 minutes (n = 6)	10 minutes (n = 4)	15 minutes (n = 3)
Time	S (U)	S (U)	S (U)
0600-0659	36.6 (47.4)	35.6 (40.4)	33.3 (36.0)
0700-0759	29.4 (31.4)	32.0 (34.4)	28.8 (30.3)
0800-0859	25.8 (15.6)	25.6 (14.0)	25.5 (13.5)
Total (3 hours)	91.8 (94.2)	93.2 (88.8)	87.6 (79.8)

would yield about the same relative error for a given total amount of field time. For species occurring in >20 percent of 15-minute counts (e.g., Wood Thrush (*Hylocichla mustelina*), Magnolia Warbler (*Dendroica magnolia*), and Hooded Warbler), occurrence rates will be more efficiently estimated if 15-minute counts are employed.

The quantitative advantage of any particular combination of count duration and sample size appears to be modest, at least under the conditions that prevail during winter in Quintana Roo (*table 5*). This finding is consistent with the results of Gutzwiller (1991), who obtained similar estimates of bird community richness whether he used many short point counts or fewer long counts. A more important determinant of the precision of point counts is the absolute magnitude of occurrence rates. The relative error of the occurrence rate of an abundant species that is recorded in 65 percent of all 15-minute point counts (e.g., Hooded Warbler) is 15 percent for 100 15-minute counts, and 20 percent for 200 5-minute counts. However, for a rare species such as Yellow-throated Vireo, whose occurrence rate in 15-minute counts is only 6 percent, the corresponding relative errors exceed 80 percent (*table 5*). Consequently, if one wishes to improve the precision of point count surveys of rare species, often it will be far more cost-effective to increase the occurrence rate per sample point (e.g., by employing aural stimuli) than to extend the count duration or increase the number of points sampled.

Pros and Cons of Using Aural Stimuli to Supplement Point Counts

Aural stimuli can substantially increase the delectability of many species, especially where spontaneous vocalizations are infrequent. In addition, birds responding to playbacks frequently approach the observer more closely and persistently than they would otherwise, thereby facilitating determination of sex, age, and color band combinations. Single-species playbacks have generally been used, but songs and calls of several target species can easily be combined on a single playback tape (Johnson and others 1981). Appropriate predator calls and generalized alarm calls also elicit responses from a range of species.

The use of aural stimuli in point count surveys does, however, have potential disadvantages. R. Hutto has suggested (personal communication) that the responses of some species to playbacks might not be constant across habitats; i.e., that detectabilities may vary spatially. This concern also applies to most other survey methods, including "standard" point counts. Indeed, one can argue that a higher proportion of the birds actually present in an area will be detected, regardless of habitat, if appropriate aural stimuli are employed. For example, use of aural stimuli in Quintana Roo virtually elim-

Table 5--Relative error (RE) of observed occurrence rates as a function of their magnitude, given two hypothetical sampling strategies. Data are extrapolated from observed frequencies in 71 winter point counts conducted in Quintana Roo. Given a constant travel time of 5 minute between sample points, both sampling strategies would require the same total field time. For each species the smaller relative error is underlined. See text for further explanation.

		Hypothetical sampling strategy					
		15-minute counts (n = 100 points)			5-minute counts (n = 200 points)		
Species	F(obs)	Percent Occurrence	95 percent Confidence Limit	RE	Percent Occurrence	95 percent Confidence Limit	RE
				pct			*pct*
Yellow-throated Vireo	4/71	6	(2-13)	103	3	(1-6)	84
Black-throated Green Warbler	10/71	14	(8-22)	50	8	(5-13)	50
Wood Thrush	20/71	28	(20-38)	32	16	(11-22)	36
Magnolia Warbler	34/71	48	(38-58)	21	26	(20-33)	24
Hooded Warbler	46/71	65	(55-74)	15	35	(28-42)	20
Hypothetical species	65/71	92	(87-95)	9	50	(43-57)	14

inated the apparent diel decline in migrant detections that was indicated by unsupplemented point counts, a result that is hardly attributable to bias on the part of supplemented point counts. On the contrary, the unsupplemented "standard" point counts introduced artifactual variation by failing to detect quiescent birds that were, in fact, present throughout the morning sampling period. Whether supplemented point counts are more effective than standard counts in reducing spatial (as opposed to temporal) artifacts in detection rates remains to be demonstrated, but I predict that habitat-reduced variation in detectability also will be reduced, not increased, by the use of aural stimuli.

As is also true of "standard" point counts, counts supplemented by aural stimuli are not immune to temporal artifacts. Resident tropical species, most of which are not responsive to the particular aural stimuli I used in Quintana Roo, showed a diel decrease in detectability even when aural stimuli were employed. Presumably, more appropriate stimuli (e.g., conspecific territorial songs) would have reduced this temporal decline in resident detectability. Seasonal differences in responsiveness to aural stimuli may complicate comparisons of results between breeding and wintering surveys. Although the responses of Hooded Warblers and Kentucky Warblers (*Oporomis formosus*) to conspecific "chip" notes appear to be similar in the breeding and nonbreeding seasons, the responses of these two species to Ferruginous Pygmy-Owl calls are much weaker during the breeding season in Maryland. Conversely, the response of these two species to conspecific territorial song is strong during the breeding season, but weak during winter (J. Lynch, personal observation).

Perhaps the most cogent objection to the use of aural stimuli is that comparisons with the results of "standard" point counts will be clouded, especially for normally inconspicuous species that respond strongly to playbacks. In this context, it is irrelevant that the higher detection rates produced by aural stimuli may reflect true densities.

Finally, an observer's preoccupation with playbacks, owl calls, and "spishing" undoubtedly reduces his or her ability to distinguish all calling species, especially early in the morning when many species may be vocalizing simultaneously. In addition, shy species may actually retreat or become silent in response to inappropriate aural stimuli, thereby reducing their detectability: The fact that slightly more species were detected early in the morning (0600-0659) in unsupplemented counts in Quintana Roo (*table 1*) suggests that one or both inhibitory effects of playbacks may have applied.

Components of an Effective Point Count Study

Given realistic limitations on sampling effort, standard point counts are clearly unsuitable for confirming even quite large relative differences in the occurrence rates of rare or cryptic species. To increase the ability of point counts to detect biologically significant variation in occurrence rates, investigators should strive to maximize both the probability of detection at each point and the number of points sampled. Detection rates will be higher and less variable if counts are restricted to the most productive portions of the day (Blake 1992, Gutzwiller 1991).

To further increase detectability, observers should consider using unlimited-radius counts, especially for species that are rare or not easily detected at close range (Gates, in this volume). Admittedly, data from unlimited-radius counts cannot be used to calculate absolute densities, but documentation of relative differences may suffice to answer many research questions (Verner 1985). For those wishing to calculate absolute densities from point count data, occurrences within a desired fixed radius can be tabulated separately from more distant detections, as in the present study.

Especially in situations where the daily period of high bird activity is shortened, observers should minimize travel time by moving rapidly between survey locations and by adopting the minimum between-point distance that prevents double counting. Gutzwiller (1991) found that a between-point distance of 200 m was sufficient to assure statistical independence in unlimited-radius point counts of overwintering passerines in Texas, but greater distances are required for taxa (e.g., parrots, corvids, cracids) that are routinely detected at distances of several hundred meters.

Standardization of Point Count Techniques

The desirability of standardizing point count methodology across very different geographic regions, habitats, seasons, taxonomic and behavioral groups, and levels of abundance is problematic. Rare and cryptic marsh birds clearly require a different sampling protocol than do common and conspicuous forest passerines. On the other hand, it is both feasible and desirable to standardize studies of ecologically and behaviorally similar species associated with one general habitat type (e.g., forest), at a particular time of year (e.g., the breeding season).

The point count technique appears to be suitable for documenting patterns in the distribution and relative abundance of birds in the northern Neotropics during winter, based on studies in the Yucatan region, western Mexico, and Costa Rica. The results of similar studies of North Temperate breeding bird communities may not be directly comparable to the cited tropical studies because of seasonal differences in detectability (Lynch and Whigham 1984).

The occurrence rates of certain species are increased if standard point counts are supplemented by aural stimuli. Observers might consider conducting the first 5-10 minutes of each point count without using such stimuli, then employing playbacks as desired for an additional set period. As long as the supplemented and unsupplemented data are tabulated separately, the twin goals of higher efficiency and increased standardization can both be served.

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Sample Size and Allocation of Effort in Point Count Sampling of Birds in Bottomland Hardwood Forests[1]

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Abstract: To examine sample size requirements and optimum allocation of effort in point count sampling of bottomland hardwood forests, we computed minimum sample sizes from variation recorded during 82 point counts (May 7-May 16, 1992) from three localities containing three habitat types across three regions of the Mississippi Alluvial Valley (MAV). Also, we estimated the effect of increasing the number of points or visits by comparing results of 150 four-minute point counts obtained from each of four stands on Delta Experimental Forest (DEF) during May 8-May 21, 1991 and May 30-June 12, 1992. For each stand, we obtained bootstrap estimates of mean cumulative number of species each year from all possible combinations of six points and six visits. ANOVA was used to model cumulative species as a function of number of points visited, number of visits to each point, and interaction of points and visits. There was significant variation in numbers of birds and species between regions and localities (nested within region); neither habitat, nor the interaction between region and habitat, was significant. For $\alpha = 0.05$ and $\beta = 0.10$, minimum sample size estimates (per factor level) varied by orders of magnitude depending upon the observed or specified range of desired detectable difference. For observed regional variation, 20 and 40 point counts were required to accommodate variability in total individuals (MSE = 9.28) and species (MSE = 3.79), respectively, whereas ± 25 percent of the mean could be achieved with five counts per factor level. Sample size sufficient to detect actual differences of Wood Thrush (*Hylocichla mustelina*) was >200, whereas the Prothonotary Warbler (*Protonotaria citrea*) required <10 counts. Differences in mean cumulative species were detected among number of points visited and among number of visits to a point. In the lower MAV, mean cumulative species increased with each added point through five points and with each additional visit through four visits. Although no interaction was detected between number of points and number of visits, when paired reciprocals were compared, more points invariably yielded a significantly greater cumulative number of species than more visits to a point. Still, 36 point counts per stand during each of two breeding seasons detected only 52 percent of the known available species pool in DEF.

Despite the extensive literature on estimating numbers of terrestrial birds (e.g., Scott and Ralph 1981), general agreement over a standardized protocol for monitoring Neotropical migrant birds using point counts is only now being achieved (Ralph and others 1993). Required sample sizes using point counts and allocation of effort among points and visits to points are poorly understood. Monitoring efforts applied over a large region (e.g., lower Mississippi Alluvial Valley) need to accommodate local, habitat, and regional variation in Neotropical migratory bird species distribution and abundance. Only then can we hope to achieve optimum sampling protocols, i.e., provide sufficient ecological information with the least amount of sampling effort.

This paper examines sample size requirements for point count surveys in bottomland hardwood forests of the Mississippi Alluvial Valley (MAV). Specific objectives were to determine (1) minimum sample size to accommodate the variation in bird species distribution and relative abundance throughout the MAV; (2) the optimum number of points to sample at each locality; and (3) the optimum number of counts at each point during a season.

Methods

Study Areas

For this paper, we compiled data from two studies. To estimate variability throughout the MAV, we developed a balanced study design that included three point counts at each of three localities within each of three habitats (Wet, Mesic, Dry). This sampling design was repeated in each of three regions (Southern, Central, Northern) of the lower MAV (i.e., 3 x 3 x 3 x 3) for a total of 81 point counts. Wet habitat localities were characterized by cypress (*Taxodium* sp.) or tupelo (*Nyssa* sp.). Mesic habitat localities were seasonally flooded, lowland flatwoods, whereas Dry habitat localities were ridges or rarely inundated bottomland forests. Each locality was >40 ha to accommodate three randomly selected points that were at least 250 m apart (Ralph and others 1993) and >200 m from the forest edge.

In addition, Delta Experimental Forest (DEF), Stoneville, Mississippi was the site of a 2-year study (1991-1992) examining the influence of forest management on breeding bird abundance and diversity (Smith 1991). DEF encompasses about 1,050 ha and represents one of the few remaining large (≥100 ha), contiguous bottomland forests in a 100-km radius.

Point Count Protocol

With few exceptions, we followed the general guidelines and procedures for point count censusing of birds by Ralph and others (1993). Point counts within the lower MAV were of 10-minute duration (with cutoffs at 3 and 5 min as well) and occurred during the first four hours after dawn (i.e., before 1000 CDT). Each point was visited once during May 7-16, 1992. An assistant estimated distance to each bird according to predefined landmarks and recorded data. Before each count began, distance to selected landmarks was estimated with a rangefinder (Ranging Optimeter 620, Ranging Inc., East Bloomfield, NY). Landmarks were used to assign birds seen or heard to one of three concentric distance bands: <25 m; 25 m to 50 m; or >50 m. When necessary, the

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rangefinder was used to verify the distance band within which individual birds should be recorded.

Briefly, we found (Smith and others 1993) that the 50-m distance band and a sampling period of 5 minutes provided the most favorable results with respect to recording number of species per unit effort. Therefore, for the purposes of this study, we will use only data recorded using those constraints.

On DEF, we established 25 randomly selected points within each of four stands: two silvicultural treatments and a paired control for each treatment. One treatment was a 1937 clearcut that regenerated naturally; the second underwent timber stand improvement cuts in 1937. Each control had not been managed since the last high-grade harvest (mid-1930's). To minimize the potentially confounding influence of treatment effects on habitat structure and probability of detection, we recorded birds seen or heard within a 20-m radius of each point.

Within each stand, each point was systematically sampled five to seven times during the 3-hour period following sunrise from May 8 to May 21 in 1991, and from May 30 to June 12 in 1992. A sampling schedule was implemented whereby each point within a stand was visited on separate days at a different time on each of the subsequent visits. Each census consisted of recording all birds seen or heard within 20 meters of the observer per minute, for a total of four minutes.

Data Analyses

Calculation of minimum sample size followed Neter and Wasserman (1974:492) for a specified α (probability of rejecting the null hypothesis when it should be accepted), β (probability of not rejecting the null hypothesis when it should be rejected), and ø, the non-centrality parameter (*appendix A*). Specifying ø requires determining how much factor (i.e., treatment) level means (e.g., region) must differ to represent a statistical difference (Neter and Wasserman 1974). For this paper we chose three different specifications for ø. The first reflected the observed variation of variables among each of the main effects, i.e., region, habitat, and locality. Here, the range of mean values observed for a dependent variable relative to each effect (e.g., mean number of species in each of the regions, or mean number of a species among habitats) was used to calculate ø. The other two specifications were arbitrary but represent extremes with respect to resolution: (1) sample sizes for a difference of ±0.25 to detect statistical significance if the greatest difference among factor levels was 0.25 birds, or 0.25 species, and (2) a precision of ±25 percent of the mean, which represents a coarser filter for investigating gross differences in species distribution and abundance.

From point count data recorded within DEF, we generated a matrix of mean cumulative number of species for censuses with all possible combinations of six points and six visits using the bootstrap procedure (Efron 1982). Within each stand, observations for each combination (e.g., two visits to each of four points) were obtained by randomly sampling the "population" of point counts (e.g., 150 counts: 6 visits to 25 points) recorded each year. For each randomly selected point count, location was constrained while successive visits were randomly selected. Each mean value was computed from 250 resampling iterations and represented an independent observation of a point x visit combination within the selected stand.

We used analysis of variance (ANOVA, GLM Procedure; SAS Institute, Inc. 1988:549) to determine whether significant variation in cumulative number of species occurred as a function of number of points, number of visits, or an interaction of points and visits. Scheffe's multiple comparison procedure was performed to determine which main effect means differed. We made an *a priori* simultaneous comparison using a contrast statement within the ANOVA (SAS Institute, Inc. 1988:560) to compare the 15 possible reciprocal combinations of points and visits that were conducted on Delta Experimental Forest.

Results and Discussion

Distribution of Point Counts

Although the proposed experimental design for the lower MAV study provided for a balanced design of 81 point counts (3 regions x 3 habitats x 3 localities x 3 counts), we did not find all three types of habitat in all localities. Specifically, only one Dry habitat locality was identified in the southern region, and one Wet habitat locality was not found in the Central region. Nonetheless, we generally followed our basic study design completing 82 10-minute point counts throughout the lower MAV during the period May 7-May 16, 1992 (Smith and others 1993).

On Delta Experimental Forest, Stoneville, Miss., we conducted 600 4-minute point counts from May 8 through May 21, 1991-six visits to 25 points in each of four stands. An additional 600 4-minute point counts were completed during the period May 30-June 12, 1992.

Variation among Point Counts and Minimum Sample Size

Nature and Extent of Point Count Variation

A critical aspect of this study was to characterize the nature and extent of variation that investigators may encounter in conducting point count censuses in bottomland hardwood forests. Only then can an appropriate study design with adequate sample sizes be developed (objective 1). There was significant variation in numbers of both individuals and species per count for the lower MAV. Mean number of individuals ranged from 10.8 birds/count in Wet habitat within the Central region to 20.0 birds/count in Mesic habitat within the Southern region. Corresponding values for species counts were 8.3 and 13.7, both in Wet habitat, within the Southern and Northern regions, respectively. Point counts in the Central region averaged the fewest number of individuals per census (13.2, s = 3.07); the Southern and Northern regions averaged 16.8 (s = 2.20) and 15.0 (s = 2.16), respectively. The Central region also averaged the fewest species per census (9.6, s = 1.93). Mean number of species per census in the Southern region was 10.2 (s = 1.74), whereas the Northern region averaged 11.2 (s = 1.70).

Variation among Localities and across Regions

Overall ANOVA models for both number of species and number of individuals were significant; differences between regions and localities nested within regions were significant, but

neither habitat nor the interaction between habitat and region were significant (*table 1*). This result suggests that at the finer scale most of the variation in point counts occurs among locations, but less so among habitats. This may be because continuously forested habitats in the lower MAV are very similar; most habitats have comparable elevation and microrelief, experience perennial inundation, and generally support forest cover types that are similar in composition and structure. In contrast, species composition and other habitat features presumably show appreciable variation among regions.

Minimum Sample Size

There are two major approaches to estimating minimum sample size. The "non-power method" (Ott 1977) calculates the minimum sample size for a specified difference between two means, given the variance in the data, but considers only the probability of making a Type I error. The "power method" (Neter and Wasserman 1974) calculates minimum sample size relative to the probability of making Type I and Type II errors. The power method dictates minimum sample sizes greater than or equal to the non-power method and thus is more conservative.

Minimum sample size estimates for the lower MAV varied greatly according to the variable measured and scale of resolution (*table 2*); only extremely large sample sizes would accommodate all possible measurements. The sample size (given a particular variance) determines the magnitude of the difference between factor means that can be detected with statistical significance. If the difference between two means is small relative to their variance, the power of the test will probably be low. To achieve greater power in this situation usually requires very large sample sizes, even approaching infinity. Unfortunately, selecting an acceptable power for each test may often be largely subjective.

Nevertheless, one does not want all comparisons for all species to be significant. If all tests were significant, there would be little information about the relative importance of each factor in determining bird distributions. Thus, it is necessary to choose a minimum sample size that is reasonable for identifying biologically important factors, yet is achievable with reasonable effort. We calculated minimum sample sizes for a variety of differences among means, and for several different variables: number of species, number of individuals, and for species exhibiting different distributions and abundances throughout the lower MAV (*table 2*). Also, *appendix B* summarizes minimum sample sizes for 20 selected species with differences among localities across all three regions. (Scientific names of species included in *appendix B* are included in an appendix of this volume.)

For each variable in the table, we presented four minimum sample sizes (*table 2*). Note that these are minimum sample sizes for each level of a factor. Thus, the total sample size for a study comparing three regions would be three times the number given in the table. The numbers in the column called "actual difference" represent minimum sample sizes that would have been required to detect the difference in factor means according to the variation incorporated in the point counts conducted in the lower MAV. (Note that the MSE [mean square error], mean, and range were also calculated from these censuses.) The actual difference could not be statistically significant for variables with sample sizes greater than about 82, which was the number of counts conducted in the lower MAV. For example, differences among habitats (*table 2*) could have been significant only for the Prothonotary Warbler (*Protonotaria citrea*) or Red-eyed Vireo (*Vireo olivaceus*).

Sample sizes for a difference of ±0.25 birds are those that would be required for statistical significance if the greatest difference among factor levels was 0.25 birds (or 0.25 species). Since this value designates an absolute change in abundance, the relative difference identified as statistically significant will vary with the mean. When the mean is large, such as mean total number of species or number of individuals, the relative difference represented by ±0.25 is small (about 2.4 percent and 1.7 percent of the means for regional total species and total individuals, respectively). In contrast, our regional estimate of mean number of Wood Thrush (*Hylocichla mustelina*) was 0.23 per census (*table 2*); a difference of ±0.25 individuals becomes an increase or decrease of >100 percent of the mean. This was the situation for the majority of species in the lower MAV, including nine of the 20 more common species reported in *appendix B*.

Perhaps a better approach for estimating minimum sample sizes of individual species is to specify some relative change in population abundance. For this reason, we included a column in *table 2* that summarizes sample sizes for detecting differences of ±25 percent of the mean. This translates into a maximum difference among treatment means of 50 percent of the overall mean. One can readily compute sample sizes for a wide range of relative changes in abundance by simply increasing or decreasing the disparity between treatment means and overall mean (i.e., $\mu_j - \mu$; Neter and Wasserman 1974:493). Selecting an appropriate magnitude of relative change will depend on the objectives of the research or monitoring program. We calculated sample sizes required to detect variation of ±25 percent of the mean because such a difference should frequently reflect biologically meaningful changes, and it represents an achievable goal for most public and private land managers. For more detailed research endeavors such as modeling population dynamics or population viability analyses of endangered species, consistent detection of smaller relative changes may be necessary.

Finally, to provide a different perspective on the question of sample size, we presented minimum difference detected among factor level means (given the MSE) with a sample size of 70 (*table 2*). We initially selected a sample size of 70 for this exercise because it was the largest sample size value presented in the table of curves (TABLE A-10, Neter and Wasserman 1974:827). Since then, however, we recognized that 70 point counts was an achievable goal and would probably accommodate the needs of most public and private land managers. Although the values for minimum sample size vary widely, most of the values are ≤70, and many fall into the range of 40-60, especially for differences that probably are biologically meaningful. For species that have large differences relative to their overall mean (e.g., Prothonotary Warbler), sample size could be much smaller, especially if the study were designed carefully with respect to selected

Table 1-ANOVA ***tables (overall models) for the number of species and individuals per count. (Region and habitat were treated as main effects with patch nested within region).***

Effect	Degrees of freedom	*F*	*P* > *F*
	Species		
Region	2	5.70	0.005
Habitat	2	0.32	0.730
Region*Habitat	4	1.11	0.357
Locality (Region)	6	2.82	0.017
Within	67		
	Individuals		
Region	2	7.46	0.001
Habitat	2	0.61	0.546
Region*Habitat	4	0.31	0.871
Locality (Region)	6	2.33	0.042
Within	67		

Table ***2-Minimum sample sizes calculated for several variables according to the power method with several detectable difference values among factor level means. MSE, mean, range, and actual difference were calculated from observed variation among factor levels in this study. (Unless otherwise noted,*** $\alpha = 0.05$ ***and*** $\beta = 0.10$***).***

				Sample size required for			
Variable	MSE[1]	Mean[2]	Range[3]	Actual Difference[4]	±0.25 Birds[5]	±25 percent of mean[6]	Difference[7] detected if n = 70
Total species							
Region	3.791	10.30	1.53	41	>500	5	1.192
Locality	3.759	9.60	1.87	29	>500	5	1.187
Habitat	4.143	10.30	0.69	>500	>500	5	1.246
Total birds							
Region	9.283	14.95	3.56	20	>500	5	1.866
Locality	9.174	13.21	2.63	35	>500	6	1.855
Habitat	11.272	14.95	0.87	>500	>500	5	2.056
Northern Cardinal							
Region	1.292	1.59	0.48	>200	>200	53	0.696
Locality[8]	1.144	1.71	1.04	28	>200	44	0.655
Habitat	1.326	1.58	0.27	>200	>200	53	0.705
Prothonotary Warbler							
Region	0.563	0.95	1.38	9	58	70	0.453
Locality	0.571	0.57	0.35	>200	58	>200	0.463
Habitat	0.822	0.95	0.94	23	90	95	0.545
Red-eyed Vireo							
Region	0.358	0.52	0.79	15	37	>200	0.366
Locality	0.208	0.32	0.78	9	23	>200	0.279
Habitat	0.445	0.52	0.36	44	44	>200	0.408
Wood Thrush							
Region	0.232	0.23	0.13	>200	27	>200	0.295
Locality	0.151	0.18	0.24	58	15	>200	0.238
Habitat	0.235	0.23	0.03	>200	27	>200	0.297

[1]Mean Square Error of one-way Analysis of Variance, with three levels of treatment (for example, northern, central and southern region).

[2]Mean birds or species per count. This value is the same for Region and Habitat.

[3]Range between the means for the highest and lowest levels of treatment.

[4]Sample size that is required to get statistical significance for the actual observed difference among factor level means (range). Note that the minimum sample sizes in *table 2* were all calculated using a design with one factor and three factor levels. If more or fewer levels were used, this number would be slightly greater or smaller; however, the numbers in *table 2* are a useful approximation.

[5]Sample size that would be required to detect a significant difference of 0.25 birds (or species) above or below the overall mean.

[6]Sample size that would be required to detect a significant difference between two treatments that is between 25 percent above and 25 percent below the overall mean (that is, the difference between two treatment means of 50 percent of the overall mean).

[7]The difference (in number of birds) that could be significantly detected by a sample size of 70.

[8]Because locality was nested within region, no overall minimum sample size can be calculated for locality. The minimum sample sizes in this table were calculated from one-way ANOVA of the three patches within the central region because of the balanced sample size design.

variables and factor levels. An analysis of regional choices by Prothonotary Warblers at three factor levels would require 27 counts (nine point counts per factor level). Conversely, species that have more variation and exhibit smaller differences, such as the Northern Cardinal (*Cardinalis cardinalis*), would require larger sample sizes.

Multiple Points Versus More Visits to Points

We initially compared all possible combinations of six visits to each of six points by using ANOVA to model cumulative number of species as a function of number of points visited, number of visits to each point, and their interaction across all four stands. We considered each year independently because total species recorded in DEF during 1991 (S = 39) and during 1992 (S = 55) were substantially different, presumably because of late flooding in 1991. There was significant variation in mean cumulative species among number of points and among number of visits to each point, both in 1991 ($F \geq 91.30$, df = 35, $P < 0.0001$) and 1992 ($F \geq 89.78$, df = 35, $P < 0.0001$). There was no significant interaction between number of points and number of visits. However, the ANOVA model explained about 97 percent of the variation in mean cumulative number of species both in 1991 ($R^2 = 0.9673$) and 1992 ($R^2 = 0.9668$).

In 1991, cumulative number of species increased significantly with each added point through five points (*fig. 1*), but six points did not differ from five points (F = 3.19, Minimum Significant Difference = 0.7853, df = 108, $P < 0.05$). Similarly, cumulative number of species increased with each revisit up to four visits to a point station, but four visits did not differ from five visits to a point station (F = 3.19, Minimum Significant Difference = 0.7853, df = 108, $P < 0.01$). Also, as we increased the number of points from one to six, total increase in cumulative number of species (across all six visits) averaged 7.4 species across all stands and represented an addition of 20 percent of the species pool to our estimate. Total increase in cumulative number of species with six visits to a point station (across all six points) averaged 5.49 species, adding only 14 percent of the species pool to our estimate. In 1992, significant increases in cumulative number of species occurred with each added point through all six points, whereas significant increases with revisits occurred through four visits as in 1991 (F = 2.29, Minimum Significant Difference = 1.0451, df = 108, $P < 0.05$) (*fig. 2*). Average total increase in cumulative number of species with six points in 1992 was 11.82, a 21 percent increase in total number of species; six visits increased the total cumulative number of species by 8.9, a 16 percent increase in total number of species.

Although no interaction was detected between points and visits, when all possible paired reciprocals (e.g., one point-two visits vs. two points-one visit) were compared,

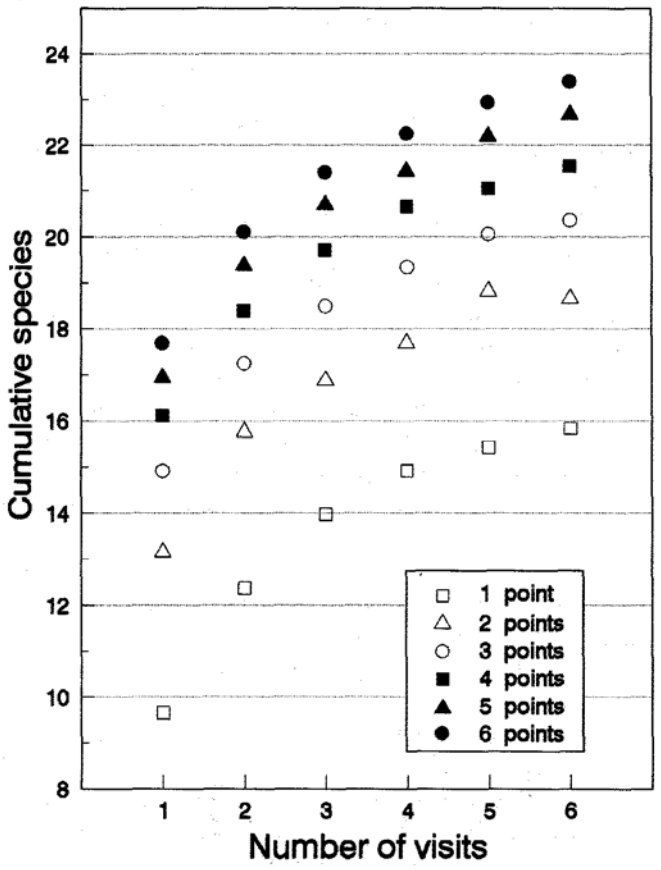

Figure 1-Cumulative number of bird species recorded during 1991 censuses for all possible combinations of six visits to each of six points on Delta Experimental Forest, Stoneville, Miss.

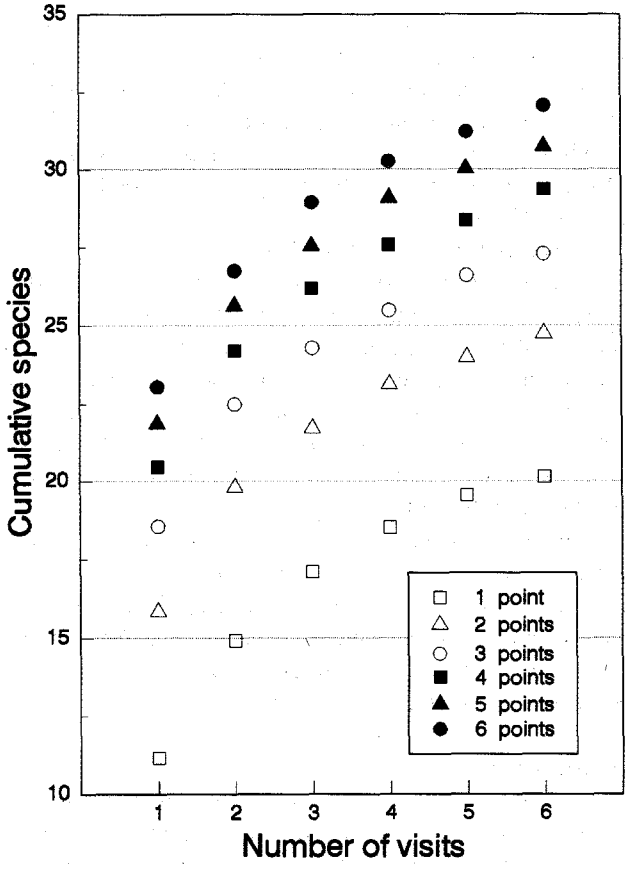

Figure 2-Cumulative number of bird species recorded during 1992 censuses for all possible combinations of six visits to each of six points on Delta Experimental Forest, Stoneville, Miss.

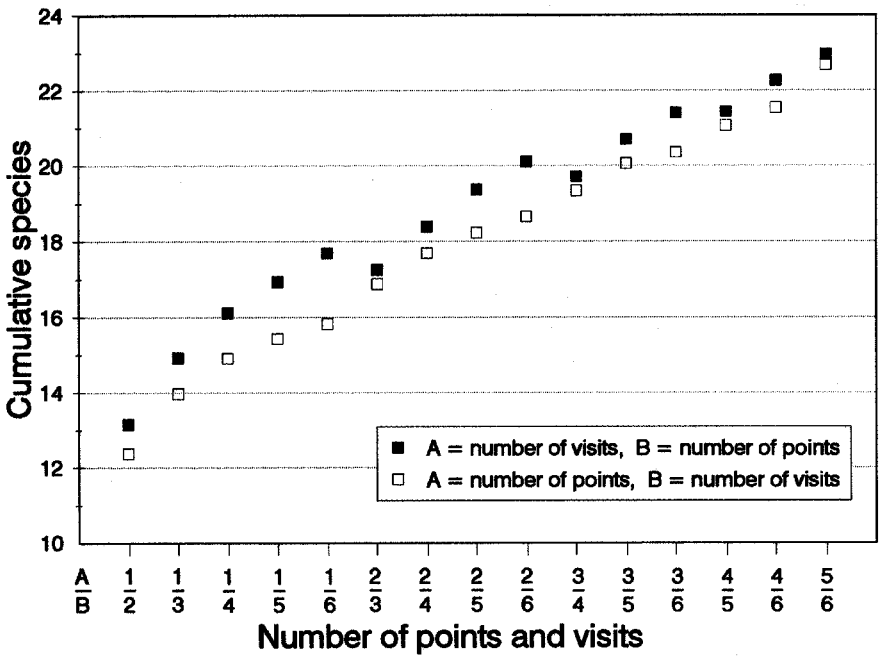

Figure 3-Comparison of cumulative number of bird species recorded between 15 possible paired reciprocals (e.g., 1 point-2 visits vs. 2 points-1 visit) of number of points visited and number of visits to each point, Delta Experimental Forest, Stoneville, Miss., 1991.

more points visited yielded significantly greater cumulative number of species than more visits to each point both in 1991 (F = 4.34, df = 15, $P < 0.0001$) and in 1992 (F = 4.07, df = 15, $P < 0.0001$). Moreover, in all individual-paired comparisons, more points visited invariably yielded more species than more visits to each point in both 1991 (*fig. 3*) and 1992 (*fig. 4*). Also, as number of points and visits approached their maximum values, increases in either had increasingly less effect on cumulative number of species recorded in 1991 (*fig. 3*) and 1992 (*fig. 4*).

Despite the suggestion that five points or four visits to each point represented sufficient sampling effort (i.e., increases beyond either level did not significantly increase total number of species), our performance relative to capturing the variation in DEF was not impressive. In both years, the maximum proportion of the total species pool (estimated by total species recorded for the entire DEF) included in our censuses (i.e., sampling efficiency) continued to increase gradually with additional points, but approached only 55 percent in 1991 and 52 percent in 1992 (*fig. 5*). Increasing revisits beyond five visits in 1991 did not improve our ability to capture more of the species pool (*fig. 6*); in 1992, a sixth visit increased the efficiency by 1.5 percent (Δp_i = 0.015). In both years, increased efficiency (Δp_i) began to decrease rapidly beyond three visits and three points.

Applications

In planning a monitoring scheme, the amount of effort (money, personnel, time) one can expend is often fixed. Often there is a tradeoff between allocation of sampling effort toward increasing the number of experimental units, which increases statistical power, or allocation of effort toward increasing the precision and accuracy of bird abundance estimates within experimental units, which decreases statistical power if overall effort remains constant. Increasing precision and accuracy can be done by visiting more points in an experimental unit or by making more visits to single points in an experimental unit.

Our results from bottomland hardwood forests suggest that, if bird abundance is to be compared among different factor levels (patch size, habitat type, silvicultural treatment), about 50 counts per factor level should be sufficient to detect most of the biologically meaningful differences. Thus, a study comparing species distribution and abundance among three forest patch-size categories would require a minimum of 150 counts (50 counts per treatment or factor level). To avoid pseudoreplication (Hurlbert 1984), an independent observation (i.e., single point count or the mean of ≥2 censuses) should be obtained from each of the 150 forest patches. Our results also suggest that up to five points should be visited per experimental unit. Increasing the number of points, rather than the number of visits to a point, is likely to be more efficient in terms of detecting new birds. After three points or visits, efficiency decreases.

Finally, another means of reducing sample size is to accept a higher probability of rejecting the null-hypothesis when it is true (i.e., accept an ($\alpha > 0.05$); or accept a lower probability of rejecting the null when it is false, i.e., increase β or reduce the power of the test (Neter and Wasserman 1974). Most biologists recognize the need to report the alpha level associated with each statistical test. It is equally important to report the power of each test when the null hypothesis is not rejected (Forbes 1990). This provides the reader with explicit information regarding the likelihood that the null hypothesis was not rejected because of small sample size.

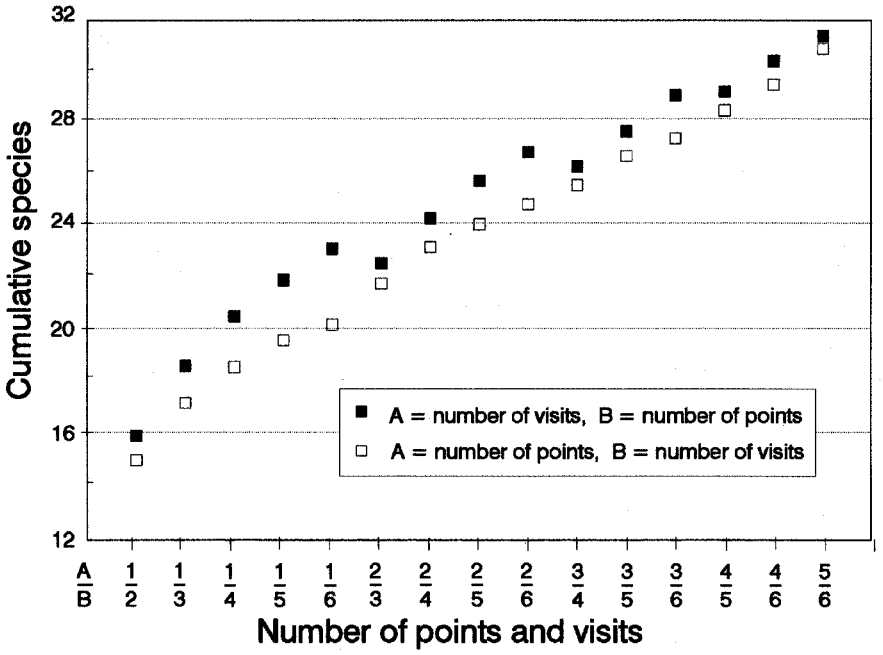

Figure 4-Comparison of cumulative number of bird species recorded between 15 possible paired reciprocals (e.g., 1 point-2 visits vs. 2 points-1 visit) of number of points visited and number of visits to each point, Delta Experimental Forest, Stoneville, Miss., 1992.

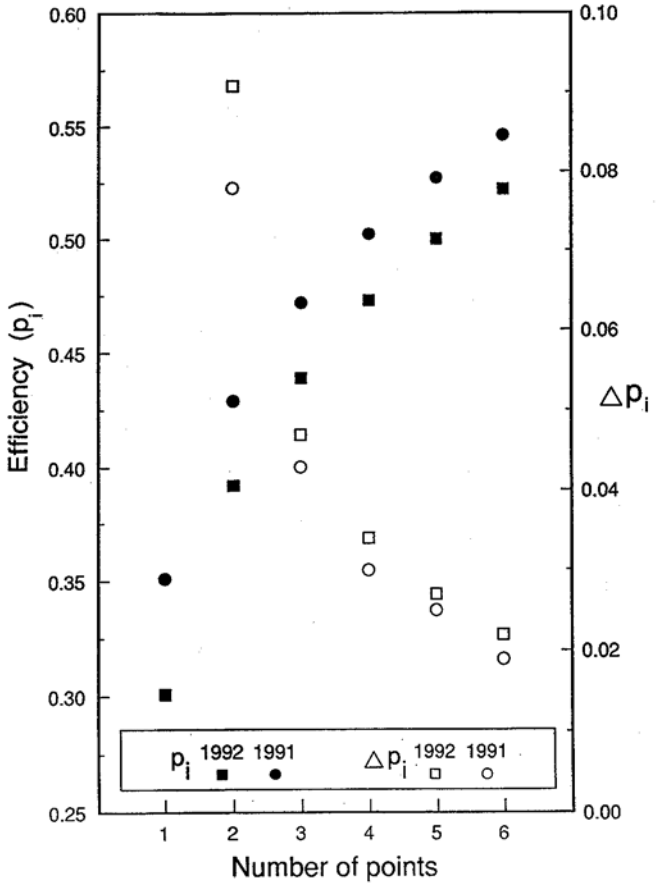

Figure 5-Proportion of 1991 and 1992 species pool included in point count censuses (EFFICIENCY, p_i) and change in efficiency (Δp_i) relative to number of points visited within a stand (averaged across all six visits), Delta Experimental Forest, Stoneville, Miss.

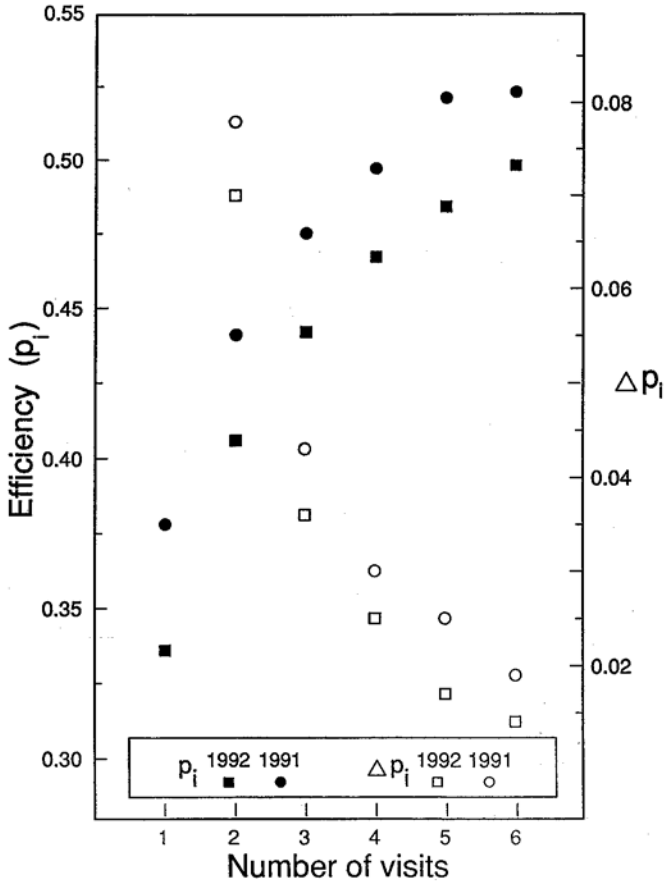

Figure 6-Proportion of 1991 and 1992 species pool included in point count censuses (EFFICIENCY, p_i) and change in efficiency (Δp_i) relative to number of visits to each point within a stand (averaged across all six points), Delta Experimental Forest, Stoneville, Miss.

Acknowledgments

Joseph H. McGuiness and Tracy D. McCarthey provided valuable assistance with point counts of songbirds on Delta Experimental Forest. Richard Cody contributed valuable field assistance during point count censuses throughout the lower Mississippi Alluvial Valley. Funding for this work was provided by the Southern Hardwoods Laboratory of the USDA Forest Service's Southern Forest Experiment Station and by the Vicksburg Station of the Southern Research Center, USDI National Biological Survey.

Appendix A-We calculated minimum sample size using the power method according to Neter and Wasserman (1974:492). For this paper, we selected $\alpha = 0.05$ and $\beta = 0.10$. The power of the test is given by $1-\beta$; for this calculation, it is necessary to compute ø, the non-centrality parameter, which reflects how evenly dispersed the factor level means are relative to the overall mean. The actual factor level means were used for the calculation of "actual difference" in *table 2;* the remaining minimum sample size estimates in the table were derived using uniformly dispersed and symmetrical factor means, which minimizes the value of ø and provides the most conservative (i.e., maximizes) estimates of minimum sample size (Neter and Wasserman 1974). The formula for ø' is:

$$\phi' = \frac{1}{MSE}\sqrt{\frac{\sum(\mu_i - \mu)^2}{r}},$$

where:

ø' = estimate of the non-centrality parameter ø.
MSE = mean square error from ANOVA.
μ_i = mean for factor level *i*.
μ = overall mean.
r = number of factor levels (3, for this paper).

Once ø' has been calculated, the minimum sample size can be obtained for a specifed α and β from TABLE A-10 in the appendix tables of Neter and Wasserman (1974:827).

Appendix B-Minimum sample sizes for point counts of selected species in the lower Mississippi Alluvial Valley. Sample size was computed with the power method for α. = 0.05 and β = 0.10 with several detectable difference values among factor level means.

Species	MSE[1]	Mean[2]	Sample Size Required for Actual Difference[3]	±0.25 Birds[4]	±25 percent of mean[5]
Acadian Flycatcher+					
Region	0.59	0.915	53	65	80
Southern	0.89	1.038	>200	95	90
Central	0.22	0.607	9	23	65
Northern	0.58	1.107	>200	65	50
Habitat	0.62	0.915	>200	70	85
American Redstart					
Region	0.02	0.024	>200	9	>200
Southern	0.04	0.038	65	9	>200
Central	0.03	0.036	53	9	>200
Northern	0.00	0.000	>200	>200	>200
Habitat	0.02	0.024	>200	9	>200
Blue-gray Gnatcatcher+					
Region	0.55	0.744	9	58	100
Southern	0.41	0.308	>200	44	>200
Central	0.39	0.429	44	44	>200
Northern	0.91	1.464	>200	95	44
Habitat	0.83	0.744	>200	90	>200
Brown-headed Cowbird					
Region	0.43	0.415	23	44	>200
Southern	0.00	0.000	>200	>200	>200
Central	0.78	0.750	50	85	>200
Northern	0.45	0.464	33	44	>200
Habitat	0.48	0.415	44	50	>200
Carolina Chickadee+					
Region	1.16	0.805	85	>200	>200
Southern	2.32	1.077	>200	>200	>200
Central	1.91	0.893	>200	>200	>200
Northern	2.58	0.464	>200	>200	>200
Habitat	1.22	0.805	>200	>200	>200
Carolina Wren+					
Region	0.76	1.402	>200	85	44
Southern	0.77	1.615	>200	85	33
Central	0.78	1.357	19	85	44
Northern	0.67	1.250	>200	80	44
Habitat	0.64	1.402	23	70	33
Hooded Warbler					
Region	0.08	0.098	65	9	>200
Southern	0.15	0.192	33	15	>200
Central	0.00	0.000	>200	>200	>200
Northern	0.11	0.107	>200	9	>200
Habitat	0.09	0.098	>200	9	>200
Indigo Bunting					
Region	0.19	0.110	50	19	>200
Southern	0.00	0.000	>200	>200	>200
Central	0.04	0.036	58	9	>200
Northern	0.51	0.286	65	53	>200
Habitat	0.18	0.110	33	19	>200

continued

AppendixB-*continued*

Species	MSE[1]	Mean[2]	Sample Size Required for Actual difference[3]	Sample Size Required for ±0.25 birds[4]	Sample Size Required for ±25 percent of mean[5]
Kentucky Warbler					
Region	0.09	0.110	80	9	>200
Southern	0.07	0.077	27	9	>200
Central	0.03	0.036	44	9	>200
Northern	0.18	0.214	>200	19	>200
Habitat	0.09	0.110	23	9	>200
Northern Cardinal+					
Region	1.29	1.585	>200	>200	53
Southern	0.91	1.769	9	95	33
Central	1.14	1.714	27	>200	44
Northern	0.85	1.286	>200	90	53
Habitat	1.33	1.585	>200	>200	53
Northern Parula					
Region	0.22	0.220	27	23	>200
Southern	0.22	0.462	9	23	>200
Central	0.24	0.214	9	27	>200
Northern	0.00	0.000	>200	>200	>200
Habitat	0.25	0.219	>200	27	>200
Prothonotary Warbler+					
Region	0.56	0.951	9	58	70
Locality					
Southern	0.74	1.885	53	85	23
Central	0.57	0.571	>200	58	>200
Northern	0.32	0.464	15	33	>200
Habitat	0.82	0.951	23	90	95
Red-bellied Woodpecker+					
Region	0.82	1.256	>200	90	53
Southern	0.37	1.115	9	37	33
Central	0.66	1.143	85	70	53
Northern	0.92	1.500	29	95	44
Habitat	0.82	1.256	100	90	53
Red-eyed Vireo					
Region	0.36	0.524	15	37	>200
Southern	0.50	1.038	44	53	50
Central	0.21	0.321	9	23	>200
Northern	0.24	0.250	23	27	>200
Habitat	0.44	0.524	44	44	>200
Rufous-sided Towhee					
Region	0.02	0.024	>200	9	>200
Southern	0.04	0.038	65	9	>200
Central	0.04	0.036	58	9	>200
Northern	0.00	0.000	>200	>200	>200
Habitat	0.02	0.024	58	9	>200
Summer Tanager					
Region	0.25	0.244	53	27	>200
Southern	0.04	0.038	65	9	>200
Central	0.38	0.321	15	37	>200
Northern	0.25	0.357	>200	27	>200
Habitat	0.26	0.244	>200	27	>200

continued

Appendix **B--*continued***

Species	MSE[1]	Mean[2]	Sample Size Required for Actual difference[3]	Sample Size Required for ±0.25 birds[4]	Sample Size Required for ±25 percent of mean[5]
Tufted Titmouse+					
Region	0.52	0.878	58	53	80
Southern	0.47	0.615	15	50	>200
Central	0.44	0.893	15	44	58
Northern	0.45	1.107	33	44	37
Habitat	0.56	0.878	>200	58	85
Wood Thrush					
Region	0.23	0.232	>200	27	>200
Southern	0.32	0.308	>200	33	>200
Central	0.15	0.179	58	15	>200
Northern	0.26	0.214	>200	27	>200
Habitat	0.23	0.232	>200	27	>200
Yellow-billed Cuckoo					
Region	0.43	0.659	80	44	100
Southern	0.45	0.885	>200	44	65
Central	0.36	0.607	27	37	100
Northern	0.42	0.500	23	44	>200
Habitat	0.45	0.659	>200	44	>200
Yellow-throated Vireo					
Region	0.05	0.049	100	9	>200
Southern	0.00	0.000	>200	>200	>200
Central	0.10	0.107	37	9	>200
Northern	0.04	0.036	80	9	>200
Habitat	0.05	0.049	>200	9	>200

[1] Mean Square Error of one-way Analysis of Variance, with three levels of treatment (for example, northern, central and southern region).

[2] Mean birds or species per count. This value is the same for Region and Habitat.

[3] Sample size that is required to get statistical significance for the actual observed difference among factor level means (range). Note that the minimum sample sizes in *appendix B* were all calculated using a design with one factor and three factor levels. If more or fewer levels were used, this number would be slightly greater or smaller; however, the numbers in *table 2* are a useful approximation.

[4] Sample size that would be required to detect a significant difference of 0.25 birds or 0.25 species above or below the overall mean.

[5] Sample size that would be required to detect a significant difference between two treatments that is between 25 percent above and 25 percent below the overall mean (that is, the difference between two treatment means of 50 percent of the overall mean).

+ denotes the most abundant species, i.e., those whose totals comprised >50 percent (872/1621) of all birds recorded during point counts conducted throughout the lower Mississippi Alluvial Valley, May 7-16, 1992.

Detectability of Forest Birds from Stationary Points in Northern Wisconsin[1]

Amy T. Wolf, Robert W. Howe, and Gregory J. Davis[2]

Abstract: Estimation of avian densities from point counts requires information about the distance at which birds can be detected by the observer. Detection distances also are important for designing the spacing of point counts in a regional sampling scheme. We examined the relationship between distance and detectability for forest songbirds in northern Wisconsin. Like previous investigators, we found that some birds can be heard from much greater distances than others. Within the same species, some individuals (or the same individual under different circumstances) can be heard from greater distances than others. In general, this within-site variation in detectability is similar to variation in detectability among individuals in different forest types. Knowledge about the relationship between distance and detectability can be used to approximate the area sampled from a stationary point. This information can then be used to estimate the density of vocalizing birds. Even under ideal field conditions with accurately measured distances, detectability does not follow a simple threshold relationship. On the basis of our empirical data, we use a statistical probit analysis to describe the attenuation of detection with distance; the resulting sigmoidal function can be used to approximate the effective sampling area. Complications arise because individual birds become increasingly difficult to distinguish from conspecifics at greater distances from the observer. Coupled with variation caused by habitat structure, wind conditions, observer bias, and other factors, we conclude that data from point counts can give only a crude picture of avian density. Nevertheless, such estimates might be the best available, and the costs or ambiguities associated with alternative procedures might outweigh the disadvantages of the point count method.

Point counts are attractive for avian population monitoring programs because they are methodologically straightforward and permit sampling of numerous geographic sites. Results from unlimited-radius point counts are generally accepted as valid indices of abundance for a single species under some circumstances (Blondel and others 1981), but between-species comparisons of point counts are complicated by species-specific differences in delectability. Even within-species comparisons are based on the untested assumption that detectability is consistent among different sites. Of course, virtually any method for sampling bird populations is burdened with weaknesses (Ralph and Scott 1981). Despite its shortcomings, the point count method is probably the least subjective of today's widely used procedures. Unlimited-radius point counts are probably the simplest of all approaches because, unlike the variable-radius point count method (Reynolds and others 1980) or the fixed-radius method (Gates, in these Proceedings), observers do not need to estimate the distance of each bird from the observer. Interpretations of unlimited-radius point counts, on the other hand, are more sensitive to differences in detectability among individuals of the same or different species.

In this paper we provide an objective analysis of the relationship between distance and detectability of forest songbirds in northern Wisconsin. We focus particular attention on the maximum distance from which an observer can detect a singing bird. This distance dictates the area covered by an unlimited-radius count and has obvious implications for designing and interpreting point count procedures. We also consider how empirically derived relationships between detectability and distance might be used in conjunction with point count data to generate estimates of relative (or perhaps absolute) avian abundance.

Emlen and DeJong (1981) pointed out that detection of bird vocalizations is a threshold phenomenon--a bird is either heard or it is not heard. If detectability thresholds (the maximum distances from which birds can be heard) are species-specific and reasonably consistent among the habitats of interest, then the area covered by an unlimited-radius point count theoretically can be determined empirically (area = πD_t^2 where D_t = the detectability threshold) (Reynolds and others 1980). The number of vocalizing individuals detected within this area then can be used to calculate bird density. Estimates of detectability thresholds also may provide insight into other issues considered in this volume, notably the ideal distance between census points needed to assure independence of sample points.

Methods

Field work was carried out in second-growth northern hardwood forests approximately 10 km southwest of Wabeno, Wisconsin, in the heart of the Nicolet National Forest. Data were collected mainly from an extensive forest area dominated by sugar maple (*Acer saccharum*), aspen (*Populus tremuloides*), yellow birch (*Betula lutea*), and several other tree species. The site was logged intensively before the 1930's, and trees have been selectively removed since that time. Canopy cover is approximately 80 percent to 85 percent based on field measurements with a forest densimeter (Schneider 1992). Average tree height is approximately 20 m to 25 m. The understory consists mainly of irregular patches of elderberry (*Sambucus pubens*), gooseberry (*Ribes* sp.), and other shrubs (especially *Rubus* sp.). Additional data were collected at two sites dominated by aspen (*Populus tremuloides*) and two lowland sites dominated by northern white cedar (*Thuja occidentalis*).

A primary site of 18 ha (600 m by 300 m) was marked with a grid of color-coded forestry flagging at 50-m intervals. Distances between flags were measured carefully with a compass and meter tape. Positions of birds and observers were mapped with reference to these color-coded grid points. Once a bird was located by one observer, a second observer in communication via a two-way radio would take a marked

[1] An abbreviated version of this paper was presented at the Workshop on Monitoring Bird Population Trends by Point Counts, November 6-7, 1991, Beltsville, Maryland.

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grid position. The second observer then recorded whether the target bird was audible from his or her position. Beginning at a mutually established time, the two observers would record the precise moment of up to five consecutive songs. Before the observation period, digital watches were synchronized to the second, permitting comparisons of the independent records. If the bird was still audible, the second observer moved to a position farther (usually 12.5 m to 25 m) away from the bird. As long as the bird remained stationary, this procedure was repeated until the bird could no longer be heard by the second observer. Exact distances between recorded positions (given as angles and distances from grid points) were later calculated using a computer program.

Observations were recorded from sunrise until approximately noon, generally under calm conditions (wind 0 to 3 mi/h). Windspeed and cloud cover were recorded at the beginning of the observation period, but these variables, as well as differences among observers, will not be considered in this paper. Four observers took part in the analysis by locating singing birds, but the bird detections reported here were made exclusively by R.W. Howe and A.T. Wolf.

Results

We recorded delectability of vocalizations at various distances for individuals of 23 bird species. The maximum detection distance was recorded for American Crow (*Corvus brachyrhynchos*) which, on one occasion, could be heard clearly from 725 m. White-throated Sparrows (*Zonotrichia albicollis*) were heard at every distance tested, with a maximum distance of 287 m. Indigo Buntings (*Passerina cyanea*) could be heard from 392 m along a road corridor, and other individuals of this species (six of eight birds tested) were heard at distances exceeding 300 m. At the other extreme, Brown Creepers (*Certhia americana*), White-breasted Nuthatches (*Sitta carolinensis*), and Golden-crowned Kinglets (*Regulus satrapa*) could not be heard beyond 100 m. Typically, however, forest songbirds in northern Wisconsin become inaudible between approximately 125 and 250 m. Among forest interior species, Hermit Thrush (*Catharus guttatus*) and Veery (*Catharus fuscescens*) could be detected for the greatest distances (*table 1*). We were able to detect 71 percent of Hermit Thrush songs between 200 m to 275 m (n = 48 songs, 11 individuals). By comparison, only 7.4 percent of Ovenbird (*Seiurus aurocapillus*) songs could be detected in this range of distances.

Table 1-*Maximum and minimum distances (delectability distances) at which singing birds became inaudible to an observer in the Nicolet National Forest. Species with detection distances that extended well beyond our sample distances (American Crow, Indigo Bunting, and White-throated Sparrow) and species with records representing only a few distances (Eastern Wood-Pewee, and Brown Creeper) are not included*

	Detection distance				Total	
Species	Minimum[a]	Maximum[b]	D_{50}[c]	(s.d.)[d]	Records[e]	
Veery	180	208	272	(90)	13	(42)
Hermit Thrush	179	271	240	(88)	33	(104)
Ovenbird	168	206	182	(35)	89	(298)
Winter Wren	156	236	170	(43)	20	(55)
Nashville Warbler	158	222	165	(220)	17	(41)
Red-eyed Vireo	78	188	164	(100)	27	(27)
Least Flycatcher	92	193	163	(83)	50	(50)
Black-throated Green Warbler	122	217	151	(57)	20	(49)
Black-throated Blue Warbler	121	153	140	(26)	16	(40)
Chestnut-sided Warbler	83	126	129	(47)	10	(18)
Mourning Warbler	109	133	125	(52)	24	(66)
Black-capped Chickadee	-	125	100	(1)	10	(13)
Black-and-White Warbler	98	104	98	(12)	13	(14)
Golden-crowned Kinglet	-	95	91	(3)	11	(19)
White-breasted Nuthatch	-	72	76	(1)	4	(8)

[a]Minimum = the shortest distance from which an observer failed to hear an individual bird.

[b]Maximum = the longest distance from which an observer was able to detect an individual.

[c]D_{50} is the midpoint of a best-fit cumulative normal distribution describing the attenuation of detection with distance. At this distance, the probability of hearing a bird is 50 percent.

[d]*s.d.*= standard deviation (σ) of the fitted normal distribution; a low value reflects a steeper decline of delectability with distance.

[e]Total records indicate the total number of birds for which distances were measured. Total number of songs evaluated by observers is indicated in parentheses.

We focus particular attention on the Ovenbird, by far the most common species in our study area. Ovenbirds could be heard from a maximum distance of 206 m, yet even at 67 m individual songs were occasionally overlooked or confused with those of nearby individuals. As a result of unidentified factors (presumably topography, weather, individual differences among birds, etc.), bird song detectability does not follow a clear threshold function. We found a gradual decline in our ability to detect vocalizations as we moved farther away from these birds (*fig. 1*). Other species show a similar relationship between distance and detectability although the detection distances vary (*table 1*). Bird songs within a certain range of distances are audible during some trials but inaudible during others. For example, an Indigo Bunting singing from a tree 256 m from the observer (R.W. Howe) could be heard clearly, but when it flew into dense shrubs (*Rubus* sp.) beneath the tree its songs became inaudible to the distant observer. An Ovenbird could be heard from 194 m in one part of the forest, but on the same day at the same site another individual was inaudible from a distance of 174 m.

Note that detection of even one song during a sampling period would be enough to include the bird in a stationary point count. A typical Ovenbird will sing approximately three times during a single minute (average time between songs, t_s = 20.89, (σ = 8.23, n = 140), while many other species sing even more frequently (Black-throated Green Warbler (*Dendroica virens*) t_s = 8.5, σ = 1.64, n = 24; Hermit Thrush t_s = 5.89, σ = 1.67, n = 55; Indigo Bunting t_s = 12.3, σ = 2.45, n = 20; Mourning Warbler (*Oporornis philadelphia*) t_s = 13.65, σ = 3.89, n = 31; Winter Wren (*Troglodytes troglodytes*) t_s = 16.03, σ = 4.29, n = 34).

Clearly, detection distances are not adequately expressed by a single threshold number; instead, some other descriptor or function is needed to describe the area sampled by a stationary point count. Using field data like ours, plots can be generated showing the attenuation of detectability with distance (*fig.1*). One can then superimpose or fit a theoretical function to describe the relationship between distance and detectability. Here we use probit analysis (Finney 1971), a procedure that has been used to describe the relationship between dosage and response to toxins, loss of seed viability in plants (Wilson and others 1989), spread of disease in oaks (Bruhn and others 1991), and other applications where the probability of some event is related to a cumulative form of a standard distribution. On the basis of the sigmoidal shape of our detectability distance plots, we assume that the probability

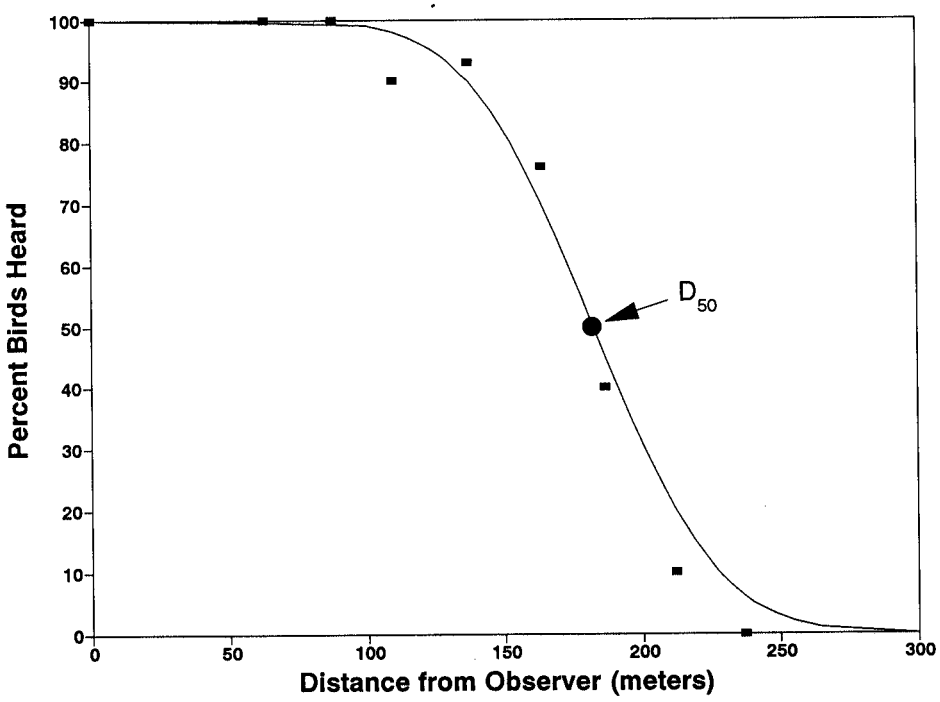

Figure 1-Relationship between song detectability and distance from observer for the Ovenbird in northern Wisconsin. Line indicates the inverse of the best-fit cumulative normal distribution as determined by statistical probit analysis. Solid squares (■) indicate pooled data for 25-m distance categories (*n* >10 birds for all categories between 100 m to 200 m; *n* = 3-7 for others). D_{50} indicates the distance where one-half of the birds of a given species are audible.

of hearing a bird declines with distance according to the inverse of a cumulative normal distribution (*fig. 1*). Parameters of the distribution (μ and σ) were estimated using an algorithm in the SAS statistical software program. A critical value, D_{50} (an estimate of μ), indicates the distance where one-half of the birds of a given species are audible. D_{50} marks a useful definition of sampling radius (and hence, area) insofar as the probability of hearing a bird is the same as the probability of missing a bird. Because birds sing more than once and undoubtedly move during a given sampling period, D_{50} must be recognized as a somewhat arbitrary definition of sampling radius. Values of D_{50} vary according to relative detectability; species with high values can be heard for greater distances from a sampling point than can species with a low D_{50}. Note that these curves are similar to those derived empirically in variable circular-plot sampling (Reynolds and others 1980).

Probably as important as the ability to detect a given species is the ability to distinguish one individual from another. We found that this became increasingly difficult as an observer moved farther away from a bird. In many cases, the observer's failure to record 100 percent of the target bird's songs was caused by confusion with other singing birds. This was particularly true for Ovenbirds and Red-eyed Vireos (*Vireo olivaceous*), which were abundant and highly vocal in our study area. Confusion of individual songs occurred even at relatively short distances (<100 m), and at distances of 150 m or more, separation of nearby individuals was nearly impossible.

We noted only slight differences in detectability for the same species among different habitats. Hermit Thrushes, for example, were detectable from a maximum of 271 m in the aspen sites compared with 242 m in the swamp conifers. In only one instance did we find a habitat-related difference in detectability: Ovenbirds were significantly more detectable in hardwoods (71 percent, $n = 87$) than in aspens (55 percent, $n = 29$) at a distance of 150 m to 175 m ($P < 0.05$, Chi-square contingency test). In all other cases either the species was effectively restricted to a single habitat type or differences between habitats were not statistically significant ($P > 0.05$).

Discussion

The maximum detection distances recorded during our study generally agree with those reported by Emlen and DeJong (1981). For example, they found among 11 species of deciduous forest birds that Wood Thrush could be heard from the greatest distance. Similarly, we recorded long detection distances for Hermit Thrush, a species whose song is very similar to that of the Wood Thrush. Although both sample sizes are rather small, together our results show that many songbirds in forests of Northeastern America can be detected from distances exceeding 150 m; certain species (e.g., Veery, Winter Wren) can be heard from 200 m or more, and birds like Indigo Buntings and White-throated Sparrows are audible beyond 250 m to 300 m. Given this fact, two separate point counts would need to be more than 400 m apart to assure that no individual birds would be recorded in both counts. Even this distance would be insufficient if birds near the mutual boundary move from one sampling area to the other during the count period.

Estimation of avian densities from point counts is complicated by several problems. Like Emlen and DeJong (1981), our results show significant variations in detection distances even among records from the same species and by the same observer. Such variations mean that calculations based on a standard detection radius will lead to overestimates or underestimates of population densities. Suppose, for example, we used a value of 180 m as the standard detection radius for Ovenbirds. If the actual detection distance at a given site due to topography or individual differences in song quality was actually 200 m, then the area covered by the point count would be 12.56 ha (assuming a 200-m radius) instead of 10.18 ha (assuming a 180-m radius). Individual counts would overestimate actual densities by approximately 23 percent. If the actual detection radius was 160 m, an area of only 8.04 ha would be covered, leading to underestimates of 21 percent.

Our detection distances tended to be slightly but consistently greater than those reported by Emlen and DeJong (1981). We suspect that this might be due to the shorter and more open forests of the Nicolet National Forest compared with the taller forest studied by Emlen and DeJong. Within the Nicolet National Forest, however, we found little evidence of differences in detection distances among different forest types. Of course, factors such as the perch height and orientation of the bird, hearing ability of the observer, wind conditions, individual variation in song intensity, and vegetation structure all can be expected to affect detection radii and their applications. The effects of these factors can be minimized if counts are limited to calm weather and to habitats that resemble the areas from which detectability radii are derived. Longer census durations improve the probability that a singing bird will be detected, but since birds typically offer three or more cues during a single minute, 5-minute counts would seem to offer adequate opportunity to detect a bird within the maximum detection radius.

Our analysis revealed an unanticipated difficulty with the estimation of density from point counts. As the distance between the observer and a singing bird increases, the bird's songs become increasingly difficult to distinguish from the songs of neighboring individuals. This effect typically occurs well before the song itself becomes inaudible. For example, two birds singing from perches approximately 20 m apart would be separated by an angle of 23° from an observer 50 m away. At 100 m, the same birds would be separated by an angle of only 11.5° from the observer's perspective. The closer birds would be much easier to distinguish from each other. Likewise, two birds that are aligned in approximately the same direction, but at different distances from an observer, will be more difficult to distinguish from one another the farther they (as a pair) are away from the observer. The net result of both circumstances is the same: unlimited-radius point counts will tend to underestimate the number of individuals within the detection range of a species because certain pairs or even trios far from the observer will be counted as a single individual. This problem will be most severe for locally abundant species and might be insignificant for

species that occur in low densities. In our study area, 88 percent of the species recorded during 10-minute point counts (n = 641) were represented by only one or two individuals (Howe and others, in this volume).

A further complication arises when birds from adjacent areas move into detection range during the count period. Inadvertently including them will lead to overestimates of abundance, because corresponding birds that move out of the detection range obviously are not subtracted from the total. This effect might be partly compensated by birds moving out of the detection range before they are detected. Fixed-radius (e.g., 50-m) point counts are more vulnerable to these boundary effects than are unlimited-radius (e.g., much greater than 50-m) point counts because smaller areas have higher ratios of perimeter to area. Based on considerations discussed earlier, however, movements of birds into the count area are more likely to be recognized close to the observer (i.e., <50-m), at least partly mitigating this boundary effect. Whatever the balance between these factors, point counts should be as short in duration as possible (e.g., 5 minutes or less) to minimize undetected movements of birds into or out of the count area.

Estimation of density from point counts requires either a fixed-sampling radius or some empirically derived function that describes the relationship between bird detectability and distance (Emlen and DeJong 1981, Ramsey and Scott 1981, Reynolds and others 1980, Scott and others 1981). We have attempted to systematically describe this relationship for forest birds in northern Wisconsin. Our results show that the relationship is complicated. In spite of inherent (and probably unavoidable) difficulties, crude estimates of detection radii such as those presented here are more objective than the *ad hoc* estimates described by Reynolds and others (1980) and related studies. Estimates of densities using systematically derived detection radii such as the D_{50} from probit analysis have practical value insofar as they are far better than no quantitative estimates at all, and they provide standardized comparisons between point counts within the same habitat type.

Acknowledgments

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Comparison of Point Count Sampling Regimes for Monitoring Forest Birds[1]

William H. Buskirk and Jennifer L. McDonald[2]

Abstract: A set of 255 counts was compiled for 13 points using 10-minute periods subtallied at 3 and 6 minutes. The data from each point were subsampled using combinations of count periods, numbers, and schedules to compare the effectiveness of these different regimes at per point coverage. Interspecifically, detection frequencies differed in level and pattern as a function of count period length. The complex nature of detection frequencies is discussed in relation to density and to species-specific activity patterns. Short count periods (3 minutes) are more sensitive to changes in activity levels than long ones. The use of longer periods effectively increases the number of comparable hours for sampling per field day, probably increases the usable length of the field season, and may reduce the effects of observer differences. Analyses of detection frequency data and of species and individual accumulation curves suggest that a point of diminishing returns has been reached well before conducting five 10-minute counts per point. We detect no difference in the effectiveness of same-day and different-day count regimes during our June study period. An increase in count period decreases the number of points that can be surveyed per unit of field time, but increases the total amount of time surveyed. Once between-point time reaches 10 minutes, the count period has little effect on the number of points at which many species are detected per unit of field time. Because data from each has different applications, we recommend that a 10-minute count period with 3- and 5-minute subtotals be used for some monitoring regimes. The selection of the number of repeat counts per point depends on the purpose of the project, but for most monitoring applications three or fewer surveys should be conducted per point per season.

Point counts without distance estimation, i.e., simple tallies of all species and individuals detected during a standard observation period at a specific location, are useful for long-term and comparative monitoring of bird populations (Blondel and others 1981, Robbins and others 1989). The duration, number, and scheduling of individual count periods can be expected to influence this technique's ability to characterize the avifauna at a single point or in a larger sample of points.

The design of a point count monitoring system needs to take into account the tradeoffs between the quality of coverage from intensive sampling at single points and the statistical power of extensive sampling across many points (Verner 1985, 1988). As the amount of time required to move between points is dependent upon topography, access, and the geographic layout of points, the physical character of the terrain will influence the design of optimal sampling regimes.

In this paper we compare the extent of coverage of individual points achieved by using different regimes of count period, number, and scheduling. We then consider the tradeoffs involved between intensive per-point sampling versus extensive among-points sampling as they are influenced by between-point travel time. This paper, however, does not assess quantitatively the influence of these tradeoffs on the statistical power of different monitoring regimes.

Modified point count methods may allow density measurement (Reynolds and others 1980); however, the application of these is difficult and subject to considerable error (Verner 1985). We do not address the issue of density measurement in this paper. Point counts provide an "`audio-visual' density index" (Beals 1960: 158), which can be used most effectively for comparisons of samples from single points or from standardized series of points.

Methods and Study Areas

Terminology

We attempt to follow the use of terminology summarized in Ralph (1981). In addition, we use *count* for a single bout of surveying at an individual point. A *point* is a single station from which a count is made, and a *site* is a location or tract at which a number of point counts may be made. *Count period* is the duration or length of a single count. As we use it, *coverage* refers to the relative completeness of sampling at a given point, judged against a standard derived from more extensive sampling at that point. A *point count regime* is a specific protocol for the period, number, and schedule of counts at individual points. A *monitoring regime* is a specific protocol for the selection of sites, placement and number of points, and the point count regime employed at those points. *Detection frequency* is the likelihood of observing a species at points where it is known to be present. This differs from "frequency," the proportion of points at which a species is found, which is a function of both presence across points and detectability (Ralph 1981, Verner and Milne 1989). Detection frequencies were calculated as the proportion of counts on which a species was recorded among all counts at points where it was observed at some time during the study.

Count Methods

Counts of all birds seen and heard were made for 10-minute periods with cumulative subtotals recorded at 3- and 6-minute intervals. Birds were identified by primary song, other calls, and sight. All individual birds, except for dependent fledglings, were recorded. Therefore, our data were not limited to territorial or singing males, though these make up the great majority of our records. To reduce the potential for overcounting moving birds, multiple individuals of a species were recorded *only when concurrent observations* clearly established their presence. Field data forms listing most species were used. We follow the nomenclature of the American Ornithologists Union (AOU) Checklist (AOU 1983, table 4). Flyovers and distant birds outside forests (e.g., Northern Bobwhite (*Colinus virginianus*), American Crow (*Corvus brachyrhynchos*), black icterinae except Brown-headed Cowbird (*Molothrus ater*), and House Finch

[1] An abbreviated version of this paper was presented at the Workshop on Monitoring Bird Population Trends by Point Counts, November 6-7, 1991, Beltsville, Maryland.

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(*Carpodacus mexicanus*)) were excluded from all our analyses except those producing detection frequencies. We did include American Goldfinch (*Carduelis tristis*), as this species appeared to be a nonbreeding resident in the canopy during our study. To summarize data for a point, we compiled the cumulative total number of species and the highest single counts of individuals for all species.

At each point, five counts were made each morning, one per hour between 0500 and 1000 e.s.t. Sunrise during the study was approximately 0525 e.s.t. Counts were made only on mornings with no rain or leaf drip noise and with winds less than 13 km/h (8 mi/h). This matches the weather restrictions for North American Breeding Bird Surveys (Robbins and others 1986). In practice, winds were less than 6 km/h for more than 90 percent of our counts. Temperatures recorded in the shade 1 m above ground level at the time of our point counts ranged from 16°C-20°C at 0600 and 20°C-26°C at 1000.

Study Sites

Points were placed more than 50 m inside exterior forest edges and at least 100 m apart. As spacing among points was not sufficient to achieve full independence of data among them, a subset of eight points greater than 150 m apart was used in some of our analyses. Even at this distance, complete independence is not realized for species with far-carrying calls or large home ranges (e.g., Red-bellied Woodpecker (*Melanerpes carolinas*), Pileated Woodpecker (*Drycopus pileatus*), Louisiana Waterthrush (*Seiurus motacilla*)). We believe this lack of total independence among our points does not compromise the specific interpretations we make.

In all, 13 points were surveyed in 3 deciduous woods near Richmond, Wayne County, Indiana. A combined total of 255, 10-minute counts were completed at these points. Robert's Run is a floristically diverse forest (e.g., American beech (*Fagus grandifolia*), sugar maple (*Acer saccharum*), flowering dogwood (*Corpus florida*), tulip poplar (*Liriodendron tulipifera*), white ash (*Fraxinus americana*), slippery elm (*Ulmus rubra*), hackberry (*Celtis occidentalis*), black walnut (*Juglans nigra*), eastern red cedar (*Juniperus virginiana*), black cherry (*Prunus serotina*), red oak (*Quercus borealis),* Chinquapin oak (*Q. muhlenbergii*), white oak (*Q. alba*), shagbark hickory (*Carya ovata*), bitternut hickory (*C. cordiformis*), sycamore (*Platanus occidentalis*), cottonwood (*Populus deltoides*)) on dissected terrain with a stream near all points (lat. 39° 45' N., long. 84° 55' W.; 6 points censused on 5 days each, = 150 counts). Canopy heights there ranged from 20 to 25 m. Wildman's Woods is a floristically-mixed forest similar to Robert's Run. It is also on dissected terrain, has a 20- to 25-m canopy, and has a brook near all points (lat. 39° 47' N., long. 84° 58' W.; 3 points censused on 3 days, = 45 counts). Lewis' Woods is a mixed forest with a 25-m canopy on flat land. One point is near a small creek (lat. 39° 56' N., long. 85° 00' W.; 4 points censused on 3 days, 60 counts).

All points were located to avoid significant noise from roads, streams, etc. Robert's Run and Wildman's Woods are parts of extensive wooded complexes of 50+ ha connected to other such complexes by wooded corridors along streams. Lewis' Woods is a 32-ha woodlot. Another 12-ha woods is adjacent across a paved road, but these woods are otherwise well-isolated from other canopied forests by agricultural land.

Dates

All counts were conducted between June 17 and 30, 1991, with the exception of one set on June 2 at Robert's Run. This period falls well within the breeding season at a time when second clutches and fledgling care are under way for many species. But it is after the peak of song activity for some species, especially permanent residents. April and May 1991 were unusually, warm and wet, and breeding for most species was advanced' a "week" or more compared to most years. Hence, the timing of our counts should yield a mildly conservative measure for typical breeding activity.

Observers

The two observers were of comparable ability and familiarity with visual; and auditory identification of the breeding birds of the region. We covered separate sets of points and made no attempt to study between-observer effects systematically.

Point Count Regimes

To evaluate the effectiveness of hypothetical point count regimes, we made the assumption that our level of sampling (15 or more 10-minute counts per point) exceeded a point of diminishing returns and was greatly in excess of the intensity that would be, feasible or desirable for most long-term monitoring projects. To assess the kind of coverage achieved by different point count regimes we selected subsamples from the data for our eight most independent points. We used a total of 150 minutes of sampling over 3 days to establish a "universe" of observations against which to compare the results of subsampling. For this analysis three dates were selected at random from the five dates at each of the Robert's Run points. Differences in numbers of species and of individuals detected by different sampling regimes were tested using one-factor ANOVA.

Three hypothetical sampling intensities at individual points were compared: single counts for each of the three count period durations (i.e., 3-, 6-, and 10-minute samples); *sets of three counts* for each of the durations (totaling 9, 18, and 30 minutes of sampling); and *sets of five counts* for each of the durations (totaling 15, 30, and 50 minutes). Single-count data were selected in a stratified. random fashion from each point (i.e., 3 random samples from: each of the 8 points) to produce a sample size of 24. Three-count sets were compiled in two ways to reflect different sample scheduling: *same-day* compilations of the counts at 0500, 0700, and 0900 and *different-day* compilations using one of these 3 hours from each of the three dates (e.g., 0500 count from the first date, 0700 count from the second date, and 0900 count from the third date; 0700 from the first date, 0900 from the second date, and 0500 from the third date; etc.). Three sets of each type of compilation were produced for each point producing sample sizes of 24. Same-day and different-day sets use the same 9 censuses of each survey point; they differ only in the way they are sorted. Similarly, five-count samples were compiled in two ways: same-day sets from all 5 morning hours and different-day sets from the 3

days using two counts from each of two dates and one from the third (e.g., 0500 and 0800 from one date, 0600 and 0900 from the second date, and 0700 from the third date). Again, sample sizes of 24 were obtained. Finally, a third set (n = 12) of five-count, different-day samples was tabulated for the Robert's Run sites using all five days of data, thereby increasing the number of days sampled in each compilation. This set was compared to the other 5-count compilations from Robert's Run only (n = 12) to evaluate the effect of sampling more days.

Per Point Coverage

Results

Location and Dates

The cumulative numbers of species and of individuals recorded after 150 minutes of sampling are remarkably similar among our sites (*table 1*). Comparisons of the average number of species and individuals per 10-minute count showed no patterns among dates.

Time of Day

The average numbers of species and individuals recorded declines after 0800 (*table 2*). The decline in species is small and detectable statistically only with 3-minute count periods. The dropoff in the number of individuals recorded is also modest and significant statistically only with 3-minute count periods. In general, the variance for same-hour counts is great compared to between-hour differences in means; even with 3-minute counts, large sample sizes are required to detect these hour-to-hour differences.

Varying Count Period and Number

The coverage obtained from different point count regimes was considered by subsampling from our larger data

Table 1--*Cumulative numbers of species and individuals as functions of increasing observation time at 13 points in eastern Indiana deciduous forest. Values are means ± 1 s.e.. RR Roberts Run, WW - Wildman's Woods, LW - Lewis' Woods. n is the number of points. The number of individuals is the sum of the highest counts recorded for each species per point.*

Site	*n*	Observer	Observation time (minutes)				
			50	100	150	200	250
			Cumulative Number of Species (*Range*)				
RR	3	JM	24.0±2.1	27.0±0.6	29.0±0.6	30.3±0.3	31.0 ± 0.0
			(20-27)	(26-28)	(28-30)	(30-31)	(31)
RR	3	WB	24.7±0.7	26.7±0.9	28.3±0.7	30.0±0.6	30.7±0.3
			(24-26)	(25-28)	(27-29)	(29-30)	(30-31)
WW	3	JM	21.3±0.3	25.3±0.3	28.0±0.6		
			(21-22)	(25-26)	(27-29)		
LW	4	WB	20.0±0.7	23.8±0.9	26.3±1.1		
			(19-22)	(22-26)	(24-29)		
			Cumulative Number of Individuals (*Range*)				
RR	3	JM	37.0±3.1	47.0±1.5	51.7±1.2	55.3±2.0	57.7±0.9
			(31-41)	(45-50)	(50-54)	(52-59)	(56-59)
RR	3	WB	37.7±1.3	44.3±3.0	48.0±2.1	52.3±3.3	54.7±3.4
			(35-39)	(40-50)	(45-52)	(46-57)	(48-59)
WW	3	JM	31.3±0.9	40.3±2.0	46.3±0.3		
			(30-33)	(37-44)	(46-47)		
LW	4	WB	33.0±0.7	40.0±1.5	44.0±1.2		
			(31-34)	(37-43)	(42-47)		

Table 2--*Number of species and individuals (mean + s.e.) recorded by time of day with different count period durations. Sample size equals 51 for all.*

Count period (minutes)	Hour beginning (e.s.t.)				
	0500	0600	0700	0800	0900
	----------*Number of Species*----------				
3	10.1±0.4	10.0±0.3	9.9±0.4	9.1±0.4	8.5±0.4[a]
6	11.9±0.4	12.0±0.3	12.1±0.4	11.3±0.4	11.2±0.4
10	13.4±0.4	13.9±0.4	13.6±0.4	13.3±0.4	12.9±0.4
	----------*Number of Individuals*----------				
3	13.2±0.5	12.9±0.5	12.5±0.5	11.4±0.5	10.7±0.6[a]
6	16.0±0.5	15.9±0.5	15.8±0.6	14.6±0.6	14.4±0.6
10	18.5±0.5	19.0±0.6	18.3±0.6	17.6±0.6	16.9±0.7

[a] Significant differences among hours only for 3-minute count periods (ANOVA): F = 3.5, P = 0.008 (species); F = 4.1, P = 0.003 (individuals). For 10-minute periods F = 0.89, P = 0.47 (species) and F = 1.8, P = 0.14 (individuals).

set using hypothetically varied count durations, numbers, and schedules. The total number of species and the total number of individuals increases when the count period is increased from 3 to 6 minutes and from 6 to 10 minutes ($P < 0.001$ for all comparisons, *table 3*). The species-effort relationship for point counts is asymptotic, but even after 150 minutes per point new species and individuals continue to be recorded at low rates (*table 1*). It is the nature of these data that no matter what amount of time has been sampled, the relationship appears to have neared its asymptote.

In our subsampled regimes, the numbers of species and individuals increase significantly as the number of counts increases from one to three and from three to five for each count period duration ($P < 0.001$ for all comparisons (*table 3*)). Single, 10-minute counts yield averages of only about 48 percent of the total species and 37 percent of the individuals recorded in the 150-minute pool from which they were drawn (*table 1*). Coverage increases to about 72 percent of species and 61 percent of individuals for three 10-minute counts and 83 percent of species and 73 percent of individuals for five 10-minute counts.

The influence of the count period on coverage is substantial but declines as the total number of counts increases. The increase from a 3- to 10-minute count period yields about 43 percent more species and 49 percent more individuals (*table 3*). When sets of three counts are made, using a 10-minute rather than a 3-minute count period, increases of 30 percent and 39 percent are produced, and with 5 counts the increases are 24 percent and 34 percent.

The influence of the number of counts on coverage is also substantial but declines rapidly as the number of counts increases. The move from a single count to three counts produces, depending on the count period duration, 51-66 percent more species and 65-76 percent more individuals, but the move from 3 to 5 counts yields increases of only 15-21 percent and 20-25 percent (*table 3*).

By holding the total observation time constant, the effect of changing the number of counts is demonstrated in the following comparisons. Three, 3-minute, same-day counts (9 minutes total) detect more species ($F = 8.6$, $P = 0.005$) and individuals ($F = 7.6$, $P = 0.008$) than single 10-minute counts (*table 3*). Thirty-minute samples can be obtained by three 10-minute counts and by five 6-minute counts. No significant differences in results are found between these regimes (e.g., for 3 same-day, 10-minute counts versus 5 same-day, 6-minute counts: species, $F = 1.8$, $P = 0.18$; individuals, $F = 1.5$, $P = 0.22$; etc.).

Varying Schedule

We find that, within our late June sampling season, the scheduling of counts among days has no effect on coverage. Comparisons of single-day counts with different-day count regimes of equal sampling time show no significant differences in the average numbers of species or individuals detected (*table 3*). These comparisons were made at 3-, 6-, and 10-minute count periods for the following pairs of regimes: 3 same-day versus 3 different-days (all sites); 5 same-day versus

Table 3-*Average cumulative numbers of species and the average maximum numbers of individuals detected at eight forest points using different regimes of point count duration, number, and schedule. n is the number of samples per regime. Values are means + 1 s.e.*

Sampling regime (Number of counts, schedule)	Count period duration (minutes)			
	3	6	10	*n*
	---------- *Number of Species* ----------			
All sites:				
l, single count	9.3+0.4	11.3+0.4	13.3+0.4	24
3, same day	15.2+0.5	17.5+0.6	19.6+0.6	24
3, different days	15.5+0.5	18.2+0.6	20.5+0.5	24
5, same day	18.4+0.5	20.6+0.5	22.6+0.5	24
5, three different days	18.8+0.6	21.8+0.6	23.6+0.5	24
Robert's Run only:				
5, same day	19.3+0.9	22.0+0.9	23.8+0.7	12
5, three different days	19.4+0.8	23.3+0.7	24.5+0.5	12
5, five different days	20.0+0.6	22.1+0.6	24.3+0.7	12
	---------- *Number of Individuals* ----------			
All sites:				
1, single count	11.9+0.7	14.8+0.6	17.7+0.7	24
3, same day	20.6+0.8	24.8+0.9	28.7+1.0	24
3, different days	21.3+0.9	25.5+0.9	29.8+0.9	24
5, same day	25.9+0.8	30.3+0.9	34.3+0.9	24
5, three different days	26.6+0.9	31.6+0.8	35.8+0.9	24
Robert's Run only:				
5, same day	26.7+1.5	31,7+1.4	35.6+ 1.3	12
5, three different days	27.5+1.4	32.9+1.2	36.8+1.2	12
5, five different days	27.8+1.5	32.6+1.4	37.1+1.4	12

5 on 3 different-days (all sites); and 5 same-day versus 5 different-days (Robert's Run sites only).

Discussion of Point Count Coverage

Count Period and Time of Day

The numbers of species and individuals recorded on point counts appear to decline in midmorning, but only for 3-minute counts are these declines statistically demonstrable, and then only with large sample sizes (*table 2*). These modest declines in counts in the 0800 and 0900 hours may result from reduced activity levels or observer fatigue. Whatever the cause, data from longer count periods are less affected than those from shorter counts. Ten-minute counts allow more time either for relatively inactive birds to move or give calls (Robbins 1981) or for weary observers to register the bird's presence. The lack of significant differences in numbers of species or individuals for 6- and 10-minute count periods during the first 4 hours of daylight is similar to the results in California habitats (Verner and Ritter 1986). They used only 8- and 10-minute point counts and generally considered only the first 4 hours of daylight. Other point count studies detecting hour-to-hour differences during the morning have been based on large sample sizes and short count periods (Robbins 1981).

For practical purposes, the use of longer count periods extends usable field time. When 6- or 10-minute count periods are used, the 0900 hour is not significantly different from earlier hours for point count productivity. We agree with Verner and Ritter (1986) that the benefit of using more morning hours for surveys outweighs the potential negative effects from changes in activity before 1000. We did not anticipate this result, and we did not sample after 1000. Therefore, we cannot speak to the midday performance of different count periods. Just as longer count periods compensate for declining activity later in the morning, they should serve to extend the usable field season when song intensity begins to diminish at the end of the breeding season.

Comparison of Monitoring Regimes

An approach to estimating an effective level of sampling per point is to consider the sampling effort needed to reach a point of diminishing returns for the number of species and individuals detected. Substantially more species and individuals are detected by increasing count period length and by increasing the number of counts made (*tables 2* and *3*). Increasing the number of counts from three to five produces significant, but modest improvement in coverage in view of the effort involved. This approach suggests that a point of diminishing return has been reached before five 10-minute samples per site have been conducted.

The lack of significant differences between same-day sampling and different-day sampling indicates that where sampling across days is logistically inefficient, same-day coverage of equal duration is a suitable alternative.

Detection Frequencies: Species Comparisons

Results

The tendency toward a modest decline in numbers of individuals through the morning is not demonstrated as a significant pattern in the detection frequency of any single species (*table 2*). However, the American Goldfinch is detected more frequently after the first hour of daylight (X^2 = 14.2, df = 4, $P < 0.01$, 10-minute count period). Brown-headed Cowbirds had a distinct 0700 peak for 3-minute count periods (X^2 = 12.1, $P < 0.025$), a pattern that is not significant in 10-minute count data.

Species detection frequencies (f_{sp}) show striking differences among species (*table 4*). For purposes of comparison, we group species into categories based on the predicted number of 10-minute counts it would take to reach a 90 percent likelyhood of detecting them *if the species is present at a point* (i.e., $(1 - (1 - f_{sp})^c)$ estimates the likelihood of detecting the species after c counts at a point where it occurs).

The pattern of detection frequencies as a function of the count period also differs among species (*table 4*). Some species are detected at high frequencies during 3-minute counts, and the likelihood of their detection is not much increased in longer counts (e.g., Eastern Wood-Pewee (*Conotopus virens*), Acadian Flycatcher (*Empidonax virescens*), Wood Thrush (*Hylocichla mustelina*), Red-eyed Vireo (*Vireo olivaceus*), Kentucky Warbler (*Oporornis formosus*), and Indigo Bunting (*Passerina cyanea*)); others show relatively large increases in detection as the count period increases (e.g., Ruby-throated Hummingbird (*Archilocus colubris*), Red-bellied Woodpecker, Downy Woodpecker (*Picoides pubescens*), American Crow, White-breasted Nuthatch (*Sitta carolinensis*), Brown-headed Cowbird, and American Goldfinch). Few species demonstrate detection frequencies directly proportional to the count period length (e.g., for 3-, 6-, and 10-minute periods: Great Blue Heron (*Ardea herodias*) - 0.03, 0.07, 0.10, n = 20; Chimney Swift (*Chaetura pelagica*) - 0.01, 0.04, 0.07, n = 18; and Ruby-throated Hummingbird (*table 4*)).

Discussion of Detection Frequencies

The concept of "frequency," the number of points at which a species is detected divided by the total number of points sampled, can be parsed into its components (Ralph 1981, Verner and Milne 1989). It is a function of both the proportion of points sampled at which a species occurs (i.e., the frequency of occurrence) and the proportion of counts on which the species is recorded where it occurs (i.e., the species' detection frequency). In turn, a species' detection frequency is the product of both the detection frequency of a single individual and the number of individuals present at a given point.

Interspecifically, detection frequencies vary greatly. Species that vocalize continuously or are present at higher densities, as suggested by a higher maximum number of individuals recorded per point (e.g., Acadian Flycatcher, Wood Thrush, Red-eyed Vireo, and Northern Cardinal (*Cardinalis cardinalis*)), are readily recorded within 3 minutes and show little change in detection frequency as count period increases from 3 to 10 minutes (*table 4*). For these species at least one individual is so likely to be active in the first 3 minutes of observation that the species is rarely missed then.

We would anticipate that if such a species' abundance declined, its pattern of detection would begin to resemble that of currently less dense but similarly vocal species like

Table 4-*Detection frequencies for species during 3-, 6-, and 10-minute count periods. Frequencies are the proportions of counts on which the species was recorded among all counts at points where it was observed at some time during the study (no.). Mean number of individuals is the average of maximum counts of individuals for all points where the species was found. If frequency ≥0.55, then three or fewer counts are needed to yield ≥90 percent probability of detecting the species. If >0.37 but ≤0.54, four or five counts are needed. If ≥0.21 but ≤ 0.36, 6 to 10 counts are needed If <0.21, more than 10 counts are needed.*

Species	Frequency Count Period (minutes) 3	6	10	Sites	Points	Counts	Mean number of individuals
				----------*no.*----------			
Frequency > 0.55:							
Red-bellied Woodpecker	0.45	0.51	0.70	3	13	255	1.8
Eastern Wood-Pewee	0.62	0.69	0.73	3	13	255	1.6
Acadian Flycatcher	0.75	0.81	0.85	3	13	255	2.4
Tufted Titmouse	0.58	0.65	0.73	3	13	255	2.6
House Wren	0.53	0.58	0.60	2	5	85	1.8
Blue-gray Gnatcatcher	0.38	0.53	0.57	3	11	225	1.6
Wood Thrush	0.68	0.74	0.77	3	13	255	2.5
Red-eyed Vireo	0.73	0.80	0.83	3	13	255	2.3
Cerulean Warbler	0.58	0.67	0.73	2	8	180	2.1
Northern Cardinal	0.71	0.86	0.90	3	13	255	2.8
Indigo Bunting	0.49	0.55	0.60	3	13	255	2.0
Brown-headed Cowbird	0.37	0.53	0.65	3	13	255	3.6
Frequency = 0.37 - 0.54:							
Northern Bobwhite	0.40	0.45	0.52	1	4	60	1.5
American Crow	0.21	0.31	0.40	3	13	255	2.5
Carolina Chickadee	0.33	0.40	0.48	3	13	255	2.5
White-breasted Nuthatch	0.20	0.30	0.37	3	13	255	1.4
Carolina Wren	0.31	0.46	0.50	2	9	195	2.1
Ovenbird	0.29	0.36	0.39	2	4	70	1.3
Kentucky Warbler	0.31	0.36	0.41	2	9	195	1.9
Scarlet Tanager	0.38	0.50	0.53	3	13	255	1.5
American Goldfinch	0.29	0.40	0.52	3	13	255	2.2
Frequency = 0.21 – 0.36:							
Yellow-billed Cuckoo	0.14	0.18	0.26	3	12	240	1.5
Downey Woodpecker	0.15	0.23	0.29	3	13	255	1.3
Blue Jay	0.16	0.21	0.25	3	13	255	1.7
Yellow-throated Warbler	0.16	0.24	0.33	1	6	150	1.0
Louisiana Waterthrush	0.18	0.26	0.34	2	9	195	1.2
Frequency < 0.21:							
Wild Turkey	0.12	0.12	0.12	1	1	25	1.0
Black-billed Cuckoo	0.07	0.10	0.13	2	2	40	1.0
Great Horned Owl	0.06	0.06	0.06	1	1	15	1.0
Ruby-throated Hummingbird	0.04	0.10	0.16	3	11	225	1.3
Hairy Woodpecker	0.09	0.13	0.19	3	10	190	1.0
Northern Flicker	0.05	0.09	0.14	3	10	200	1.0
Pileated Woodpecker	0.02	0.05	0.06	3	9	170	1.1
Great Crested Flycatcher	0.07	0.10	0.16	3	11	225	1.3
Yellow-throated Vireo	0.08	0.11	0.16	2	8	180	1.0
Hooded Warbler	0.11	0.13	0.13	1	3	45	1.0

The following additional species with frequencies < 0.21 were recorded as fly-overs, birds heard from outside forest habitat, or as probable nonbreeding vagrants: Great Blue Heron; Killdeer, Mourning Dove; Chimney Swift; Belted Kingfisher; Purple Martin; Eastern Kingbird; Eastern Bluebird; American Robin; Gray Catbird; Brown Thrasher; European Starling; Black-throated Green Warbler; American Redstart; Yellow-breasted Chat; Rose-breasted Grosbeak; Field Sparrow; Red-winged Blackbird; Common Grackle; Northern Oriole; and House Finch.

Cerulean Warbler (*Dendroica cerulea*), Blue-gray Gnatcatcher (*Polioptila caerulea*), Ovenbird (*Seirus aurocapillus*), Scarlet Tanager (*Piranga olivacea*), and Yellow-throated Warbler (*Dendroica dominica*). Species with large territories are not likely to be recorded frequently at any given point (e.g., Pileated Woodpecker, and Louisiana Waterthrush).

If the likelihood that a species will be detected at a given point is a function of the number of individuals present, an interesting relationship exists between actual density and the detection frequencies derived from different count periods. As density at a given point declines, the change in detection frequencies for short count periods more nearly reflects the actual decline than frequencies based on data from longer periods (*table 5*). The species detection frequency as a function of the number of birds present is hypothesized to be: $f_{sp} = (1 - (1 - f_{in})^n)$, where f_{in} is the frequency of detection of single individuals and n is the number of individuals present. This model assumes no facilitation or inhibition of activity among birds within earshot of the observer. If this model applies, the use of longer count periods underestimates actual declines (or increases) in the number of individuals per point to a greater extent than the use of shorter periods (*table 5*).

Density alone does not account for all differences in detection patterns. Obviously, changes in calling rates through the season will influence detection frequencies. We suspect that we have low estimates of frequency for some resident and early migrant species because our study was late, after their activity peaked (e.g., Downy Woodpecker, Hairy Woodpecker (*Picoides villosus*), Northern Flicker (*Colaptes auratus*), Carolina Chickadee (*Parus carolinensis*), Yellow-throated Warbler, and Louisiana Waterthrush). Also species specific singing patterns influence the likelihood of detection as a function of the count period. Species that sing more or less continuously in bouts of considerable duration are highly likely to be detected in the first 3 minutes (e.g., Eastern Wood-Pewee, House Wren (*Troglodytes troglodytes*), Red-eyed Vireo, Cerulean Warbler, and Indigo Bunting). Their frequencies for longer count periods will not climb rapidly. Others that give single calls or short bouts at greater intervals are more apt to be missed during the first 3 minutes and recorded in proportion to the time spent observing (e.g., Yellow-billed Cuckoo (*Coccyzus americanus*), Red-bellied Woodpecker, Hairy Woodpecker, Great Crested Flycatcher (*Myiarchus crinitus*), American Crow, White-breasted Nuthatch, and Brown-headed Cowbird). Species that are detected in rare, brief events are apt to be recorded nearly at random and in proportion to the time spent counting (e.g., Ruby-throated Hummingbirds and other "fly-bys" like herons, black icterinae, etc.). For recording rarely detected species, the benefits of longer count periods are greater than for common species (*table 4*). These differences in detectability among species indicate optimal monitoring regimes may differ depending on the species studied. At the least, larger amounts of time must be spent to establish the presence or absence of some species.

Unmated males of some species sing more actively than mated individuals (Gibbs 1988, Hayes and others 1985). This poses a troublesome bias if point count detections are used to assess habitat optima. The specter of detection rates increasing as a population declines is raised by these observations. 'Presence/absence' data from longer count periods will be less biased by differences in song activity levels among residents.

Table 5--*Relationships among species detection frequencies, count period, and number of individuals present at a point.*

1. Hypothetical species detection frequencies as functions of the number of individuals (n) and count period. The random model sets individual detection frequencies at a moderate magnitude and in proportion to count period length. Yellow-throated Warbler model uses frequencies for a species thought to have been represented by only one individual per point.
f_{in} is the detection frequency for a single individual. f_{sp} is the species detection frequency calculated as: $(1 - (1 - f_{in})^n)$, where n is the number of individuals present.

		Count Period (minutes)					
		Random model			Yellow-throated Warbler		
		3	6	10	3	6	10
Frequency	n						
f_{in} =		0.15	0.30	0.50	0.16	0.24	0.33
f_{sp} =	1	0.15	0.30	0.50	0.16	0.24	0.33
f_{sp} =	2	0.28	0.51	0.75	0.29	0.42	0.55
f_{sp} =	3	0.39	0.66	0.87	0.41	0.56	0.70
f_{sp} =	4	0.48	0.76	0.94	0.50	0.67	0.80

2. The predicted percent decline in species detection rates as a function of count period given hypothetical declines in the number of individuals present. The percent decline in species detection frequency is ratio of (f_{sp} before decline minus f_{sp} after decline) to (f_{sp} before decline).

Hypothetical decline in number of individuals		Percent decline in species detection frequency					
		Count Period (minutes)					
		Random model			Yellow-throated Warbler		
		3	6	10	3	6	10
Numbers	Percent						
2 →1	50	46	41	33	45	43	40
3 →1	67	62	55	43	61	57	53
4 →1	75	69	61	47	68	64	59

A further factor influencing detection rates across species and across count period lengths is observer bias (Verner 1985, Verner and Milne 1989). Unconsciously or consciously, we tended to start our counts by listening for specific species (in our cases usually parulinae) and change to other species later in the count period. One of us recognizes that he filters out crows whenever anything interesting is calling. Rare species, because of their intrinsic interest, are less apt to be missed or go unrecorded than common species. We believe that the prompting offered by a prepared data sheet with a species list reduced our likelihood of overlooking some species. In general, longer count periods are likely to reduce the effects of observer biases stemming from differences in alertness and, perhaps, some forms of acuity (e.g., stimulus filtering or saturation).

Our frequency values suggest that the majority of breeding passerine species are detected by five 10-minute samples (*table 4*). Because our study was conducted late in the season of some species' activities, we believe this may be a modest overestimate of the sampling effort required for our sites.

Design of Monitoring Regimes

Tradeoffs Between Count Period and Travel Time

Thus far we have considered sampling effectiveness as it relates to the coverage of individual points. Ultimately, statistical power in monitoring population trends depends on surveying large numbers of points (Verner 1985, 1988). Trends are detected as changes in frequencies of occurrence across points and the statistics of larger samples are less likely to be influenced by stochastic changes in habitat or observation variability at a few points.

The number of points covered per unit time is a function of count period and between-point travel intervals; the quality of per-count coverage depends on the count period. Where average travel time (i.e., "noncounting time") among independent points is great, the number of points that can be covered per unit of field time is limited (Verner 1988). Travel times are considerable in cases where lack of roads or trails makes access difficult as when wilderness areas or scattered Midwestern woodlots are to be monitored. It is important to consider the tradeoffs between count period duration and the number of counts in designing effective monitoring regimes, especially under these conditions.

For any given travel time, an increase in count period decreases the number of counts per hour, but increases the total time spent counting. For example, when travel time is 2 minutes, a change in count period from 3 to 10 minutes gives a 58 percent decrease in number of points and a 39 percent increase in survey time (*table 6*). At 10-minute travel intervals, the change in period reduces the count number by 35 percent and increases the time surveyed by 114 percent.

The tradeoffs of selecting different count periods can be illustrated by comparing the total number of individuals recorded per hour under different regimes (Droege and Ralph, personal communication). Using our results, when travel time between points is short, as if it were the 2-minute period used for roadside surveys (Robbins and others 1986), 3-minute counts produce about 60 percent more individuals per hour of field time than 10-minute counts (*table 6*). This difference disappears under conditions where between-point travel time approaches 10 minutes. The number of species-point records (i.e., the number of species per point summed over all points) shows the same pattern.

This approach can also be used to compare the efficiency of different count periods at detecting individual species (*table 7*). For some common and vocally active species like Acadian Flycatcher, Red-eyed Vireo, Wood Thrush, and Cerulean Warbler, shorter count periods produce a greater number of point records per hour. However, as travel intervals increase to 10 minutes, this relative advantage of shorter counts diminishes. For species with detection frequencies that

Table 6-Sampling effects of the tradeoff between count period duration and between point travel time.

1. Effects on the number of counts and number of minutes surveyed per hour.

	Count period duration (minutes)					
	3	6	10	3	6	10
Travel time (minutes)	Counts/hour			Minutes/hour		
2	12.0	7.5	5.0	36	45	50
5	7.5	5.4	4.0	23	33	40
10	4.6	3.8	3.0	14	23	30

2. Effects on the number of individuals recorded per hour and the number of species-points per hour. Species-points are the sum of the number of species per point for all points covered. Mean is the mean number of individuals and species per point, carried from the data in *table 3*.

		Count period duration (minutes)					
		3	6	10	3	6	10
Travel time (minutes)		Individuals/hour			Species-points/hour		
	Mean =	11.9	14.8	17.7	9.3	11.3	13.3
2		143	111	89	108	85	67
5		89	80	71	70	61	53
10		55	56	53	43	43	40

Table 7--*Effects of the tradeoffs between count period duration and between point travel time on the number of points at which selected species will be recorded per hour. The values are based on the frequency of a species' detection (f_{sp}), the proportion of counts in which it was detected* (table 4) *at points where it occurred. The values therefore represent a model situation in which the species is present at all points. Acadian Flycatcher's pattern is approximately the same as those of Red-eyed Vireo and Wood Thrush. Yellow-throated Warbler's pattern is similar to that of the Louisiana Waterthrush.*

Travel time (minutes)	*Count period duration (minutes)*								
	3	6	10	3	6	10	3	6	10
	Number of points per hour								
	Acadian Flycatcher			Cerulean Warbler			Red-bellied Woodpecker		
f_{sp} =	0.75	0.81	0.85	0.58	0.67	0.73	0.45	0.51	0.70
2	9.0	6.1	4.3	7.0	5.0	3.7	5.4	3.8	3.5
5	5.6	4.4	3.4	4.4	3.6	2.9	3.4	2.8	2.4
10	3.5	3.0	2.6	2.7	2.5	2.2	2.1	1.9	2.1
	Brown-headed Cowbird			Scarlet Tanager			Kentucky Warbler		
f_{sp} =	0.37	0.53	0.65	0.38	0.50	0.53	0.31	0.36	0.41
2	4.4	4.0	3.3	4.6	3.8	2.7	3.7	2.7	2.1
5	2.8	2.9	2.6	2.9	2.7	2.1	2.3	1.9	1.6
10	1.7	2.0	2.0	1.7	1.9	1.6	1.4	1.4	1.2
	Yellow-throated Warbler			R.-thr. Hummingbird					
f_{sp} =	0.16	0.24	0.33	0.04	0.10	0.16			
2	2.0	1.8	1.7	0.5	0.8	0.8			
5	1.2	1.3	1.3	0.3	0.5	0.6			
10	0.7	0.9	1.0	0.2	0.4	0.5			

increase substantially with count period like Red-bellied Woodpecker, Brown-headed Cowbird, Scarlet Tanager, Kentucky Warbler, Yellow-throated Warbler, Louisiana Waterthrush, and Ruby-throated Hummingbird, shorter count periods produce more station records only when travel intervals are short. Little is gained by using shorter count periods when between-point travel times approach or exceed 10 minutes, especially for relatively uncommon species, which are apt to be the targets of many monitoring programs.

Layout of Points

When selecting a monitoring regime, optimization can be approached by adjusting two variables: between-point travel interval and count period (Verner 1988). Travel time is less readily adjusted as it is strongly constrained by the physical environment. Nevertheless, travel time depends on decisions about the layout of points. It can be reduced by placing points: (1) close together; (2) along topographic contours; or (3) along trails to improve ease of movement. It can be shortened greatly if points are placed along roads and a vehicle is used. In each case, these decisions may compromise statistical assumptions about independence of points or representativeness of the sample.

The primary goal of most long-term monitoring is to detect trends in bird populations. To do this using a series of repeated point counts, it is necessary to make the assumption that changes in our counts over time are representative of changes in populations on a larger regional scale. We assume that no changes in habitat quality will occur among our sample points that are unrepresentative of changes in habitats in general. Either we place our points representatively (probably involving random placement) or we apportion them more or less equally among defined habitat types and then must separately monitor changes in the frequency of these habitats over time on the regional level.

The use of trails or roadsides for monitoring is based on the assumption that these points will continue to sample habitats representatively over the next decades, and that disturbance regimes (Denslow 1980) and patch dynamics (Pickett 1980, Pickett and Thompson 1978) will be no different along them than elsewhere. Among other aspects, this assumes that current trails are not laid out unrepresentatively relative to successsional states of habitats. This is an assumption that cannot be made in those National Forests where trails are more apt to be on ridges or along streamsides where historic land use is likely to have been more intense than on slopes.

The papers at this workshop that compare roadside to off-road point counts find modest differences between selected points (Hutto and Hejl, in these Proceedings, Keller and Fuller, in this volume, Ralph and others, in this volume), yet they do not establish equivalent susceptibility of these areas to disturbance through time (e.g., fires, forest harvest, windfalls, and rights-of-way maintenance).

Several papers in this symposium mention the importance of adequately sampling habitat types as units. There are compelling management reasons to tie population data to habitat classifications. However, the definitions of forest types or stands may pose a variety of difficulties for long-term monitoring. If any of these are successional habitats, their character will change over time. Relatively uncommon habitats

may be oversampled now compared to later, when succession has removed them from sampled points, but disturbance and succession have not replaced them proportionally at other points. Likewise, the layout of points should not avoid existing disturbed habitats (e.g., treefall gaps, burns, etc.) as this will produce a nonrepresentative sampling now compared to later when future disturbances will have affected some of the points we set up now.

This all argues for random placement of points--or careful attention must be paid to comparing the dynamics of habitats at count points to those at regionally-representative points so that point count data can be converted to assess actual population trends. Arguing against random placement is the loss of sample size that results from increased travel time between points and the loss of clear ties to current habitat classification schemes as a component of management decision making. A compromise is required in setting up a point count monitoring program. The decisions made in setting up a system should be clearly documented so that future interpretations of trends in the data can be made more knowledgeably.

Pros and Cons of Different Count Period Durations

Compared to longer count periods (e.g., 10 minutes), the use of shorter count periods (e.g., 3 minutes) has advantages, such as: (1) more counts can be conducted per unit of field time; (2) 3-minute counts are compatible with the existing large Breeding Bird Survey (BBS) data base; and (3) changes in detection frequencies will more closely measure changes in abundance at individual points (longer periods will underestimate changes in abundance). The use of short count periods also has disadvantages, such as: (1) less time will be spent censusing per unit of field time; (2) greater sensitivity to changes in activity levels during the day (and probably the season) thereby "shortening" the day (they may also be more sensitive to observer differences); (3) greater sensitivity to differences in activity levels among species and individuals; and (4) lower effectiveness at sampling less abundant or less conspicuous species on a per-point basis.

Increases in between-point travel time affect the relative strengths of these advantages and disadvantages of designs with shorter count periods. As travel interval increases, the advantage of more points per unit of field time decreases and the disadvantage of less time counting per unit of field time intensifies. At travel intervals of approximately 10 minutes, the advantages of shorter count periods are expressed only in the more common (dense and easily detected) species.

Recommendations

Because the advantages of increasing sample sizes are great (Verner 1985, 1988), shorter count periods (i.e., 3 or 5 minutes) should be used whenever between-point travel times are short (approximately 2 to 5 minutes). This assumes that the layout of points to achieve reduced between-point time does not compromise the assumptions necessary for statistical analysis or the representativeness of the sample points.

Multiple counts per point during a season yield improved coverage, thereby improving the data for presence or absence determinations such as those used in habitat association analyses. A point of diminished returns has certainly been reached with five 10-minute counts per point. However, repeated counts substantially reduce the number of points that can be canvassed per unit effort. Based on our results, more than three counts per season at a point seems unwarranted for population monitoring purposes.

Some monitoring projects will have special reasons to be designed with long travel times among points. For example, given the possible alternative patterns of habitat selection by declining populations (Askins and others 1990, Robbins and others 1989, Wilcove and Terborgh 1984), monitoring forests of differing vegetation, sizes, and geographic relationships is crucial. When point counts are used to monitor patterns like these of habitat selection in fragmented landscapes, large numbers of suitable sites with multiple points per site may not be available or feasible and travel times among sites will be great. Increased per-point sampling intensity will be at a premium. Longer count periods, and perhaps multiple counts per point, will yield better correlations between species presence and habitat states: there will be fewer events of missed detection at points with suitable and occupied habitats. A similar situation would exist when monitoring roadless or pathless wilderness areas.

In situations such as these, where access to points will involve relatively long travel times, and therefore the relative advantages of short versus long periods diminish, we would recommend the use of longer count periods. A mixed method in which 10-minute count periods are subtallied at the 3- and 5-minute intervals would have many benefits, such as: (1) comparability with BBS (3 minutes) and with the standard recommended by this workshop (5 minutes); (2) improved coverage per point (10 minutes) for better habitat association analysis, especially for less frequently detected species; (3) increased amount of time per day with comparable sampling (10 minutes) and, perhaps, increased length of season with comparable sampling; (4) abatement of variance due to breeding status effects on activity levels (10 minutes); (5) perhaps abatement of variance because of some observer differences (10 minutes); and (6) ability to more directly estimate changes in populations from changes in detection frequencies (3 minutes).

In many cases such as monitoring fragments or pockets of rare habitats, the geographic layout of study areas requires large amounts of travel time among sites and relatively less among points within sites. Only one or a few independent monitoring points can be placed in each site. In these situations, multiple same-day counts within sites and different-day coverage among sites would seem to be appropriate as long as weather and seasonal effects are standardized among areas.

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Point Count Length and Detection of Forest Neotropical Migrant Birds[1]

Deanna K. Dawson, David R. Smith, and Chandler S. Robbins[2]

Abstract: Comparisons of bird abundances among years or among habitats assume that the rates at which birds are detected and counted are constant within species. We use point count data collected in forests of the Mid-Atlantic states to estimate detection probabilities for Neotropical migrant bird species as a function of count length. For some species, significant differences existed among years or observers in both the probability of detecting the species and in the rate at which individuals are counted. We demonstrate the consequence that variability in species' detection probabilities can have on estimates of population change, and discuss ways for reducing this source of bias in point count studies.

The point count technique is commonly used for surveying bird populations. Because counts are made from a stationary location, an observer can concentrate fully on visual and aural detections of birds within a fixed or unlimited distance.

Point count length has not been standardized among surveys. Three-minute counts are used in the Breeding Bird Survey, which has been in operation throughout North America since the late 1960's (Robbins and others 1986). Among off-road studies conducted by other investigators, however, count length has ranged up to 20 minutes (Robbins and others 1989). For most species, the number of individuals counted at a point is a function of the time spent counting. Birds that are inconspicuous because of their distance from the point or that vocalize infrequently have a higher probability of being detected with longer counting periods. In addition, observers with less experience or hearing acuity may be more likely to detect birds when counting periods are longer. However, Scott and Ramsey (1981), Fuller and Langslow (1984), and Verner (1988) caution that the probability of counting birds more than once increases with increasing count length.

Analytical comparisons of species' abundances among years or among habitats assume that the rates at which birds are detected or counted are constant within species (Barker and Sauer, in these Proceedings). Detections of birds are affected by factors that influence singing frequency (e.g., time-of-day or season, weather conditions, and presence of conspecifics) or the perceptive abilities of observers (e.g., habitat, experience, and hearing acuity). Thus, an important consideration in the development of a protocol for bird surveys should be to set a count length that reduces variability in the probability of detecting the birds present at points.

In this paper, we use point count data collected in forests of the Mid-Atlantic states to estimate the probabilities of detecting Neotropical migrant bird species at points as a function of count length. We test the effect of year and observer on species' detection probabilities and on the rates at which new detections of individuals are accumulated. Finally, for selected species we demonstrate the consequence that variation in detection probabilities can have on estimates of population change, and suggest how this source of bias can be reduced.

Methods

Bird Counts

The data used in our analyses were collected during 1979 through 1983 as part of a study on the effects of forest area on bird distribution (Robbins and others 1989). Bird counting points were established in mature forests ranging in area from 0.1 ha to >3,000 hectares within four physiographic regions in Maryland and adjacent counties in Pennsylvania, Virginia, and West Virginia (*fig. 1*). In most forests, a single point was established in the approximate center of the tract. In tracts >500 hectares, two or more points, at least 200 m from each other and from the forest edge, were established. The study sites selected included the major forest types of the Mid-Atlantic Region: upland deciduous forests, pine forests, mixed evergreen and deciduous forests, floodplain forests, and mountain swamps. In each year of the study, emphasis centered on sampling a wide range of forest areas within one physiographic region; thus no regions or forest types were sampled in all years of the study.

Each point was visited three times during 1 year of the study; the median date was June 5 for first visits to points, June 17 for second visits, and June 25 for third visits. The starting times for counts were varied among visits so that each point was sampled at different times during the early morning period (within 4 hours of sunrise). Visits were generally made by different observers to maximize the probability of detecting each species present. Over the 5 years of the study, eight different observers, each a skilled birder with previous experience in conducting standardized counts, assisted with data collection during one to four seasons.

On each visit, counts were made of all birds detected during a 20-minute period; birds clearly outside the habitat in which the point was located were excluded. For each species, counts were tallied separately for singing males, nonsinging adults (generally females), juveniles, and birds observed flying over the site. Relative locations of each bird detected were mapped for each 5-minute interval of the count period. With this technique for data recording, it was possible not only to determine in which 5-minute interval of the count period a species was first detected but the 5-minute intervals in which additional individuals of the species were detected. Mapping the relative locations of birds also helped to reduce the possibility of counting individuals more than once. After the count was completed, the observer recorded the cumulative counts of singing males and nonsinging adults for each species

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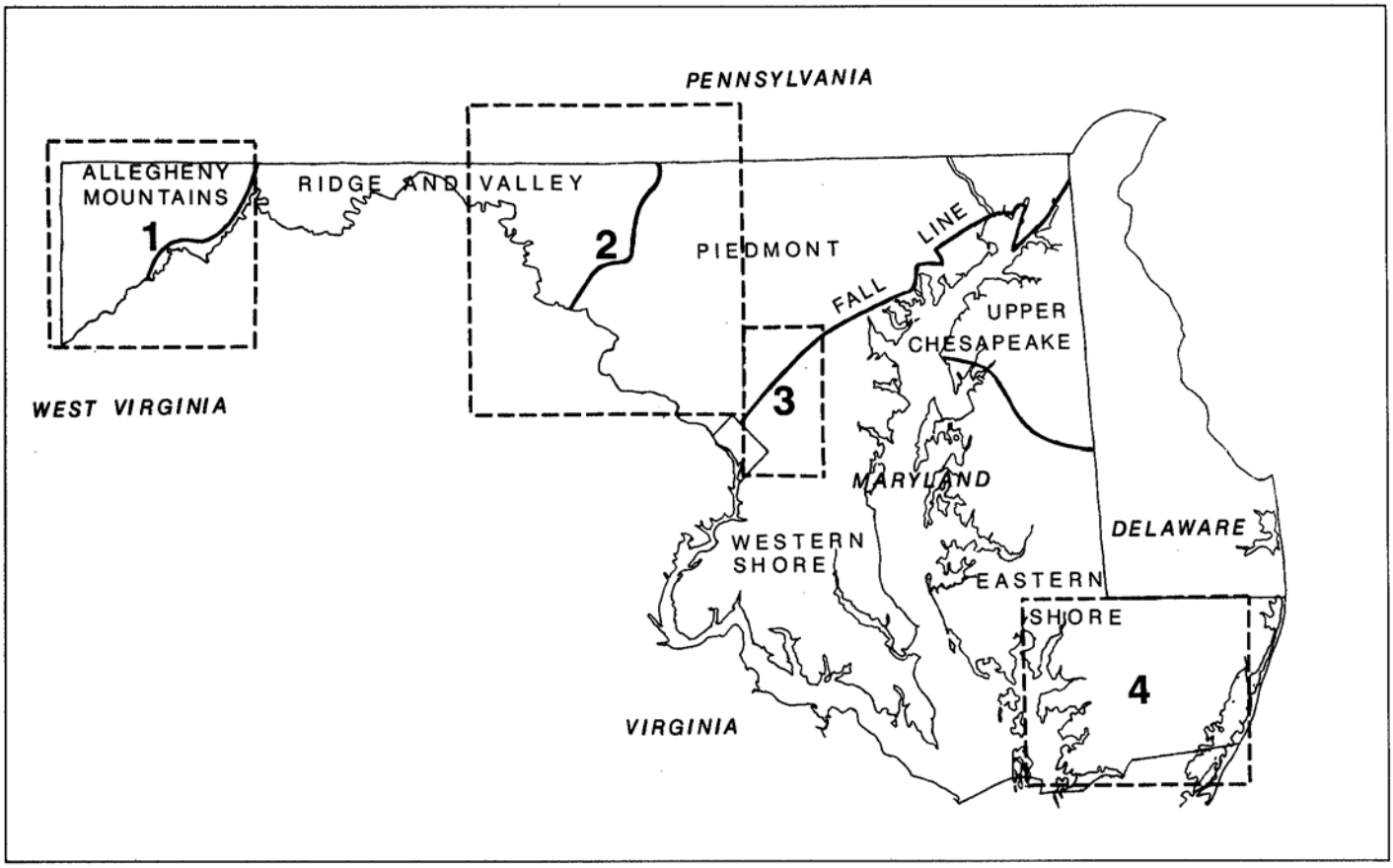

Figure 1--Location of the four physiographic regions of Maryland and adjacent states in which point counts were conducted, 1979-83 (Robbins and others 1989).

detected at the point. Species detected immediately before or after, but not during, the count period were noted.

Statistical Analyses

We used data collected at 454 points, each of which was sampled on three visits. The data for Neotropical migrant species extracted from the field sheets consisted of a cumulative count of number of individuals detected after 5, 10, 15, and 20 minutes of counting.

We used the Kaplan-Meier product limit estimator (Cox and Oakes 1984, Kaplan and Meier 1958) to estimate species' detection probabilities as a function of count length. We define a species' detection probability as the probability of detecting that species at a point given that the species is present. A species was considered present if it was detected within or outside (immediately before or after) the 20-minute count period on a visit to a point. In addition, if the species was detected during the first and third visits to a point but not on the second, it was assumed to have been present on the second visit. Because of the extensive observation at each point (a total of 1 hour of counting time during visits on 3 different days), we feel confident that there were few points at which a species was present but not detected and that, as a result, the detection probabilities estimated were minimally biased. The input data for each species consisted of the frequency distribution of the 5-minute intervals of first detection on counts; data from all visits to points were pooled for the analysis. Detection probabilities were calculated as the complement of the survivor function from the Kaplan-Meier method (LIFETEST procedure, SAS Institute Inc. 1985). Approximate 95 percent confidence limits were obtained using the normal approximation to the distribution of a logistic transformation of the probabilities.

Detection probability functions were estimated by year and averaged across years to produce estimated probabilities of detecting each species after counting for 5, 10, 15, and 20 minutes. For the 14 species that were detected in at least one physiographic region in all years of the study, we used log rank tests to test the null hypothesis that detection probabilities for each region did not vary among years or observers. In addition, we used repeated-measures analysis of variance to test the effect of year and observer on the proportion of the total number of individuals of these species counted on a 20-minute visit to a point that were detected within 5, 10, and 15 minutes. Because the same set of observers was not used throughout the study, observer and year are confounded, making it impossible to independently assess their effects on the rates at which birds were detected.

We used Monte Carlo techniques (Hammersley and Handscomb 1964) to demonstrate for six widely distributed bird species that variation in detection probabilities can affect estimates of population trend. We simulated a survey in which counts were made at n points (n = 100 and n = 200), and then repeated in a subsequent year. Each species occurred at the same number of points in each year, but the probability of detecting the species was allowed to vary. Two

Table 1-Probability of detecting 14 species of forest Neotropical migrant birds within 5, 10, 15, and 20 minutes at points at which they were known to be present. The number of points is the number at which a species was detected (maximum 454); actual sample size for Kaplan-Meier analyses is the number of point-visits during which the species was detected.

Species name	Number of points	Probability of detecting within: 5 minutes	10 minutes	15 minutes	20 minutes
Yellow-billed Cuckoo	258	0.465	0.655	0.812	0.922
Great Crested Flycatcher	270	0.540	0.704	0.839	0.926
Eastern Wood-Pewee	294	0.611	0.752	0.854	0.920
Acadian Flycatcher	176	0.747	0.820	0.896	0.936
Blue-gray Gnatcatcher	112	0.580	0.728	0.862	0.931
Wood Thrush	323	0.784	0.882	0.939	0.971
Gray Catbird	171	0.615	0.779	0.893	0.936
Red-eyed Vireo	377	0.857	0.922	0.964	0.980
Worm-eating Warbler	79	0.507	0.671	0.877	0.929
Ovenbird	244	0.765	0.885	0.940	0.977
Kentucky Warbler	82	0.580	0.773	0.827	0.945
Common Yellowthroat	125	0.606	0.740	0.852	0.950
Scarlet Tanager	295	0.718	0.833	0.910	0.948
Indigo Bunting	184	0.582	0.726	0.845	0.912

20-minute counts were made at each point in each year; on each visit, the 5-minute interval in which a species was first detected was noted. The simulation was replicated 100 times.

We assumed that the point counts could be adequately modeled by a beta-binomial distribution; the year-specific, binomial detection probabilities are assumed to be beta random variables with parameters α and β. Thus the expected value of the detection probability is $\alpha/(\alpha+\beta)$. The Kaplan-Meier estimates of yearly species' detection probabilities for counts of different lengths were used to obtain method-of-moment estimates of α and β for the simulation.

The measure of trend we consider here is the absolute value of percentage change in frequency of occurrence. Because no actual trend in the simulated populations existed, any change in frequency of occurrence is due solely to variation in the probability of detecting the species. Thus, the simulations demonstrate how variation in species' detection probabilities can lead to incorrect conclusions about population change, and the effect of count length on this source of bias. We summarize results using: (1) only the data from the fast visit and (2) data from both visits. In the latter case, a species was considered present at a point if it was detected on at least one visit.

Table 2--*Significance of log-rank tests for differences among years or observers in the probability of detecting 14 bird species that occur in all physiographic regions sampled.*

Species name	Region 1	2	3	4
Yellow-billed Cuckoo				*
Great Crested Flycatcher	**			**
Eastern wood-Pewee	***	***	***	
Acadian Flycatcher		***		*
Blue-gray Gnatcatcher				
Wood Thrush	***	*		
Gray Catbird		***		***
Red-eyed Vireo	**		*	*
Worm-eating Warbler			**	**
Ovenbird	**	*	*	
Kentucky Warbler				
Common Yellowthroat	***			
Scarlet Tanager			*	
Indigo Bunting	***	***		

*=P<0.10,**=P<0.05,***=P<0.01

Results

The estimates of species' detection probabilities after 5 minutes of counting ranged from 0.27 for Ruby-throated Hummingbird (*Archilochus colubris*), a widely distributed but inconspicuous species, to 0.92 for Northern Waterthrush (*Seiurus noveboracensis*), a species that occurs locally at relatively high densities in high-elevation swamps in Region 1. By the end of 15 minutes of counting, detection probabilities for nearly all species exceeded 0.80. Detection probabilities after counts of 5, 10, 15, and 20 minutes are shown in *table 1* for 14 species that occurred in all physiographic regions of the study. Detection probabilities for 20-minute counts are <1.0 because of instances in which species were detected immediately before or after but not within the counting periods, or in which species were not detected on second visits to points but were observed on visits one and three.

Log rank tests indicated that for some species significant differences in detection probabilities existed among years or observers; however, for no species were test results consistent across physiographic regions (*table 2*). Least square means of the proportions of individuals counted within 5, 10, or 15 minutes are presented (*table 3*) for species within physiographic regions for the years for which sufficient data were available; these represent the expected proportion of individuals of a species that would be detected in counts of 5, 10, or 15 minutes. Because the proportions are based on the total number of individuals counted within a 20-minute visit to a point (and thus forced to 1.0), we think that they are of limited use for assessing appropriate count length. However, differences among years or observers in the rates at which new individuals

Table 3--*The mean expected proportion of the total birds counted that were detected within 5, 10, and 15 minutes for species and physiographic regions for which there was sufficient data for analysis. Lower and upper bounds to the means were calculated as approximate confidence intervals. Significant year or observer effects within physiographic regions are indicated*

			Proportion detected within:								
			5 minutes			10 minutes			15 minutes.		
	Year	Observer	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper
Yellow-billed Cuckoo											
Reg. 1			0.449	0.186	0.712	0.671	0.462	0.880	0.817	-	-
2			0.655	0.449	0.861	0.722	0.547	0.897	0.896	0.748	1.000
3			0.265	0.000	0.506	0.558	0.241	0.875	0.975	0.789	1.000
4		**	0.371	0.138	0.603	0.558	0.333	0.782	0.917	0.740	1.000
Great Crested Flycatcher											
Reg. 1			0.536	0.382	0.690	0.821	0.668	0.974	0.890	0.771	1.000
2	***		0.604	0.416	0.792	0.647	0.488	0.807	0.935	0.832	1.000
3			0.292	0.000	0.741	1.000	0.603	1.000	1.000	0.681	1.000
4			0.413	0.267	0.558	0.591	0.439	0.743	0.806	0.705	0.907
Eastern Wood-Pewee											
Reg. 1		*	0.544	0.409	0.679	0.616	0.505	0.727	0.957	0.901	1.000
2		*	0.663	0.539	0.787	0.811	0.714	0.909	0.879	0.807	0.951
3			0.506	0.205	0.807	0.650	0.421	0.880	0.810	0.633	0.988
4	*		0.409	0.214	0.603	0.750	0.590	0.910	0.911	0.853	0.969
Acadian Flycatcher											
Reg. 1	***		0.842	0.713	0.972	0.931	0.850	1.000	1.000	-	-
2			0.764	0.634	0.893	0.853	0.742	0.965	0.936	0.853	1.000
3			0.744	0.610	0.878	0.844	0.739	0.949	0.965	0.899	1.000
4	*	*	0.605	0.511	0.699	0.748	0.671	0.826	0.946	0.902	0.990
Blue-gray Gnatcatcher											
Reg. 2			0.572	0.317	0.828	0.794	0.539	1.000	0.937	0.804	1.000
4			0.565	0.268	0.861	0.748	0.506	0.991	0.888	0.803	0.974
Wood Thrush											
Reg. 1			0.685	0.586	0.785	0.803	0.714	0.892	0.924	0.864	0.984
2			0.641	0.558	0.725	0.867	0.807	0.928	0.956	0.921	0.991
3			0.625	0.461	0.788	0.772	0.632	0.912	0.902	0.798	1.000
4	**		0.672	0.574	0.770	0.845	0.774	0.917	0.965	0.924	1.000
Gray Catbird											
Reg. 1	**		0.612	0.358	0.866	0.847	0.620	1.000	0.977	0.846	1.000
2			0.573	0.464	0.682	0.852	0.760	0.944	0.896	0.848	0.945
3			0.477	0.231	0.724	0.710	0.423	0.996	0.898	0.733	1.000
4			0.675	0.491	0.859	0.799	0.658	0.940	0.955	0.889	1.000
Red-eyed Vireo											
Reg. 1			0.768	0.686	0.851	0.902	0.839	0.966	0.961	0.923	0.998
2			0.688	0.567	0.810	0.815	0.715	0.914	0.932	0.880	0.985
3	**		0.690	0.584	0.797	0.829	0.743	0.915	0.880	0.822	0.939
4			0.678	0.611	0.746	0.801	0.752	0.850	0.921	0.889	0.953
Ovenbird											
Reg. 1			0.618	0.526	0.710	0.829	0.760	0.897	0.940	0.896	0.984
2	***	**	0.644	0.537	0.752	0.842	0.772	0.912	0.929	0.876	0.982
3		*	0.531	0.288	0.775	0.885	0.722	1.000	0.906	0.782	1.000
4			0.692	0.597	0.786	0.815	0.736	0.894	0.918	0.860	0.976
Common Yellowthroat											
Reg. 1			0.446	0.265	0.626	0.692	0.533	0.851	0.814	0.699	0.929
Scarlet Tanager											
Reg. 1		*	0.757	0.655	0.859	0.879	0.804	0.954	0.967	0.929	1.000
2			0.752	0.625	0.880	0.881	0.782	0.981	0.940	0.862	1.000
3			0.784	0.656	0.912	0.929	0.836	1.000	0.979	0.922	1.000
4			0.577	0.334	0.819	0.724	0.526	0.922	0.905	0.777	1.000
Indigo Bunting											
Reg. 1			0.597	0.470	0.725	0.763	0.654	0.873	0.862	0.779	0.945
2			0.538	0.354	0.722	0.685	0.521	0.849	0.940	0.867	1.000
3		**	1.000	0.245	1.000	1.000	0.481	1.000	1.000	0.406	1.000
4	*		0.520	0.358	0.682	0.661	0.523	0.798	0.898	0.779	1.000

*=$P<0.10$, **=$P<0.05$, ***=$P<0.01$

are counted would bias estimates of abundance and limit the interpretation of trends. Tests for year or observer effects on the proportion of individuals counted within 5, 10, or 15 minutes indicated significant differences existed for some species, although not across all physiographic regions (*table 3*).

Simulations of between-year change in frequency of occurrence were based on the yearly Kaplan-Meier estimates of species' detection probabilities within regions for counts of 5, 10, 15 and 20 minutes (*table 4*). Because the number of points at which a species occurred was held constant between years in the simulations, changes in frequency of occurrence result solely from random variation in species' detection probabilities, and thus falsely indicate population change. The simulated change in frequency of occurrence varied greatly among species and physiographic regions (*table 5*). The average percentage change was low (<12 percent) for Red-eyed Vireo (*Vireo olivaceus*) in each of the three regions for which simulations were run, regardless of count length. However, for Great Crested Flycatcher (*Myiarchus crinitus*) in Region 1, differential detection probabilities resulted in average percentage differences in frequency of occurrence of 76 percent, when no population change actually existed.

For all species, the simulations show that false indications of trend could be reduced by increasing the length of time spent counting at points. False trends were also reduced by making a second visit to points and considering a species to be present at a point if it was detected on at least one of the two visits. In all cases, simulated changes in frequency of occurrence were reduced by 50 percent or greater by visiting points twice and counting for 10 minutes or longer. Results were less consistent across species and regions for two visits and 5-minute counts (*table 5*). Because, in our example, the numbers of points sampled and those at which species occurred were held constant between years, change in frequency of occurrence is not a function of sample size. Consequently, our results do not address the contribution of increased sample size to reduction of bias associated with variability in detection probabilities.

Discussion

Results of this study merit consideration by those designing point count studies for monitoring bird populations. First, in fixed-length counts, detection probabilities vary among species. For species with a low probability of detection, both the number of points at which the species is detected and the number of individuals counted for the species may be increased by increasing count length. If particular species are of interest or if good measures of species richness at individual points are required, count length can be optimized to address these objectives (Barker and others 1994; Barker and Sauer, in this volume). Second, within species, detection probabilities and the rates at which individuals are counted may vary among years, among observers, or among physiographic regions. In this study, yearly variations in detection probabilities may be a result of differences among years in the set of observers conducting counts or in the set of points sampled. Differences in detection probabilities among physiographic regions likely result from regional differences in habitats or bird abundances. The consequence of the differences for monitoring programs is that variability in detection probabilities is a source of bias in estimates of population change. For example, indices of abundance can change strictly as a result of changes in detection probabilities, even when populations remain stable Alternatively, if a species tends to become more detectable while populations decline (perhaps due to habitat alteration), then the index would falsely indicate relative population stability. In either case variation in detection probabilities may result in false conclusions about population trends.

We believe that an important criterion for the design of surveys for monitoring programs should be to reduce (if not eliminate) bias due to variation in detection probabilities. Stratification by physiographic regions or by habitats may help to minimize bias caused by spatial differences in detection probabilities (Barker and others 1994). Observer differences can be reduced to some extent by enlisting birders with previous experience in conducting timed counts or by providing training in identification and counting techniques; however in our study we found differences even among skilled observers in species' detection probabilities (*table* 2) and in the rates at which new individuals were counted. These results suggest that if assessment of population change is the study objective, the same observers should be used among years whenever possible.

Our simulations demonstrate that bias resulting from variation in species' detection probabilities can also be reduced by increasing the amount of time spent counting at points. For the six species for which we did simulations, there was a decided advantage to making two visits to determine species' presence at points; false trends in the number of points at which the species was detected could often be reduced by 50 percent for counts of 10 minutes or less if points were visited twice. However, if logistical concerns make travel to points difficult, extending count length to 15 or 20 minutes one of visit might be more efficient than revisiting points.

Often the time and resources available for sampling are limited and fixed; thus allocation of sampling effort represents a tradeoff between increasing species' detection probabilities at points (by increasing the time spent at points) and increasing the number of points sampled. Therefore, we strongly emphasize the importance of defining objectives prior to initiating a point count study so that sampling effort can be allocated to best address study goals.

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Table 4--*Kaplan-Meier estimates of species detection probabilities, with approximate 95 percent confidence intervals. The mean and variance were used to estimate the parameters of the beta distribution for the simulation. The numbers 5, 10, 15, and 20 refer to point count periods in minutes.*

	Region 1					Region 2				Region 4			
	1980	1981	1982	1983	Mean and Variance	1979	1980	1983	Mean and Variance	1981	1982	1983	Mean and Variance
Yellow-billed Cuckoo													
	n=20	n=14	n=6	n=8		n=124	n=30	n=13		n=77	n=49	n=76	
5	0.60	0.36	0.33	0.50	0.45	0.49	0.40	0.69	0.53	0.49	0.53	0.41	0.48
	(0.41, 0.76)	(0.18, 0.58)	(0.11, 0.68)	(0.24, 0.76)	(0.016)	(0.42, 0.57)	(0.27. 055)	(0.46, 0.86)	(0.022)	(0.40, 0.59)	0.41, 0.64)	(0.32, 0.50)	(0.004)
10	0.70	0.57	0.50	0.75	0.63	0.69	0.63	0.85	0.72	0.75	0.61	0.63	0.67
	(0.51, 0.84)	(0.35, 0.76)	(0.21, 0.79)	(0.44, 0.92)	(0.013)	(0.62, 0.76)	(0.48, 0.76)	(0.61, 0.95)	(0.012)	(0.66, 0.83)	(0.49, 0.72)	(0.54, 0.72)	(0.006)
15	0.80	0.71	0.67	0.88	0.76	0.82	0.77	1.00	0.86	0.86	0.82	0.74	0.80
	(0.61, 0.91)	(0.49, 0.87)	(0.32, 0.89)	(0.55, 0.98)	(0.009)	(0.76, 0.87)	(0.62, 0.87)	(1.0, 1.0)	(0.015)	(0.78, 0.91)	(0.71, 0.89)	(0.65, 0.81)	(0.004)
20	0.95	0.79	1.00	1.00	0.93	0.93	0.93	1.00	0.95	0.96	0.88	0.87	0.90
	(0.78, 0.99)	(0.56, 0.91)	(1.0, 1.0)	(1.0, 1.0)	(0.010)	(0.88, 0.96)	(0.81, 0.98)	(1.0, 1.0)	(0.002)	(0.90, 0.98)	(0.78, 0.94)	(0.79, 0.92)	(0.003)
Great Crested Flycatcher													
	n=56	n=28	n=12	n=17		n=139	n=38	n=21		n=42	n=36	n=75	
5	0.54	0.21	0.75	0.71	0.55	0.64	0.45	0.62	0.57	0.62	0.61	0.41	0.55
	(0.43. 0.64)	(0.11, 0.37)	(0.50, 0.90)	(0.50, 0.85)	(0.059)	(0.57, 0.70)	(0.32, 0.58)	(0.44, 0.77)	(0.011)	(0.49, 0.73)	(0.47, 0.73)	(0.32, 0.51)	(0.014)
10	0.75	0.54	0.83	0.88	0.75	0.73	0.63	0.76	0.71	0.69	0.83	0.55	0.69
	(0.64, 0.83)	(0.38, 0.68)	(0.58, 0.95)	(0.68, 0.96)	(0.023)	(0.67, 0.79)	(0.50, 0.75)	(0.58, 0.88)	(0.005)	(0.56, 0.79)	(0.71, 0.91)	(0.45, 0.64)	(0.021)
15	0.84	0.68	0.83	0.94	0.82	0.85	0.84	0.90	0.87	0.83	0.97	0.73	0.85
	(0.74, 0.90)	(0.52, 0.80)	(0.58. 0.95)	(0.74, 0.99)	(0.012)	(0.79, 0.89)	(0.72. 0.92)	(0.74, 0.97)	(0.001)	(0.72. 0.91)	(0.87, 0.99)	(0.64, 0.81)	(0.014)
20	0.95	0.89	0.92	1.00	0.94	0.91	0.95	0.95	0.94	0.88	0.97	0.91	0.92
	(0.87, 0.98)	(0.75, 0.96)	(0.66, 0.98)	(1.0, 1.0)	(0.002)	(0.85, 0.94)	(0.84, 0.98)	(0.79, 0.99)	(0.001)	(0.77, 0.94)	(0.87, 0.99)	(0.83, 0.95)	(0.002)
Acadian Flycatcher													
	n=12.	n=12	n=12	n=19		n=55	n=64	n=17		n=50	n=30	n=55	
5	0.92	0.75	0.75	0.79	0.80	0.62	0.78	0.94	0.78	0.68	0.77	0.76	0.74
	(0.66, 0.98)	(0.50, 0.90)	(0.50, 0.90)	(0.60, 0.90)	(0.006)	(0.51, 0.72)	(0.68, 0.85)	(0.75.0.99)	(0.026)	(0.56, 0.78)	(0.62, 0.87)	(0.66, 0.84)	(0.002)
10	1.00	0.83	0.75	0.89	0.85	0.69	0.86	1.00	0.83	0.78	0.87	0.87	0.84
	(1.0, 1.0)	(0.58, 0.95)	(0.50, 0.90)	(0.71, 0.97)	(0.006)	(0.58, 0.78)	(0.77, 0.92)	(1.0, 1.0)	(0.016)0	(0.67, 0.86)	(0.73, 0.94)	(0.78, 0.93)	(0.003)
15	1.0	0.83	0.83	0.89	0.89	0.76	0.91	1.00	0.83	0.94	0.93	0.95	0.94
	(1.0, 1.0)	(0.58, 0.95)	(0.58, 0.95)	(0.71, 0.97)	(0.006)	(0.66, 0.84)	(0.83, 0.95)	(1.0, 1.0)	(0.010)	(0.85, 0.98)	(O.81, 0.98)	(0.87, 0.98)	(<0.001)
20	1.00	0.83	1.00	0.89	0.93	0.82	0.95	1.00	0.92	0.96	0.97	0.98	0.97
	(1.0, 1.0)	(0.58, 0.95)	(1.0, 1.0)	(0.71, 0.97)	(0.007)	(0.72, 0.89)	(0.88, 0.98)	(1.0, 1.0)	(0.009)	(0.88, 0.99)	(0.91, 0.99)	(0.91, 0.99)	(<0.001)
Wood Thrush													
	n=65	n=19	n=27	n=43		n=179	n=56	n=34		n=62	n=48	n=56	
5	0.54	0.84	0.85	0.70	0.73	0.86	0.77	0.91	0.85	0.84	0.81	0.70	0.78
	(0.44, 0.64)	(0.65, 0.94)	(0.70, 0.93)	(0.57. 0.80)	(0.022)	(0.81, 0.90)	(0.66, 0.85)	(0.79, 0.97)	(0.005)	(0.75, 0.90)	(0.70, 0.89)	(0.59, 0.79)	(0.006)
10	0.69	0.89	0.89	0.84	0.83	0.93	0.95	0.97	0.95	0.94	0.88	0.82	0.88
	(0.59, 0.78)	(0.71, 0.97)	(0.75, 0.96)	(0.72, 0.91)	(0.009)	(0.89, 0.96)	(0.87, 0.98)	(0.86, 0.99)	(<0.001)	(0.86, 0.97)	(0.77, 0.93)	(0.72, 0.89)	(0.003)
15	0.78	1.00	0.89	0.93	0.90	0.99	0.95	1.00	0.98	0.95	0.98	0.91	0.95
	(0.69, 0.86)	(1.0. 1.0)	(0.75, 0.96)	(0.83,.0.97)	(0.009)	(0.97, 1.0)	(0.87, 0.98)	(1.0, 1.0)	(<0.001)	(0.88, 0.98)	(0.90, 1.0)	(0.83,0.96)	(0.001)
20	0.89	1.00	0.93	0.95	0.94	1.00	0.98	1.00	0.99	0.97	0.98	0.96	0.97
	(0.81, 0.94)	(1.0, 1.0)	(0.79, 0.98)	(0.86, 0.98)	(0.002)	(1.0, 1.0)	(0.91, 1.0)	(1.0, 1.0)	(<0.001)	(0.90, 0.99)	(0.90, 1.0)	(0.89, 0.99)	(<0.001)

Table 4---*continued*

	Region 1					Region 2				Region 4				
	1980	1981	1982	1983	Mean and Variance	1979	1980	1983	Mean and Variance	1981	1982	1983	Mean and Variance
Red-eyed Vireo														
	n=128	n=105	n=44	n=56		n=129	n=75	n=30		n=79	n=73	n=115	
5	0.89 (0.85, 0.93)	0.90 (0.85, 0.94)	0.95 (0.86, 0.98)	0.84 (0.74, 0.90)	0.92 (<0.001)	0.81 (0.75, 0.86)	0.83 (0.74, 0.89)	0.83 (0.69, 0.92)	0.82 (<0.001)	0.89 (0.81, 0.93)	0.82 (0.74, 0.88)	0.76 (0.68, 0.82)	0.82 (0.004)
10	0.98 (0.94, 0.99)	0.94 (0.89, 0.97)	0.97 (0.89, 1.0)	0.89 (0.80, 0.94)	0.95 (<0.001)	0.92 (0.87, 0.95)	0.87 (0.79, 0.92)	0.90 (0.77, 0.96)	0.89 (<0.001)	0.92 (0.86, 0.96)	0.90 (0.83, 0.95)	0.83 (0.76, 0.88)	0.88 (0.003)
15	0.99 (0.96, 1.0)	0.98 (0.94, 0.99)	1.00 (1.0, 1.0)	0.96 (0.89, 0.99)	0.98 (<0.001)	0.95 (0.91, 0.98)	0.95 (0.88, 0.98)	0.97 (0.84, 0.99)	0.96 (<0.001)	0.99 (0.94, 1.0)	0.94 (0.88, 0.98)	0.90 (0.85, 0.94)	0.95 (0.002)
20	1.00 (1.0, 1.0)	0.99 (0.95, 1.0)	1.00 (1.0, 1.0)	0.98 (0.91, 1.0)	0.99 (<0.001)	0.97 (0.93, 0.99)	0.96 (0.90, 0.98)	1.00 (1.0, 1.0)	0.98 (<0.001)	0.99 (0.94, 1.0)	0.96 (0.90, 0.98)	0.97 (0.92, 0.98)	0.97 (< 0.001)
Ovenbird														
	n=45	n=44	n= 10	n=9		n= 19	n=63	n=83		n=72	n=74	n= 117	
5	0.80 (0.68, 0.88)	0.73 (0.60, 0.82)	0.60 (0.34, 0.81)	0.56 (0.29, 0.79)	0.67 (0.013)	0.53 (0.34, 0.70)	0.87 (0.79, 0.93)	0.82 (0.55, 0.94)	0.74 (0.034)	0.78 (0.69, 0.85)	0.86 (0.79, 0.92)	0.84 (0.77, 0.88)	0.83 (0.002)
10	0.93 (0.84, 0.97)	0.86 (0.75, 0.93)	0.80 (0.52, 0.94)	0.78 (0.48, 0.93)	0.84 (0.005)	0.79 (0.60, 0.90)	0.94 (0.86, 0.97)	0.91 (0.64, 0.98)	0.88 (0.006)	0.89 (0.81, 0.94)	0.89 (0.82, 0.94)	0.92 (0.87, 0.96)	0.90 (<0.001)
15	0.96 (0.87, 0.99)	0.91 (0.81, 0.96)	0.90 (0.61, 0.98)	1.00 (1.0, 1.0)	0.94 (0.002)	0.90 (0.71, 0.97)	0.95 (0.88, 0.98)	1.00 (1.0, 1.0)	0.95 (0.003)	0.96 (0.90, 0.98)	0.95 (0.88, 0.98)	0.97 (0.92, 0.98)	0.96 (<0.001)
20	0.96 (0.87, 0.99)	0.93 (0.84, 0.97)	1.00 (1.0, 1.0)	1.00 (1.0, 1.0)	0.97 (0.001)	0.90 (0.71, 0.97)	0.97 (0.90, 0.99)	1.00 (1.0, 1.0)	0.95 (0.003)	0.99 (0.93, 0.99)	1.00 (1.0, 1.0)	0.99 (0.96, 1.0)	0.99 (< 0.001)

Table 5--*The average percentage difference in frequency of occurrence simulated assuming probability of species' detection varies, but species' occurrence at points is constant. Changes in frequency of occurrence result solely from variation in species' detection probabilities.*

		Number of points Where Species Occurred			
		100		200	
Species	Minutes	1 Visit	2 Visits	1 Visit	2 Visits
Yellow-billed Cuckoo					
Region 1	5	32.2	33.5	36.2	30.3
	10	26.1	13.4	23.0	13.0
	15	14.4	6.9	15.7	6.6
	20	11.2	4.5	12.7	3.5
Region 2	5	42.5	23.8	39.5	23.9
	10	18.5	8.8	17.4	8.2
	15	16.5	5.4	17.3	6.2
	20	5.2	0.9	4.8	0.6
Region 4	5	22.9	11.2	22.5	11.4
	10	16.0	7.7	15.3	7.0
	15	9.4	4.3	8.5	3.6
	20	8.5	1.5	7.3	1.7
Great Crested Flycatcher					
Region 1	5	76.0	54.6	72.5	44.3
	10	28.4	12.0	26.6	11.0
	15	17.4	5.8	14.1	5.3
	20	5.2	0.9	5.5	0.8
Region 2	5	24.8	14.8	26.0	15.4
	10	14.2	6.1	10.5	6.5
	15	5.9	1.9	5.9	1.5
	20	4.5	0.8	3.7	0.5
Region 4	5	28.2	16.0	25.8	19.2
	10	25.3	14.4	28.3	13.0
	15	15.2	5.8	14.8	5.3
	20	7.3	1.1	6.3	1.1
Acadian Flycatcher					
Region 1	5	12.6	4.4	15.4	4.9
	10	10.9	3.7	9.1	3.1
	15	11.3	2.1	10.3	2.8
	20	9.7	2.1	8.2	1.4
Region 2	5	29.1	11.4	28.2	10.9
	10	19.0	5.0	24.5	6.7
	15	15.8	4.7	20.0	4.5
	20	1.2	3.0	11.8	3.3
Region 4	5	9.9	4.8	8.3	3.3
	10	9.0	2.7	7.9	2.3
	15	3.1	0.6	1.9	0.4
	20	2.6	0.2	2.0	0.2
Wood Thrush					
Region 1	5	23.1	13.7	25.6	13.1
	10	13.0	5.6	13.6	4.0
	15	10.9	3.0	11.3	2.7
	20	5.4	1.0	5.6	0.9
Region 2	5	10.1	2.7	10.6	3.3
	10	3.5	0.5	3.9	0.5
	15	2.5	0.2	3.1	0.2
	20	1.0	0.0	0.9	0.1
Region 4	5	12.6	4.7	11.2	4.1
	10	9.3	2.2	7.6	1.5
	15	4.6	0.8	4.3	0.6
	20	2.2	0.2	1.4	0.2

continued

Table 5--*continued*

Species	Minutes	Number of Points Where Species Occurred			
		100		200	
		1 Visit	2 Visits	1 Visit	2 Visits
Red-eyed Vireo					
Region 1	5	8.1	1.5	7.8	1.2
	10	5.8	0.8	4.2	0.5
	15	2.4	0.1	1.6	0.1
	20	0.9	0.0	1.0	0.0
Region 2	5	5.5	2.2	3.6	1.3
	10	5.0	1.3	3.8	1.2
	15	2.8	0.2	2.2	0.3
	20	2.9	0.2	2.9	0.2
Region 4	5	11.3	4.0	8.5	3.7
	10	7.3	2.2	8.0	1.4
	15	5.0	0.8	5.2	0.6
	20	2.8	0.2	2.2	0.0
Ovenbird					
Region 1	5	20.6	12.5	22.9	11.0
	10	9.9	3.2	10.8	3.0
	15	6.8	0.8	5.8	1.0
	20	3.5	0.3	4.5	0.4
Region 2	5	40.2	15.4	29.3	14.7
	10	10.2	2.7	11.4	3.3
	15	7.1	0.8	7.6	0.9
	20	5.8	1.0	5.2	0.8
Region 4	5	10.2	2.7	7.2	2.2
	10	4.7	1.0	3.7	0.9
	15	2.7	0.2	2.1	0.3
	20	0.8	0.0	0.8	0.0

Analysis of Sample Size, Counting Time, and Plot Size from an Avian Point Count Survey on Hoosier National Forest, Indiana[1]

Frank R. Thompson and Monica J. Schwalbach[2]

Abstract: We report results of a point count survey of breeding birds on Hoosier National Forest in Indiana. We determined sample size requirements to detect differences in means and the effects of count duration and plot size on individual detection rates. Sample size requirements ranged from 100 to >1000 points with Type I and II error rates of <0.1 and 0.2. Sample size was inversely related to species abundance ($r = -0.38$, $P < 0.01$). Counting efficiency was maximized at a count duration <6 minutes with a travel time of 8 minutes, but differences were slight for most travel times. Unlimited-radius plots detected more individuals than 50-m or 70-m radius plots ($P < 0.05$). We recommend serious consideration of Type II error when designing monitoring protocols. Secondary study objectives and the need for standardization should be weighed heavily when selecting counting time in the range of 5 to 10 minutes. We recommend the use of unlimited-radius plots while simultaneously recording individuals relative to a fixed radius.

Populations of some forest-dwelling Neotropical migrant birds appear to be declining in Northeastern America (Askins and others 1990, Robbins and others 1989, Wilcove and Robinson 1990). Information is needed for the development of standardized monitoring protocols that will allow determination of local population trends of migrant landbirds as well as regional comparisons of population trends. Point counts are a potentially efficient and cost effective method of monitoring population trends and habitat associations. Our objectives in this paper are to determine the effects of bird abundance and variability on the sample size required to detect a difference in mean abundances, determine the effects of count duration on counting efficiency, and to compare detection rates on fixed- and unlimited-radius plots.

Study Area

Point counts were conducted on the Hoosier National Forest, which is composed of approximately 80,939 ha of noncontiguous ownership in southern Indiana. The landscape includes the National Forest and intermixed lands in other ownerships, and is a patchwork of forest and openlands fragmented by roads, farms, industrial developments, towns, small cities, and utility corridors. The area ranges from 5 percent to 80 percent forest cover. The diversity of the landscape results in a variety of habitats that range from mesophytic communities in deep ravines and lower slopes to xerophytic communities on limestone knobs and ledges, and sandstone ridge crests. Natural forest communities are primarily oak (*Quercus* spp.) dominated types. Other associations include hemlock (*Tsuga* sp.), beech (*Fagus* sp.)-oak-maple (*Acer* sp.), mixed mesophytic, swamp forests, and mixed floodplain forests.

Methods

Counting Methods

We located a total of 300 points in 12 study sites 4 km in diameter. Four study sites were located in each of three forest units that roughly correspond to the three dominant natural divisions of Indiana that fall within the Hoosier National Forest. In addition to stratifying by natural division, in each unit two sites were located in contiguous forest and two in forested areas fragmented by nonforest habitats. We permanently marked 25 points in each study site. We determined point locations by randomly laying a 250-m grid over a study site on a topographic map and selecting the 25 most centrally located points that were on the National Forest, in mature forest cover, and had no forest openings within 70 m. This sampling strategy may not be unbiased for monitoring population trends but we used it so we could relate bird abundances to landscape patterns as part of another study.

We counted birds during three 10-minute visits to each point between 0530 and 1000 hours, May 20 to June 20, 1991. Each of the three visits to a plot was by a different observer, so observer variability would be averaged over several observers (Verner 1987). We recorded all birds heard or seen and mapped their location on a data sheet relative to the center point, a 50-m radius, and a 70-m radius. We used superscripts after the first 6 minutes to indicate what minute of the count a bird was observed. The six different observers were either knowledgeable birders or recent ornithology students. To ensure competency in bird identification, observers received a training tape with songs or calls of 35 focal species and spent several days in the field with knowledgeable birders before monitoring. Focal species were common forest birds and predominantly Neotropical migrants or management indicator species for Hoosier National Forest.

Data Analysis

We included all bird detections (visual and aural, male and female) of focal species in the analyses. All calculations are based on the mean counts from the three visits to each of the 300 points. We calculated the mean and variance of the number of detections of each species from all points ($n = 300$). We estimated the sample size required to detect a 20 percent decline in abundance (one-way test) and difference in abundance (two-way test) at different probabilities of Type I and II error. Within the context of a monitoring study, Type I error is the probability of concluding that there is a decline or difference when in fact there is not, and Type II error is the probability of

[1] An abbreviated version of this paper was presented at the Workshop on Monitoring Bird Population Trends by Point Counts, November 6-7, 1991, Beltsville, Maryland.

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concluding that there is no difference or decline when in fact there is. We selected Type I error rates (α) of 0.05 and 0.10 and Type II error rates (β) of 0.10 and 0.20. Sample sizes were calculated from formulas for the difference in two means with equal variances and sample size (Snedecor and Cochran 1978:113). We calculated the Pearson correlation coefficient between estimated required sample size and species abundance (mean detections per point).

We calculated the mean number of species detected and the total individuals detected during 6-, 7-, 8-, 9-, and 10-minute counts to determine the most efficient count length. We used paired t.-tests to determine if the difference between 6- and 7-, 7- and 8-, 8- and 9-, and 9- and 10-minute counts were significant. The mean number of birds detected per hour of surveying was calculated from mean detection rates for 6- to 10-minute counts and travel times (noncounting time) of 6, 8, 10, 12, and 14 minutes. The mean number of detections per hour was equal to: D_t (60/CT + TT)), where D_t is the mean number of bird detections in a count t minutes long, CT is counting time in minutes, and TT is the travel time between points in minutes. We used bird detections per hour to evaluate count times because it incorporates both count time and travel time. Maximizing the number of individuals observed per hour (or morning) may maximize the probability of detecting species, result in the best estimates of relative abundance, and increase statistical power.

We compared the mean number of detections among counts on 50-m, 70-m, and unlimited-radius plots. We used paired t-tests to determine if the difference in the number of species detected within 50 m versus 70 m of a point, and 70 m versus an unlimited distance from a point, was significant. Because of the dependence in counts based on different radii from a common point, the significances of the *t*-tests may be liberal.

Results

We ranked the 21 most abundant species (species with >0.1 detections per point) by decreasing abundance (*table 1*). Estimated sample size requirements ranged from 101 for the most common species to over 2,000 for uncommon species (*table 1*). Sample size requirements for Type I and II error rates of ≤0.05 and 0.10 were approximately 90 percent higher than those for Type I and II error rates of ≤0.10 and 0.20. Sample size requirements for two-way tests were 22 percent higher than those presented in *table 1* for one-way tests. The estimated sample size required to detect a decline in the mean number of detections per point for each species was inversely related to a species mean abundance (r = -0.38, P = 0.02, n = 36).

Increases in the number of species detected and the total number of individuals detected were significant for each additional minute of counting time ($P \leq 0.01$) (*fig. 1*). Bird detections per hour of survey were greatest for counting times

Table 1--*Breeding bird abundance (mean detections per point) on Hoosier National Forest, Indiana, 1991, and the estimated sample size required to detect a 20 percent difference between two means (one-way test) when controlling for different levels of Type I and II error.*

Species	Mean n = 300	Standard Deviation	Required sample size I[1] ≤0.10 II[2] ≤0.20	Required sample size I ≤0.05 II ≤0.10
Red-eyed Vireo	1.49	1.438	208	398
Acadian Flycatcher	1.03	0.846	150	287
Scarlet Tanager	0.93	0.742	142	272
Ovenbird	0.92	0.771	155	297
American Crow	0.72	0.656	181	347
Tufted Titmouse	0.69	0.465	101	194
Wood Thrush	0.64	0.630	216	414
Eastern Wood-Pewee	0.63	0.611	210	401
Brown-headed Cowbird	0.53	0.557	244	467
Worm-eating Warbler	0.48	0.547	286	547
Pileated Woodpecker	0.40	0.372	189	362
Yellow-billed Cuckoo	0.37	0.372	219	419
Red-bellied Woodpecker	0.36	0.398	261	498
Indigo Bunting	0.33	0.445	400	764
Carolina Wren	0.25	0.380	520	994
White-breasted Nuthatch	0.21	0.298	437	835
Kentucky Warbler	0.16	0.319	817	1561
Great Crested Flycatcher	0.15	0.256	583	1114
Hooded Warbler	0.15	0.302	866	1655
Rufous-sided Towhee	0.14	0.322	1081	2066
Downy Woodpecker	0.12	0.205	632	1208

[1]Type I error.

[2]Type II error.

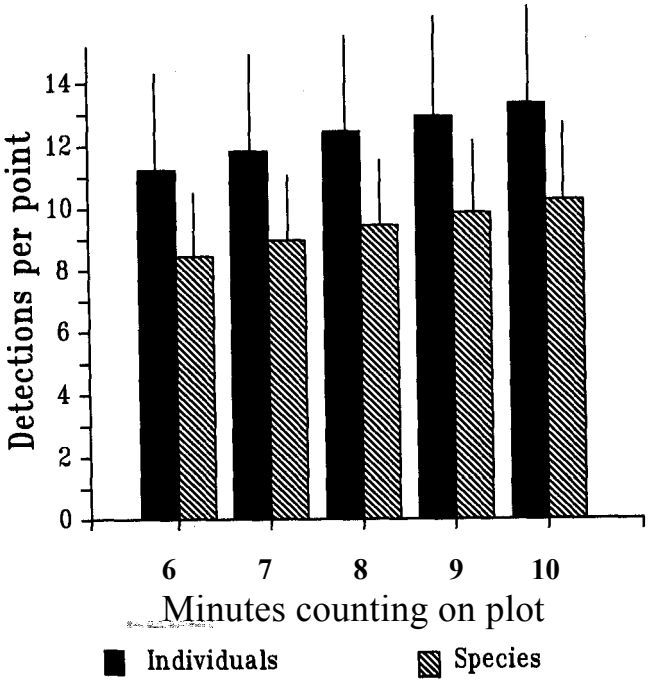

Figure 1--Mean (± 1 s.d.) number of individuals and species detected during 6- to 10-minute point counts of breeding birds on Hoosier National Forest, Indiana, 1991.

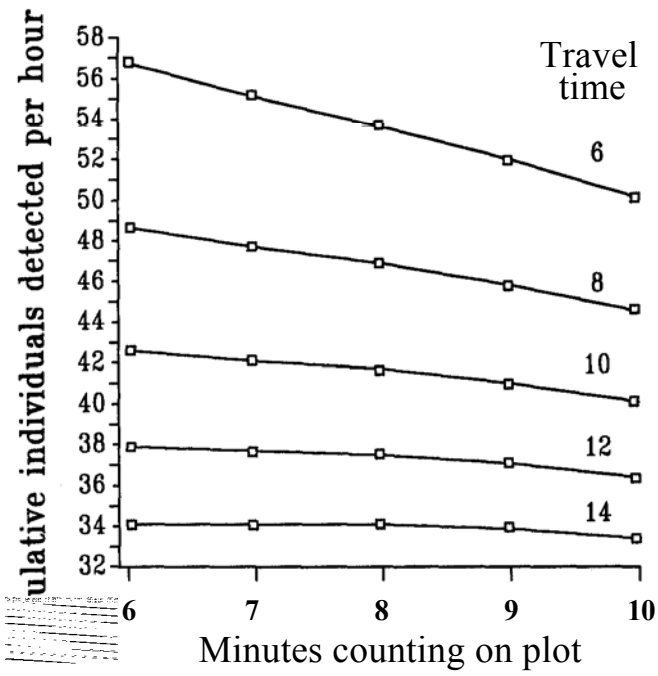

Figure 2--Estimated numbers of individual breeding birds detected per hour of survey for counting periods of different lengths and travel times on Hoosier National Forest, Indiana, 1991.

≤6 minutes when travel time was short, but counting times 6 to 8 minutes were most efficient for longer travel times (*fig. 2*). Actual travel time ranged from 5 to 30 minutes ($\bar{x}$ = 7.7, *s.d.* = 5.04).

More individual birds were detected on 70-m radius plots than on 50-m radius plots, and on unlimited-radius plots than on 70-m radius plots ($P \leq 0.01$) (*fig. 3*).

Discussion

Based on the mean and variance of species detections per plot, our monitoring system appears adequate for detecting declines in the 13 most abundant species studied. We determined sample sizes required to detect a difference between two means. Monitoring programs that are interested in identifying long-term trends through regression or correlation analysis may not require as many points. Sample size requirements and power estimates were similar to those reported by Verner and Kie (1988) for a similarly designed monitoring system in California. Two alternative approaches that address sample size concerns for less common species are to monitor management guilds instead of single species (Verner 1984) or to pick monitoring sites that have a high probability of detection for focal species (Verner 1983, 1986). Both these approaches should result in higher detection rates, less variability, and more statistical power or smaller required sample sizes.

Sample size estimates required consideration of Type I and II error and the magnitude of difference we wanted to detect. Type I error is the probability of concluding that there is a decline or difference when in fact there is not, and Type II error is the probability of concluding that there is no difference or decline when in fact there is. Even with liberal levels of Type I and II error (0.1 and 0.2), a large number of points were required to detect a 20 percent difference among means. We recommend that monitoring efforts pay particular attention to Type II errors because they may have more important consequences to the conservation of a species than Type I errors. We suggest considering Type I error rates as high as 0.1 to increase statistical power to ≥0.8 or lower the probability of Type II error to ≤0.2.

The objectives of a monitoring system also greatly affect statistical power. A monitoring project with an objective to detect species declines (a one-way test) will require fewer samples or have more power than a study with the objective to detect changes or differences in abundance (a two-way test). Sample size requirements increased 22 percent for a two-way test over those presented for a one-way test (*table 1*).

In addition to monitoring population trends, a second objective of a monitoring study may be to compare relative abundance in habitats or regions. Our sample size estimates suggest that large numbers of points could be required to detect these differences. However, habitat-specific studies will likely sample finer classifications of habitats and, hence, have lower variances and sample size requirements than those in *table 1*.

A counting time of ≤6 minutes resulted in the greatest number of individuals detected per hour for our average travel time, but differences were slight for 6- to 10-minute counts with travel times ≥8 minutes. Because differences were slight, we believe the most important factor affecting counting time should be regional standardization to ensure that results of different studies are comparable. Alternative study objectives might warrant longer travel times. Maximizing the

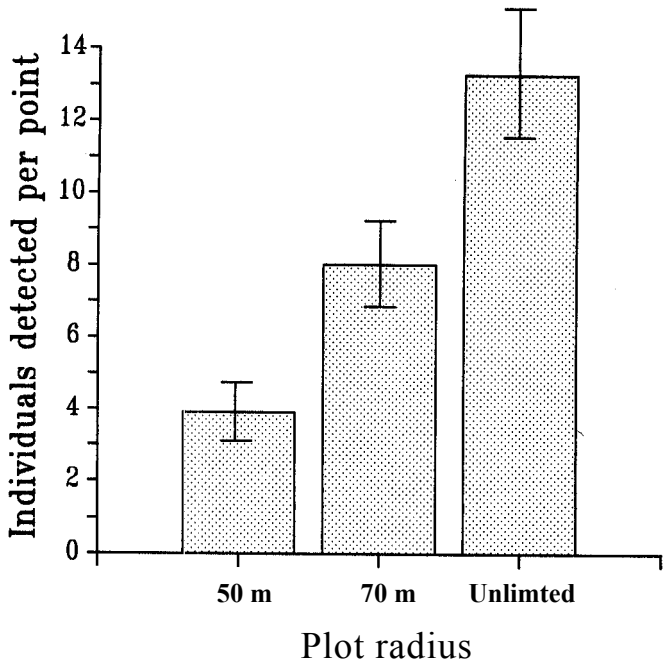

Figure 3--Mean (± 1 s.d.) number of individuals detected on plots of different radii during 10-minute point counts of breeding birds on Hoosier National Forest, Indiana, 1991.

number of individuals detected per hour of survey is appropriate when trying to minimize the number of points needed to detect population declines. Studies relating habitat or other characteristics of points to measures of bird abundance, however, should attempt to maximize the probability of detecting an individual because of the implications of failing to detect a species in a habitat when it is actually present. Under these circumstances longer counting times might be considered.

Unlimited-radius plots resulted in the highest detection rates and, therefore, probably will have the greatest statistical power. Counts on unlimited-radius plots could be affected by observer variability in hearing, but problems with distance estimation may cause comparable observer variability in fixed-radius plots. We recommend the use of unlimited-radius plots because they will result in more detections per plot and increased statistical power compared to 50- or 70-m radius plots. However, simultaneous recording of bird observations relative to a fixed radii also will allow analyses requiring a fixed size plot. Unlimited-radius plots may be undesirable when relating point characteristics to bird abundances because bird observations are not limited to a defined area that can be measured easily.

Acknowledgments

We thank the individuals who conducted bird counts and especially D. R. Whitehead for his cooperation and assistance with the study. R. L. Clawson, J. R. Probst, and S. R. Shifley provided helpful comments on the manuscript. This study was funded by the Wayne-Hoosier National Forest and the USDA Forest Service North Central Forest Experiment Station.

Fixed-Radius Point Counts in Forests: Factors Influencing Effectiveness and Efficiency[1]

Daniel R. Petit, Lisa J. Petit, Victoria A. Saab, and Thomas E. Martin [2]

Abstract: The effectiveness of fixed-radius point counts in quantifying abundance and richness of bird species in oak-hickory, pine-hardwoods, mixed-mesophytic, beech-maple, and riparian cottonwood forests was evaluated in Arkansas, Ohio, Kentucky, and Idaho. Effects of count duration and numbers of stations and visits per stand were evaluated in May to July 1991 by conducting approximately 1000 50-m (or 40-m) fixed-radius point counts. Most (>60 percent) species and individuals were detected in the first 4 minutes of the 8-minute counts, although accumulation did not cease even after extended 10-and 20-minute counts. Because of the tradeoff between count duration and number of stations that can be visited in a given period of time, counts of 6 minutes may be most appropriate for monitoring programs where maximizing number of individuals detected is important. Six stations within stands of eastern deciduous forest and 15 stations in riparian cottonwood fragments did not appear to completely document the bird community within those tracts. A single visit detected approximately 70 percent, and two visits 90 percent, of the species recorded after three repeated visits to a stand. Thus, two visits to a tract (or a single 20-minute count) may be necessary to ensure a relatively complete species list. Estimates of relative abundance from a single visit to a stand were highly correlated with cumulative estimates obtained after three visits for relatively common migratory, but not resident, species. In general, shorter count durations, fewer stations, and fewer visits were required to effectively sample migrants, as compared to residents. A greater number of stations are probably necessary when using fixed-radius compared with unlimited-distance counts because fewer individuals are detected in small, fixed-radius plots. Conversely, fixed-radius point counts provide a number of important advantages over unlimited-distance point counts in comparisons of relative abundances among habitats and sites. Moreover, fixed-radius plots may allow for greater flexibility in study design and also for better resolution of bird-habitat relationships because of the physical proximity between bird and habitat measurements.

Relatively little attention has been given to the use of fixed-radius point counts (Ralph 1981) and "circular plots" as defined by Verner (1985) to measure bird abundance, probably because of a perceived need to determine absolute densities of species. Absolute densities may be more reliably calculated from variable-distance techniques (Burnham and others 1980). Unadjusted fixed-radius point counts, however, may be effective in providing *indices* of abundance when the main objective is monitoring avian population trends (Hutto and others 1986, Verner 1985). Many uncertainties remain, however, as to the optimal design of a monitoring program based upon point counts.

During 1991, Martin, Petit, and Petit initiated a study of breeding birds in four forest types in three states as part of the Environmental Monitoring and Assessment Program (EMAP) of the U.S. Environmental Protection Agency. Concurrently, Saab and Martin commenced study of breeding birds inhabiting riparian cottonwood forests in Idaho. These studies were initiated for purposes other than evaluation of point count techniques. However, fixed-radius point counts were used in both studies to enumerate bird populations, providing us with the opportunity to evaluate some factors that may affect the efficacy of the technique. In this paper, we assess three factors that may influence the ability to accurately estimate temporal and spatial differences in population sizes and species richness of forest-dwelling birds: (1) duration of count, (2) number of stations per stand, and (3) number of visits to a point or stand. Those results are discussed with respect to the effectiveness of using this survey technique to monitor terrestrial birds at different spatial scales and in various forest types across widely separated physiographic regions.

Study Sites

Five forest types, which varied greatly in physiognomic and floristic characteristics, were surveyed in four states. Two forest associations were examined in Arkansas. Twenty-five oak-hickory forest stands were located in the Ozark Plateau region of northwestern Arkansas. Most of these sites were unfragmented and within the Ozark National Forest, although several small (4 ha to 20 ha) forest fragments outside National Forest boundaries were also used. Dominant tree species included northern red (*Quercus rubra*), black (*Q. velutina*), post (*Q. stellata*), and white (*Q. alba*) oaks, hickories (*Carya* spp.), flowering dogwood (*Cornus florida*), blackgum (*Nyssa sylvatica*), and red (*Acer rubrum*) and sugar (*A. saccharum*) maples. Canopy heights ranged between 12 m and 20 m.

Stands of the shortleaf pine-hardwoods forest type were chosen within the Ouachita and Ozark National Forests of western Arkansas. These 22 sites were dominated by shortleaf pine (*Pinus echinata*) in the overstory, although several oak species were regularly present. Understories varied in their vegetation densities and plant composition, but usually included blackgum, flowering dogwood, elms (*Ulmus*), and blueberry (*Vaccinium corymbosum*). Canopies were fairly tall (16-22 m) in these generally undisturbed sites.

Bird communities in mixed-mesophytic forests of southeastern Ohio and northern Kentucky were examined on

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45 sites. Most locations were within undisturbed tracts of Wayne National Forest, but several sites were positioned in disturbed forest fragments (5-20 ha). Common overstory trees included white and red oaks, tulip (*Liriodendron tulipifera*), and maples. Canopy heights ranged between 16 and 28 m.

Bird assemblages in beech-maple forests were studied on 36 sites in northeastern Ohio. Forest area varied greatly among these sites with nearly half occurring in fragments <30 ha in area. Characteristic trees were American beech (*Fagus grandifolia*), maples, red oak, tulip, black cherry (*Prunus serotina),* hickories, and musclewood (*Carpinus caroliniana*). Canopies were relatively tall (20-30 m).

Cottonwood (*Populus angustifolia*) gallery forests were studied at 48 sites along the Snake River in southeastern Idaho. Riparian forests in this area were partially fragmented; stands ranged from 1 ha to 200 ha, with most fragments <30 ha. Understory vegetation was dense and usually included red-stemmed dogwood (*Cornus stolonifera*) and willows (*Salix* spp.). However, several sites were disturbed because of livestock grazing or recreation activities such that understory vegetation was essentially nonexistent or highly patchy. Canopy heights were approximately 20 m.

Methods

General Survey Techniques

Bird surveys were conducted during the breeding season in Arkansas (May 5-21), Ohio and Kentucky (May 28-June 24), and Idaho (June 14-July 19). The same basic survey techniques were used in all five forest types, with the exception of several minor differences between Idaho and the other study areas. In pine-hardwoods, oak-hickory, mixed-mesophytic, and beech-maple forests, three to six stations (usually six) were positioned 150-300 m apart (typically 200 m) and at least 60 m (usually >100 m) from an edge. Number of stations (= points) per site varied according to patch size and were usually arranged in a 2 x 3 grid pattern. The identity, sex, and method of detection (call or sight) of all birds detected within 50 m were dictated into a portable cassette recorder. Counts lasted 8 minutes, but data collected after 6 minutes were noted in order to compare differences between 6- and 8-minute counting periods. A single visit was made to most sites, with the exception of one series of sites where three visits were made (see Effect of Number of Visits).

In Idaho, 1 to 5 or 15 stations were used per site depending on the stand area. Stations were located in the center of each stand and separated by 150 m. Observers counted all birds detected within 40 m and recorded observations on field forms. The radius of the census plot was smaller than in the other study areas because of dense understory vegetation (see Study Sites) and the narrow width of some of the cottonwood stands. Distinction was made between 6 and 8 minutes, and two visits were made to each site.

Effect of Count Duration

A series of 10-minute counts in mixed-mesophytic (n = 27) forests and 20-minute counts in beech-maple forests (n = 17) were made to examine the effect of count duration on species and individual accumulation curves. All new individuals detected during each 2-minute interval up to 10 minutes and, thereafter, in each 5-minute interval to 20 minutes were recorded. These data were also compared to the 6- and 8-minute counts for other forest types to help address the generality of those results.

One goal of any survey project should be to maximize the number of individuals detected (Burnham and others 1980). For point counts, this represents a tradeoff between the duration of counts and the number of stations that can be visited in a given time period. We used the technique described by Verner (1988) to estimate efficiency (E; cumulative number of individuals detected per hour) of different combinations of counting and noncounting times:

$$E = \frac{60}{C+N}\left(I_c\right), \qquad (1)$$

where, C = count duration (minutes), N = interval between successive counts (minutes), and I_c = cumulative number of individuals after C minutes of counting. Minimization of C and N maximizes the number of stations that can be visited in a given time period, thereby increasing sample sizes for statistical analyses. The mean and standard error of E for each combination of counting and noncounting times were estimated by applying results of each bird survey (I_c) to all possible combinations of C and N in Equation 1.

The Kolmogorov-Smirnov two-sample test was used to assess differences in the cumulative frequency distributions of migratory and resident species over extended 10- and 20-minute counts. Long-distance migratory species are those that overwinter, for the most part, south of 30° N latitude, whereas resident species are those that typically overwinter north of Mexico.

Effect of the Number of Stations Per Stand

Sites with 5 (n = 4) or 15 (n = 3) stations in Idaho and with 6 stations in all other forest types (range of n = 17-34) were used to examine the relationship between the number of stations and cumulative species detected. Stations were randomized before analysis (i.e., the first station surveyed within a site on a given day was not necessarily the first station in the analysis). The Komolgorov-Smirnov statistic was used to test for differences in accumulations of migratory and resident species with increased number of stations sampled within a site.

Effect of Number of Visits

Three visits were made to each of eight beech-maple and nine pine-hardwood stands to assess the effect of increased number of visits on total number of species sampled. These visits were made over a period of 2 to 3 weeks to minimize any temporal biases. Differences in cumulative number of species detected between one and two visits in those two forest types were compared with differences between one and two visits at cottonwood sites. Differences between the cumulative percentage of migratory and resident species detected after one visit and after two visits were assessed using t-tests.

Spearman's rank correlation coefficient (r_s) was used to examine whether estimates of species abundances obtained from one visit were closely related to estimates from three visits to sites in beech-maple forests. Beech-maple forests were used because we could more closely control observer variability compared to pine-hardwoods where more observers were used. For this analysis, we assumed that three visits provided an accurate measure of the relative abundance of a species. Correlations were calculated for 10 migratory and 10 resident species that were detected on ≥3 of the 8 sites. We correlated percentage of stations in which the species was detected (i.e., percent occurrence) in the first visit with: (1) percent occurrence averaged over three visits, and (2) maximum percent occurrence obtained in any one visit. We also related average number of pairs per station (i.e., relative density) in the first visit to (3) number of pairs per station averaged over 3 visits, and (4) maximum number of pairs per station obtained in any visit. In all of the analysis, the variables may not be independent. Results based upon number of pairs ([3] and [4]) were nearly identical to those of percent occurrence ([1] and [2]) because usually no more than one pair per species was detected at a single station. Therefore, we present only results based upon percent occurrence.

Results

Count Duration

Ten-minute counts were insufficient in both mixed-mesophytic and beech-maple forests to record all species and individuals that ranged across the 50-m radius sampling plot (*fig. 1*). In fact, accumulation of species and individuals did not lessen substantially even between 10 and 20 minutes of counting in beech-maple forests (*fig. 1*). Much of this latter accumulation is probably due to individuals moving into the plot boundaries during the count period. Accumulation curves may fairly accurately represent the species-effort relationships in other forest types, as the ratio of 6- to 8-minute counts of cumulative species and individuals were similar among beech-maple (0.90 and 0.90), mixed-mesophytic (0.90, 0.89), pine-hardwoods (0.93, 0.91), and oak-hickory (0.92, 0.91). Six-minute efforts in riparian cottonwoods (0.86, 0.86) were less efficient than those in other forest associations (analysis of variance; $F = 7.1$ and $F = 4.7$ for species and individuals; df = 4, 1015; $P < 0.01$; Student-Newman-Keuls multiple range test, $P < 0.05$). Long-distance Neotropical migrants were generally detected at a faster rate than residents in mixed-mesophytic forests, although this trend was not statistically significant in either forest type (Kolmogorov-Smirnov two-sample test; mixed-mesophytic, $D = 0.19$, $P > 0.10$; beech-maple, $D = 0.11$, $P > 0.10$; *fig. 1*).

Increases in noncounting time necessarily reduced available counting time per hour and caused fewer numbers of individuals to be detected for any given count duration (i.e., reduced efficiency; *fig. 2*). Duration of counts also affected numbers of individuals detected per hour, but had less influence than duration of noncounting time (*fig. 2*). With relatively short noncounting intervals (e.g., 3 or 5 minutes), the maximum number of individuals were detected (i.e., greatest efficiency achieved) with count durations ≤6 minutes in both mixed-mesophytic and beech-maple forests. As noncounting time increased, however, the most efficient counting times generally also increased. For example, in beech-maple forests, the maximum number of individuals was detected in 4- or 6-minute counts when the noncounting interval was 5 minutes. When noncounting time was increased to 20 minutes, count periods of ≥6 minutes were predicted to detect the greatest cumulative number of individuals (*fig. 2*). Migrants and residents exhibited similar trends in beech-maple forests, but migrants generally were more efficiently sampled with shorter counting times, as compared to residents in mixed-mesophytic forests.

Number of Stations

A single visit to fewer than six stations was not adequate to detect all species occupying our 15-ha to 20-ha plots in eastern deciduous forests, as no asymptote in numbers was reached (*fig. 3*). The adequacy of six stations can be evaluated

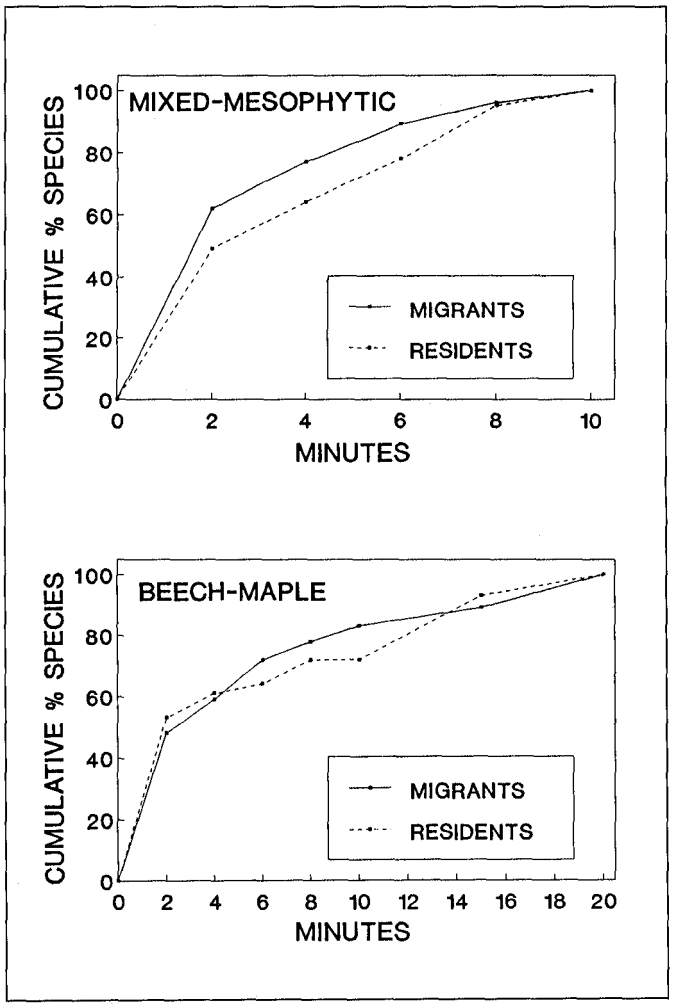

Figure 1-Species accumulation curves over time in mixed-mesophytic (top) and beech-maple (bottom) forests. Points in each curve represent the means from 27 counts in mixed-mesophytic and 17 counts in beech-maple forests.

only through a more exhaustive survey of each plot, either through spot-mapping to determine more accurate density estimates of species or through increased sampling effort within the plot (see Number of Visits). Single counts at fewer than five stations in relatively small stands (10-70 ha), or 15 stations in larger tracts (70-200 ha), also did not document the full species complement inhabiting riparian cottonwood forests in Idaho (*fig. 4*).

In general, migrants and residents exhibited similar patterns of species accumulations across stations. However, migrants showed a greater rate of increase than residents in mixed-mesophytic, oak-hickory, and large cottonwood stands, although only in mixed-mesophytic forests (Kolmogorov-Smirnov test; $D = 0.23$, $P < 0.05$) was the relationship significant (all other comparisons, $P > 0.10$).

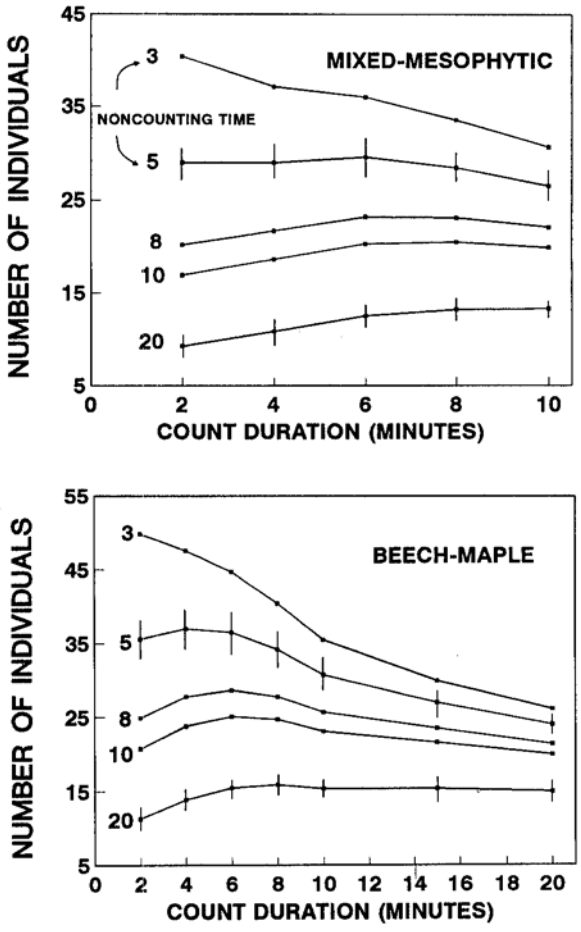

Figure 2--The expected mean number of individuals detected per hour of effort for different counting times as a function of different noncounting times (indicated by numbers next to curves within the graph) in mixed-mesophytic (top) and beech-maple (bottom) forests (see Methods: Equation 1). Vertical bars represent ±1 s.e. and are provided as examples of the typical variance about each mean.

Number of Visits

Three visits to beech-maple and pine-hardwoods sites appeared to be sufficient to record nearly all species found there during the breeding season (*fig. 5*), as evidenced by the lowered rate of accumulation after the second visit. A single visit detected 70 percent to 75 percent of the total species counted in three visits, whereas two visits averaged approximately 90 percent (*fig. 5*). These, of course, are liberal estimates of the completeness of our surveys because probably we would have detected additional species with additional visits to sites (Robbins and others 1989, Whitcomb and others 1981).

Long distance migratory species generally were detected at a faster rate than residents, but these differences were marginally significant in beech-maple forests (visit 1, $t = 1.8$, df = 14, $P = 0.09$; visit 2, $t = 2.4$, df = 14, $P = 0.04$) and nonsignificant in pine-hardwoods forests (visit 1, $t = 1.1$, df = 14, $P = 0.31$; visit 2, $t = 0.3$, df = 14, $P > 0.50$; *fig. 5*). In riparian cottonwoods where only two visits were made to a site, the ratio of cumulative species in visit 1 to visit 2 (0.72) was slightly lower ($F = 2.5$; df = 2, 58; $P = 0.09$) than that same ratio in beech-maple (0.79) and pine-hardwoods (0.80) forests. Those data suggest that more than three visits may be necessary in cottonwood stands to reach the same level of thoroughness achieved in beech-maple and pine-hardwoods forests in three visits. This apparent discrepancy may be the result of smaller survey plots or denser vegetation in the Idaho study or simply because of observer variability.

We compared the cumulative number of species detected in multiple 6-minute counts at one station with that found after a single 20-minute count at the same station to determine if a longer count duration could offset the potential need for repeat visits to a site. Three 6-minute counts ($\bar{x}$ cumulative species = 9.70 ± 1.78 s.d., $t = 4.03$, df = 32, $P < 0.01$) were superior, and two 6-minute counts (8.29 ± 1.77, df = 32, $t = 0.66$, $P > 0.50$) were comparable to a single 20-minute count (7.94 ± 1.98) in beech-maple forests.

Relative abundances of species estimated after a single visit were often highly correlated with estimates obtained after three visits for both indices of abundance (*table 1*). This is in part due to the three-visit data containing the single visit data; they are not independent. However, migrants (median $r_s = 0.82$, range = 0.15-1.0) consistently had larger correlation coefficients than did residents (median $r_s = 0.56$, range = -0.24-0.92).

Discussion

We found that point counts of ≤20 minutes duration do not record all species that range across the area sampled (Hamel 1984, Verner 1988), but complete enumeration of all species (individuals) at a given point is not essential for monitoring population trends. Rather, design of a program with the goal of monitoring population trends should, given other constraints, maximize the number of individuals encountered per unit effort. In this context, bird surveys on a site or local scale where travel (noncounting) time between stations is short (e.g., 3 to 5 minutes as in this study) are most efficient with counting durations between 2 and 6 minutes (Verner

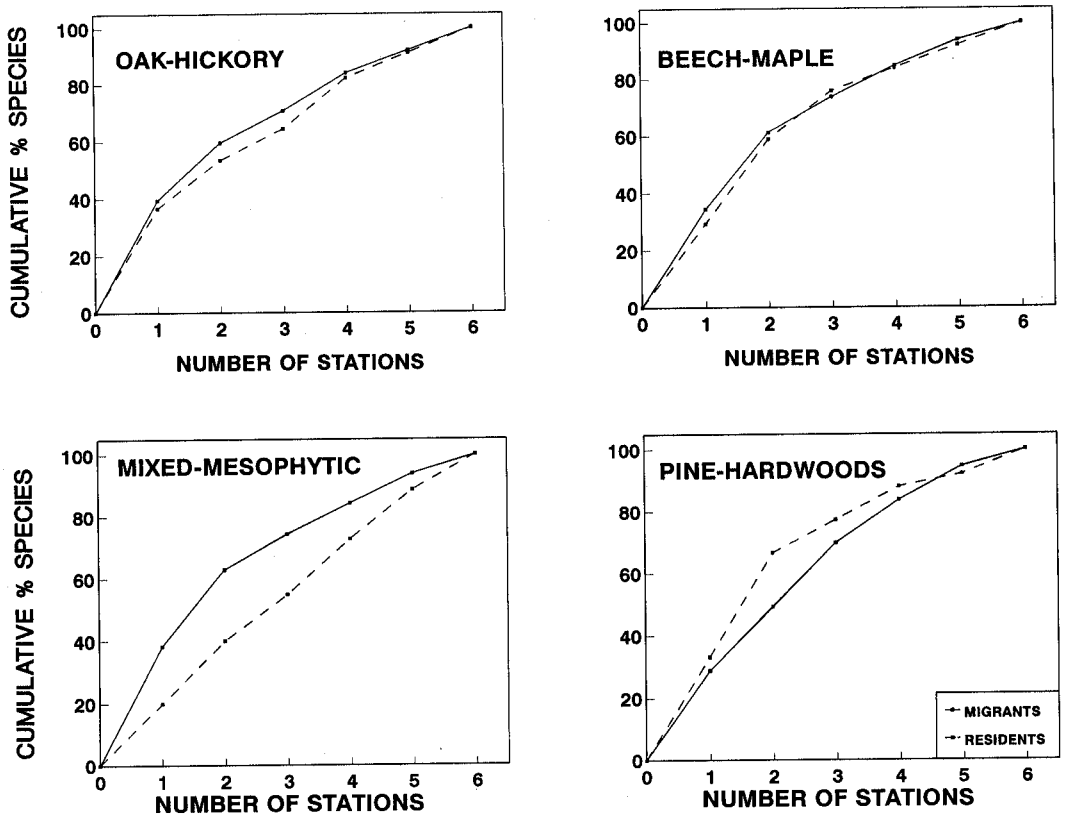

Figure 3--Effect of the number of stations on cumulative (mean) percentages of migratory and resident species detected in oak-hickory (*n* = 20 sites), pine-hardwoods (*n* = 17), mixed-mesophytic (*n* = 34), and beech-maple (*n* = 18) forests. Only sites containing six stations are included.

1988). For relatively large-scale monitoring programs where travel time between stations may be 10 to 20 minutes, however, 6- to 20- minute counts would sample the greatest number of individuals. We suggest that, when using fixed-radius circular plots, a 6-minute count duration would provide high efficiency for monitoring programs that vary in scale across forested areas (e.g., local versus regional). Verner (1988) and Fuller and Langslow (1984) recommended that counts last no longer than 10 minutes. Both Verner's (1988) and our study demonstrated, however, that counting periods longer than 6 minutes conferred little advantage in the accumulation of new individuals (*fig. 2*).

Furthermore, shorter counting periods (e.g., 6 minutes versus 10 minutes) would allow an observer to visit 15-35 percent more stations (depending on noncounting time between stations) during a morning of field work. Increases in sample sizes (numbers of stations) are thought to be more important in detecting population trends than is more thorough coverage of sampling units (Johnson 1981), although this tradeoff must consider inflated bias or variance associated with relatively short counting periods (Gates 1981, Hanowski and others 1990, Johnson 1981).

For studies in which bird-habitat relationships are of interest, counts of longer (>6 minutes) duration may be most appropriate because longer counts would more accurately reflect the presence or absence of a given species within the circular plot boundaries. The incorrect classification of a species as absent within a circular plot, when in fact it would have been present if count duration had been longer, could decrease the reliability of habitat-use models.

A single visit to fewer than 6 stations in mixed-mesophytic, beech-maple, oak-hickory, and pine-hardwoods forests, or to fewer than 15 stations in riparian cottonwood stands, did not record all species within the boundaries of sites. The addition of more stations, however, is not the solution to this deficiency in sampling. Additional stations placed outside the bounds of the plot originally defined (area bounded by the outermost stations) would sample an area not previously examined. A greater number of species is expected with an increase in area surveyed, such that an asymptote in species numbers would not be reached without extraordinary sampling effort over large areas (Hamel 1984, *fig. 3*). Additional points within the original plot (see above) would not be feasible because of the proximity of stations and the need to maintain independence of count stations. The most feasible means of ensuring more complete species counts are through repeated counts at stations or single counts of longer duration (see below).

On the basis of multiple visits to some sites, we found that one visit recorded approximately 70 percent, and two

visits 90 percent, of the total species detected in three visits. Species accumulated at a slightly slower rate in cottonwood habitats. The relative effectiveness of one visit to fixed-radius circular plots compares favorably with other survey techniques. For example, several studies have demonstrated that 50 percent to 90 percent of the species occupying a site are detected in a single visit (Anderson and Ohmart 1977, Haila and Jarvinen 1981, Hilden 1981, Jarvinen 1978, Mayfield 1981, Whitcomb and others 1981). One caveat, though, is that fixed-radius counts do not cover as much area per station and, therefore, do not record as many species as do variable- or unlimited-distance surveys.

The adequacy of a single visit to a site to estimate relative abundance of species is a critical consideration for a monitoring program, as it is often logistically difficult to incorporate multiple visits (Haila and Jarvinen 1981). Our results indicated that abundance estimates of common species from a single visit were often significantly correlated with that obtained after a more intensive effort, particularly for migratory species. Those data suggest that the single survey design, such as that employed in the EMAP portion of this study, may generate results that could be used as an index of relative abundance for many migratory species. Of course, some correlation is "built-in" to the analysis because of the dependence of the data sets that were correlated. To obtain reliable indices for resident species, however, more than one visit to a site is probably necessary as evidenced by the poor correlations between estimates of abundance after one versus three visits (*table 1*). An alternative to multiple visits may be to increase count duration during a single visit. We found that one 20-minute count yielded similar numbers of species as two 6-minute counts.

In general, fixed-radius point counts sampled migratory species more efficiently than residents, as evidenced by several instances in which migratory species accumulated at faster rates over time during counts (*fig. 1*), across stations (*fig. 3*), and across multiple visits to the same site (*fig. 5*). Migrants may be better sampled than residents with fixed-radius point counts for several reasons. First, migratory species in these forests generally defend smaller territories than residents (Whitcomb and others 1981). Larger territories lower the probability that an individual will occur within the radius of a station during a given count period. Secondly, migrants appeared to be more vocal during our study period, thereby potentially increasing their detection rate relative to residents within a count period. We do not believe the latter greatly influenced differences observed in detection of migrants and residents across stations or visits, however, because most species sing (or call) at least once during any 8-minute period (Robbins and others 1966). The small radius of the circular plots provided high reliability that all singing birds within plot boundaries were detected. Instead, the increase in residents with duration of the count probably reflects individuals moving into the survey plot. Also, several resident species (e.g., Black-capped Chickadee (*Parus atricapillus*), Tufted Titmouse (*P. bicolor*)) had completed breeding by the time we surveyed, and those species were

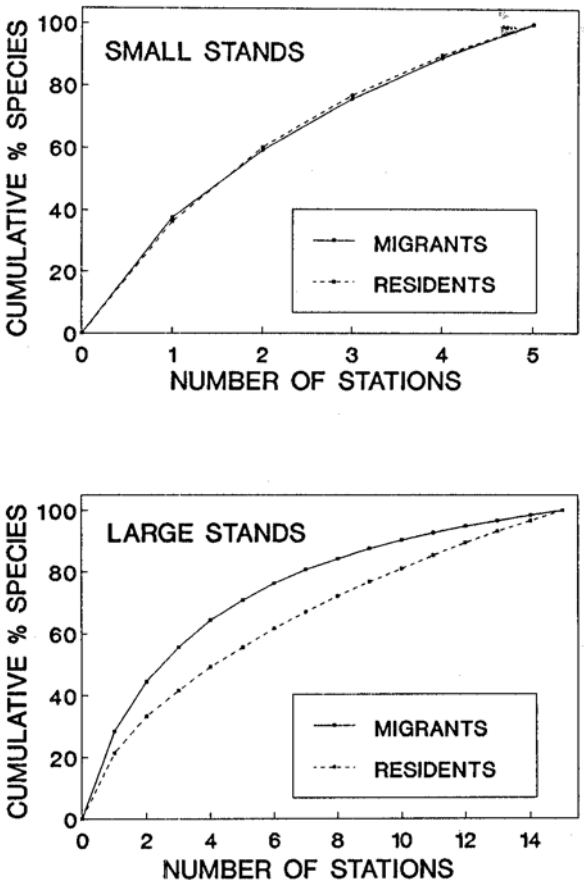

Figure 4--Effect of the number of stations on cumulative (mean) percentages of migratory and resident species detected in large (15 stations; *n* = 3) and small (5 stations; *n* = 4) stands of riparian cottonwoods. Values are based on 450 randomized draws for each station number.

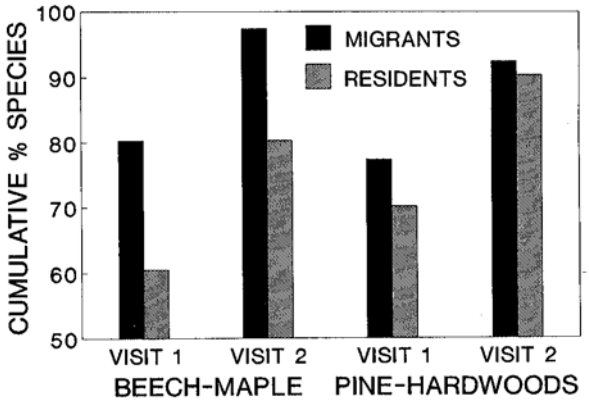

Figure 5--Cumulative (mean) percentages of migratory and resident species detected in the first two of three visits in beech-maple (*n* = 8) and pine-hardwoods (*n* = 9) forests.

observed moving about over large areas with fledglings. The nonvocal and wide-ranging habits of those species during the time period of the survey may have caused our estimates of relative abundances to be relatively unpredictable.

Comparison of Fixed Radius versus Unlimited-Distance Point Counts

Unlimited-distance point counts are often used to monitor annual trends in bird populations. Comparisons of relative abundance estimates among sites and habitats may be severely hampered, however, with unlimited-distance methods because of observer error due to (1) weather, (2) vegetation structure, (3) "saturation" effects, and (4) observer limitations. The fixed-radius point count method potentially provides a number of advantages over unlimited-distance point counts because of these biases.

Weather. Local weather conditions affect an observer's ability to detect individual birds, and this problem is exacerbated as distance between the surveyor and birds increases (Emlen and DeJong 1981). Indeed, Emlen and DeJong (1981) demonstrated that mean detection distance of forest birds decreased by approximately 20 percent in simulated windspeeds of 13-24 km/h compared with windspeeds of 5 km/h. Most recommendations suggest a maximum windspeed of between 12 and 20 km/h (Anderson and Ohmart 1977, Robbins 1981, Verner 1985). Detection threshold distances (maximum distance from which a bird can be heard) in Emlen and DeJong's (1981) study never were <50 m, and, therefore, little detection bias due to windspeed should exist in estimates of abundance if surveys are based upon 50-m fixed-radius plots.

Vegetation Structure. Vegetation structure influences the probability of detecting a bird (Emlen 1971, Oelke 1981, Rodgers 1981, Verner 1985, Verner and Ritter 1988), and birds are less easily detected with increasing distance from observers because of concealment by vegetation and increased sound attenuation due to obstruction (Waide and Narins 1988). Thus, across-habitat comparisons of bird abundance and species diversity are tenuous unless corrections are made to account for habitat-specific detectabilities (Burnham and others 1980, Emlen 1971, Ralph and Scott 1981, Reynolds and others 1980). Often, measures of abundances are calculated on the basis of the area within a basal radius (Reynolds and others 1980), the distance within which all, or nearly all, individuals are assumed to be detected. Basal radii generally range between 25 m and 75 m depending on vegetation structure (DeSante 1981, Franzreb 1981, Verner and Ritter 1988), and thus fixed-radius circular plots of ≤50 m radius may be an appropriate compromise between unlimited-distance counts and point count techniques that rely on correction procedures.

"Saturation" Effects. Saturation is a source of bias in bird counts, whereby the observer cannot accurately distinguish among individual birds because of their relatively high number within the area surveyed (Jarvinen and Vaisanen 1976, Walankiewicz 1977). Observers who focus on counting only a restricted set of species detect more individuals of those species than observers who attempt to count all species (Scott and Ramsey 1981). In fact, 30-50 percent of all singing males within hearing distance are likely to be overlooked in unlimited-distance point counts (Bart 1985, Bart and Schoultz 1984). Bias introduced through saturation is likely to be a greater problem for unlimited-radius point counts than for fixed-radius point counts because <7 individuals (all species combined) are typically detected at a 50-m (or less) radius station in forested areas (Fuller and Langslow 1984, Hutto and others 1986, Koen and Crowe 1987), whereas at least twice this number are often detected in a single unbounded plot (Anderson and Ohmart 1981; Hamel 1984; Scott and Ramsey 1981; Verner 1987, 1988).

Other Observer Limitations. Finally, limitations inherent to all observers introduce error into estimates of relative abundance (Cyr 1981, Enemar 1959, Mayfield 1966, Saunders 1934), but bias is likely to be more severe in unlimited-distance versus fixed-radius plots. For example, unequal hearing abilities among observers could lead to data that are not comparable (Cyr 1981, Faanes and Bystrak 1981, Ramsey and Scott 1981) because up to 95 percent of all birds in a survey are detected by hearing (Faanes and Bystrak 1981). Data in Ramsey and Scott (1981) suggest that even if observers with hearing thresholds ≥20 dB were excluded from monitoring programs, substantial differences in abundance estimates would still exist among observers attempting to detect birds singing >75-100 m away; audiological ability would not greatly affect counts made within 50 m of the observer. Given that the effective area surveyed can vary by up to an order of magnitude based *solely* upon hearing ability (Ramsey and Scott 1981), observer variability in unlimited-distance counts dramatically increases the chances of producing biased indices of abundance. The cumulative bias introduced into bird counts from the above sources of error is unknown. We believe, however, that use of relatively small fixed-radius plots is likely to minimize those errors in forested habitats.

Fixed-Radius Point Counts and Bird-Habitat Relationships

The relationship between bird populations and habitat characteristics is central to any monitoring program because effects of habitat changes must be separated from true demographic changes in population trends (Koskimies 1989, Martin 1992). Consequently, birds should be surveyed using a technique that allows population trends to be related directly to vegetation features at survey sites. Use of relatively small (≤50-m radius) fixed-radius plots allows measurement of vegetation characteristics in physical proximity to locations of birds. In contrast, habitat characteristics are recorded at increasing distances from areas actually used by individual birds when size of a survey plot increases (Lynch and Whigham 1984, Robbins and others 1989). This could lessen the accuracy and interpretation of subsequently derived bird-habitat relationships.

Fixed-radius circular plots may also be more easily incorporated into various research designs than unlimited-distance counts. For example, a 50-m fixed-radius plot requires a minimum area of only 100 m x 100 m (1 ha) of continuous habitat if the desire is to survey birds *within* the patch.

Table 1-*Correlations (Spearman's rank correlation coefficients) between the percent of stations per site in which a species was detected in one visit versus: (1) percent occurrence averaged over three visits and (2) maximum percent occurrence in any one of three visits. Similar correlations using number of pairs per station yielded nearly identical coefficients and so are not presented here. Data were taken from eight sites in beech-maple forests. Only species occurring on at least three of the eight sites are included.*

Species	Percent occurrence	Maximum percent
Migratory		
Acadian Flycatcher	0.86	0.81
Blue-gray Gnatcatcher	0.99	1.00
Cerulean Warbler	0.82	0.82
Eastern Wood-Pewee	0.91	1.00
Great Crested Flycatcher	0.82	0.59
Hooded Warbler	0.90	0.86
Rose-breasted Grosbeak	0.80	0.80
Red-eyed Vireo	0.70	0.83
Scarlet Tanager	0.17	0.15
Wood Thrush	0.88	0.82
Resident		
Black-capped Chickadee	0.69	0.54
Blue Jay	0.58	0.42
Northern Cardinal	0.66	0.53
American Crow	0.35	0.43
Downy Woodpecker	0.79	0.74
Hairy Woodpecker	0.55	0.50
Tufted Titmouse	0.57	0.42
White Breasted Nuthatch	0.21	-0.24
Red-bellied Woodpecker	0.92	0.86
Brown-headed Cowbird	0.59	0.59

Alternatively, an unlimited-distance plot with a "working" radius (distance; within which most birds are detected) of 150 m necessitates a minimum area of 300 m x 300 m (9 ha). Thus, nine times as much area is needed for a *single* survey point using the latter technique, whereas the same area would support four fixed-radius plots (spaced 200 m apart). A habitat area >17 ha would be needed to accommodate more than one independent unlimited-distance point count station (250 m between stations). Fixed-radius point counts may allow for greater flexibility in study design for studies other than large-scale monitoring programs, where stations usually are not placed within discrete patches.

Conclusions

The main drawback of fixed-radius point counts is that fewer individuals are sampled because of the smaller effective area surveyed compared to unlimited-distance and variable-distance techniques. Thus, a larger number of stations may be needed to adequately sample rare species (Blondel and others 1981, Dawson 1981, Verner and Ritter 1988). In addition, observers need training to estimate distance to the perimeter of circular plots. Accuracy of ±10 percent is attainable with several hours or more of practice (Scott and others 1981, Verner 1985).

No single point count technique is best for every type of research project. Rather, the merits and biases associated with each technique need to be reconciled with the goals of the study. We have presented some of the benefits of restricting analyses, in some cases, to survey data collected within a fixed area. The drawback of sampling fewer individuals in this technique compared to other census techniques is compensated by the greater probability of detecting all individuals within the sampling area, thereby reducing biases associated with differences in vegetation structure and observer variability. Furthermore, 50-m (or less) fixed-radius circular plots can be used across forest stands that vary greatly in size and shape. Finally, such area-restricted techniques provide a better means of examining habitat relationships.

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Influence of Survey Length and Radius Size on Grassland Bird Surveys by Point Counts at Williams Lake, British Columbia[1]

Jean-Pierre L. Savard and Tracey D. Hooper[2]

Abstract: We examine the effect of survey length and radius on the results of point count surveys for grassland birds at Williams Lake, British Columbia. Four- and 8-minute counts detected on average 68 percent and 85 percent of the number of birds detected during 12-minute counts. The most efficient sampling duration was 4 minutes, as long as travel time between points was under 15 minutes. Density estimates derived from 4-minute counts were significantly lower than 12-minute counts for most radius sizes. A larger radius yielded a larger number of detections but not always proportionally with the increase in area. This resulted in lower estimated density with an increase in radius size, especially when using maximum values at a given point. However for the Horned Lark (*Emeophilia alpestris*), the most abundant species, estimates of densities derived from individual counts did not differ significantly with radius size. A 100-m radius yielded nearly as many detections as an unlimited radius for most species, suggesting that it may be the most efficient radius to use in open habitats.

The estimation of bird abundance in a given area still presents a challenge for researchers. Three main techniques are currently used: spot mapping, point counts, and transects (Ralph and Scott 1981, Verner 1985). Each technique has its strengths and weaknesses; however, in recent years point counts have been widely used.

In a pilot year of a study of grassland birds in Williams Lake, British Columbia, we examined the efficiency of the point count technique in estimating the relative abundance of birds in a grassland setting. In this paper, we compare the number of bird detections obtained with various survey lengths and survey radii and attempt to identify the most efficient survey length in terms of the number of detections per hour.

Methods

Our study area centered around Williams Lake, British Columbia. The grasslands sampled were located within the Fraser River Basin in the Interior Douglas-fir and Bunchgrass biogeoclimatic zone (Krajina 1969, British Columbia Ministry of Forests 1988).

Throughout 12 different grassland areas, 48 points were established. Point counts had a radius of 100 m and were placed at least 300 m apart. Counts were made for three consecutive 4-minute periods at each point (12 minutes total per point), and the distance of all bird detections from the center of the point was recorded. In each 4-minute period, we started the count over and recorded all detections during that 4 minutes. We also noted, however, whether the individual detected in the second or third period had been detected in the first or second period. Thus, we could determine the number of detections in a 4-, 8-, and 12-minute count as well as divide the 12 minutes into three 4-minute segments.

To compare the relative efficiency of point counts of different lengths, we used the total number of birds detected per hour of survey time and compared this value for different travel time between points. Nonparametric tests (Kruskal-Wallis and Mann-Whitney) were used in statistical analysis. We calculated, for each of the four surveys, the average number of birds detected per point (n = 48) during 4-, 8-, and 12-minute counts. We multiplied this value by the number of points that could be surveyed in 1 hour, given various travel times. The sample size for each comparison is thus four.

Points were located away from fencelines, crop fields, woodlands, forests, dense shrubbery, and wetlands to avoid edge effects. Each point was surveyed on four different mornings between 0530 and 1000 from May 8 to June 17. Analyses were done using the number of bird detections at a given point without using correcting factors.

When more than one survey is carried out at a given point, all surveys are often combined for a given point using either the mean, the median, or the maximum. Use of the mean considers all counts as comparable estimates, the median considers only the middle value(s) excluding high and low counts, and the maximum takes the highest value. Here, we used either single counts as replicates or the maximum as the best estimate of the abundance of a species at a given point. As our surveys were conducted well after migration had finished, maximum values may represent a realistic approximation.

Results

Relative Abundance of Birds

Fourteen bird species were recorded in the point count surveys (*table 1*). Horned Larks were dominant in terms of total numbers recorded and in frequency of observations. Vesper Sparrows (*Pooecetes gramineus*) were second in abundance, followed by Long-billed Curlews (*Numenius americanus*) and Savannah Sparrows (*Passerculus sandwichensis*). All other species occurred in low numbers at fewer than 5 of the 48 point locations. Mountain Bluebirds (*Siala currucoides*) and Western Meadowlarks (*Sturnella neglecta*) occurred mostly along grassland edges. Because these edges were not sampled, relative abundance of these species was probably underestimated.

Effects of Point Count Duration on Individual Count Results

Four- and 8-minute counts averaged 68±3 percent and 90±1 percent of the 12-minute counts for the total number of

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Table 1--*Numbers and species of birds recorded by the point count method. The number of points at which species was recorded (n) = 48.*

Species	Number recorded	Frequency observation	Number per point
Horned Lark	210	47	4.38
Vesper Sparrow	49	26	1.02
Long-billed Curlew	24	16	0.50
Savannah Sparrow	11	8	0.23
Common Raven	11	3	0.23
European Starling	8	4	0.17
Mountain Bluebird	4	3	0.08
Western Meadowlark	4	4	0.08
Brewer's Blackbird	4	1	0.08
American Crow	1	1	0.02
American Robin	1	1	0.02
Brewer's Sparrow	1	1	0.02
Killdeer	1	1	0.02
Northern Harrier	1	1	0.02
Total	330		

birds, and 87±5 percent and 91±3 percent for the number of species (*table 2*). Generally, 4-minute counts were nearly twice as variable: (based on coefficients of variations) as 8-minute counts (*table 2*). The use of the maximum number of birds seen at a given point doubled the overall number of detections, and 4- and 8-minute counts recorded 75 percent and 89 percent of the birds seen in a 12-minute count.

Four- and 8-minute counts recorded an average of 68±4 percent and 84±3 percent of the total number of Horned Larks, and 73±6 percent and 87±4 percent of the Vesper Sparrows recorded during 12-minute counts (*table 2*). Patterns for less numerous species like Savannah Sparrows and Western Meadowlarks were inconsistent between counts, probably because of small sample sizes.

For travel times under 8 minutes, 4-minute counts yielded significantly more detections per hour than 12-minute counts (Mann Whitney, $P < 0.05$, *fig. 1*). For travel times under 2 minutes, all count lengths differed in their yield of detections per hour with the smaller length yielding significantly more detections ($P < 0.05$). No significant differences were found in the number of bird detections per hour between 8- and 12-minute counts or between 4- and 8-minute counts for travel times between 4 and 32 minutes. For travel times over 20 minutes, however, 4-minute counts yielded significantly fewer detections than 12-minute counts ($P < 0.1$ for 22, 24 minutes and $P < 0.05$ for 26 to 32 minutes). Our ability to establish the presence or absence of Horned Lark and Vesper Sparrow at a given point did not improve greatly with count length (*table 2*).

Effect of Point Count Radius on Count Results

Detections of total numbers of birds and numbers of species increased as point count radius increased (*fig. 2*). There was an obvious disturbance created by the observer's presence though, as no birds were detected within 10 m of the observer (*fig. 2*). For three of the four most common species-Horned Lark, Savannah Sparrow, and Vesper Sparrow-a radius of 100 m provided almost as many detections as an unlimited radius (*fig. 3*). However, more than three times the numbers of Long-billed Curlews were recorded with an unlimited radius as with a 100-m radius. Patterns

Table 2--*Influence of count duration on the number of detections.*

	Total number of birds			Total number of species			Horned Lark			Vesper Sparrow			Long-billed Curlew		
		Percent of n[b]			Percent of n			Percent of n			Percent of n			Percent of n	
Survey	*n*[a]	4 min	8 min	*n*	4 min	8 min	*n*	4 min	8 min	*n*	4 min	8 min	*n*	4 min	8 min
1	168	65	81	7	86	86	124	60	78	18	67	78	13	85	100
2	145	72	83	8	75	88	96	74	84	34	74	88	7	71	100
3	180	73	91	8	75	88	142	75	90	21	90	95	5	20	100
4	173	63	86	8	100	100	125	62	84	21	62	86	11	55	100
x		68.3	85.3		84.0	90.5		67.8	84.0		73.3	86.8		57.8	100
Standard Error		2.5	2.2		5.9	3.2		3.9	2.5		6.1	3.5		14.0	-
Maximum[c]	330	75	89	14	86	93	210	77	90	49	78	90	24	67	92
Frequency[d]							47	100	100	26	96	96	16	81	94
Coefficient of Variation		7	5		14	7		12	6		17	8		48	-

[a] *n* = total of 48 points for a 12-minute count at each point.
[b] 4- and 8-minute counts as a percent of the 12-minute count.
[c] We used the higher of the four counts at a given point and then summed it up for the 48 points.
[d] The number of points at which the species was recorded; *n* = number for a 12-minute count with percent seen in 4- and 8-minute counts.

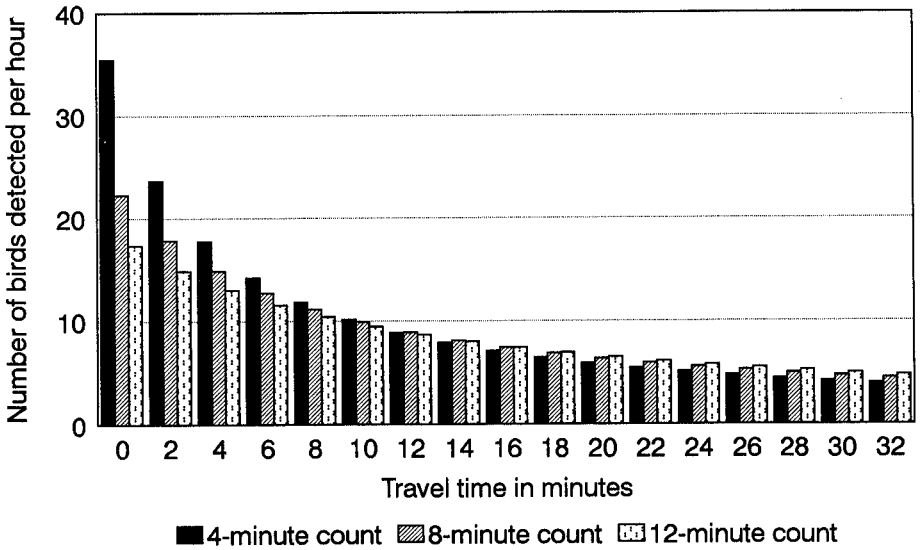

Figure 1--Comparison of efficiency in terms of the number of birds detected per unit of time of point counts of various duration.

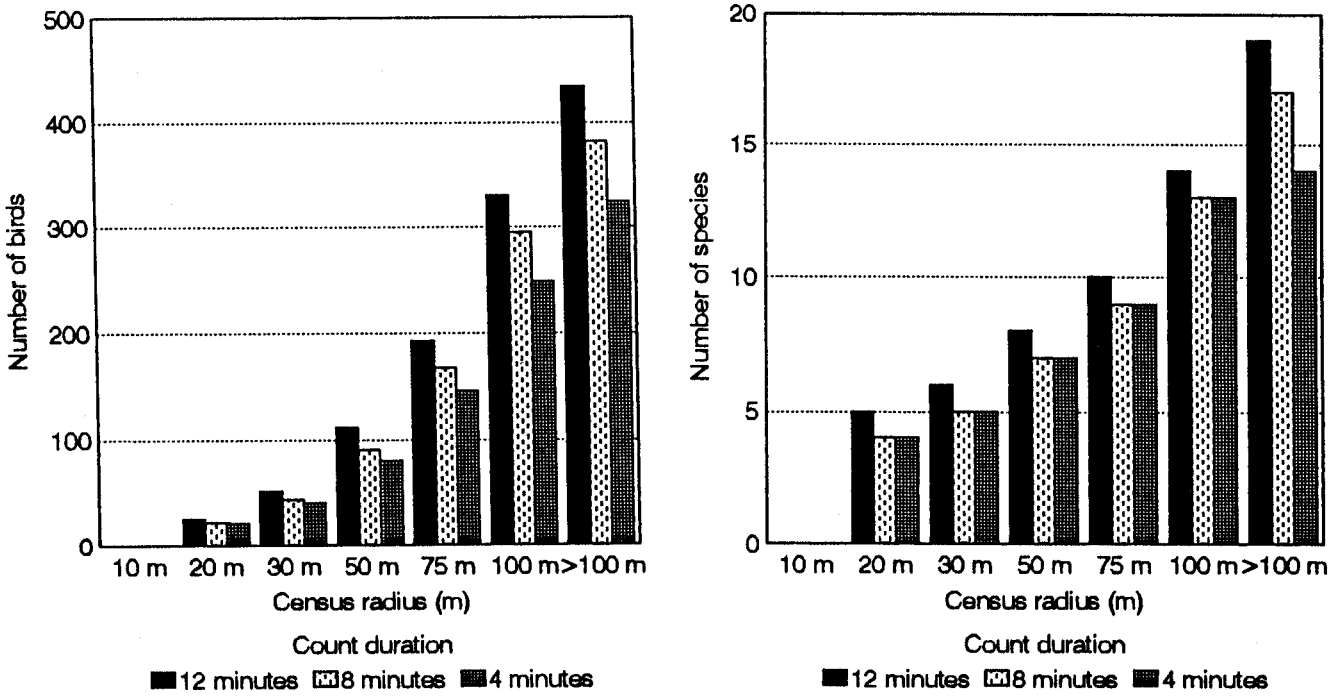

Figure 2--The total number of birds and number of bird species detected by variable point count radii during 48 point counts (using maximum values).

were similar for all three survey durations for any one species. Detections for most species increased more with radius size than with count length (*fig. 3*).

Density estimates based on different radius sizes and count duration were analyzed for the Horned Lark and Vesper Sparrow using maximum values (*table 3*). Density estimates of Horned Larks decreased with increasing radius size, especially between 50 m and 75 m. Radii of 20 m and 30 m provided the highest and somewhat similar estimates. Density estimates of Vesper Sparrows were highest at 30 m, then decreased with increasing radius size. The lower density with 20-m radius may reflect observer avoidance by the species. Shorter counts yielded lower densities than longer counts.

We recalculated Horned Lark densities using individual counts. Density estimates were nearly one-half those based on

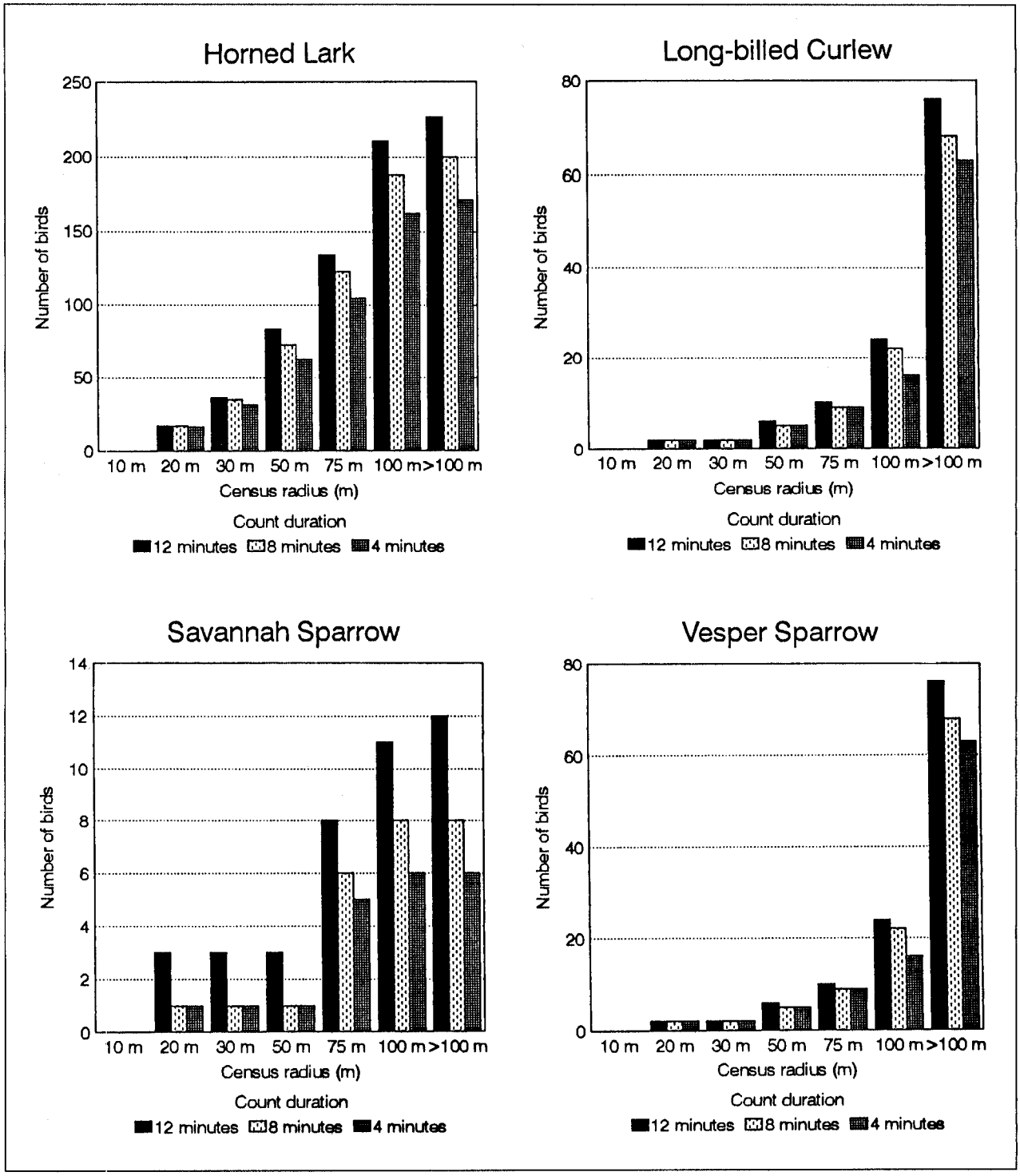

Figure 3--The number of Horned Larks, Long-billed Curlews, Savannah Sparrows, and Vesper Sparrows detected by variable point count radii during 48 point counts (using maximum values).

Table 3--*Density estimates (number of birds per ha) of Horned Lark and Vesper Sparrow derived from different point count radii and count length (mean of 48 points, using the maximum of 4 counts).*

Species	Count length	Radius (m) 20	30	50	75	100
	min					
Horned Lark	4	106.1	91.4	65.8	49.0	43.0
	8	112.7	103.2	76.4	57.5	49.9
	12	112.7	106.1	88.1	63.2	55.7
Vesper Sparrow	4	13.3	14.7	8.5	9.9	10.1
	8	13.3	14.7	9.5	11.3	11.7
	12	13.3	23.6	15.9	14.6	13.0

Table 4--*Density estimates of Horned Lark estimated from 4- and l2-minute counts using individual counts (Mean ± s.e., n = 4).*

Count duration	Radius (m) 30	50	75	100
4-minute	29.5+6.3	23.9+2.3	21.8+1.1	21.8+2.2
12-minute	37.5+4.2	36.4+3.6	31.5+1.7	32.3+2.5
P[a]	0.14	0.02	0.02	0.04

[a] Mann-Whitney Test

maximum values (*table 4*). Density estimates based on 4-minute counts were lower than those derived from 12-minute counts for 50-m, 75-m and 100-m radii (Mann-Whitney $P < 0.05$). Estimates based on individual counts did not vary significantly with radius size either for 4-minute counts (Kruskal-Wallis $P = 0.52$) or for 12-minute counts ($P = 0.53$), although the significance level of the test is approximate due to dependence in the data.

Discussion

Results of bird counts in this study were typical for grassland habitats. In general, grasslands provide habitat for about two to six passerine species and, occasionally, as many nonpasserine species (Cody 1985).

As many curlews were detected in 8-minute counts as in 12-minute counts at a given site; but for all other species, 12-minute counts detected more individuals. As expected, 12-minute counts yielded more detections than shorter counts. This is due in part to increased detection of less conspicuous individuals, but also to movement of birds within the census area (Verner 1985). Because of the openness of the habitat and the low number of species present, count duration had less effect on the number of species detected. Most species present at a given point were detected within the first 4 minutes of the count, which is likely due to the openness of the habitat and the low number of species. In closed habitats with more species, such as forests, this may not be the case.

By far the most efficient sampling unit in terms of number of birds detected per unit of time were 4-minute counts. Using this criterion, whenever you have to compromise between the number of points and the count duration, you should maximize the number of points. However, when habitats are restricted and travel time between points is over 15 minutes, efficiency can be increased by using longer counts. Fuller and Langslow (1984) reached similar conclusions for birds in British habitats. Also, in cases where birds' presence or relative abundance has to be related to habitat features at a given census point, longer counts may be more appropriate, especially in view of the greater variability of shorter counts.

Caution is needed when using point counts to estimate breeding density. Point count estimates vary with the radius used, the species, the area, and the actual density of the species (Bollinger and others 1988, DeSante 1986, Verner 1985, Walankiewicz 1977). DeSante (1986) found that 48-point count stations could distinguish common from rare species but that nearly three times more effort was needed to obtain reliable estimates of the relative abundance of the most common species. Our results are, therefore, not surprising given our small number of points.

Larger radius yielded a larger number of detections, but not always proportionally with the increase in area. This resulted in significant differences in calculated bird density with density decreasing with radius size, especially when using maximum values. In the case of the Horned Lark, density estimates derived from individual counts did not differ significantly with radius size. It remains to be seen, however, if this applies to other species and other habitats. The difference in density estimates for counts of different length indicates the difficulty of deriving real density estimates from point counts. When real density estimates are sought, 4-minute counts will not be appropriate. The absence of detection within the first 10 m from the observer reflects observer effect in this open habitat and cautions against the use of small radius in point counts. A 100-m radius yielded for most species nearly as many detections as an unlimited radius, suggesting that it may be the most efficient radius in this open habitat.

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Evaluating Point Count Efficiency Relative to Territory Mapping in Cropland Birds[1]

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Abstract: Species richness, composition, and abundance of farmland birds were compared between point counts (50-m, 100-m, and 150-m radius half circles) and territory mapping on three 40-ha plots in Québec, Canada. Point counts of smaller radii tended to have larger density estimates than counts of larger radii. Territory mapping detected 10 species more than 150-m radius point counts. Territory mapping at 150-m radius detected more birds per species than point counts; relative abundances, however, were similar. Bird density is probably optimally estimated with a 100-m radius point count. After four visits, more than 80 percent of species and birds from 7 visits had been detected by 150-m radius point counts. Our modified point count method appears to be accurate enough to reflect the farmland avifauna characterized by more labor-intensive methods such as territory mapping.

Several methods have been widely tested to estimate the number of birds in terrestrial habitats. Papers in Ralph and Scott (1981) give a broad overview of such methods and compare many of them. Territory mapping has usually been considered the standard technique against which most bird census methods have been compared (Anonymous 1970). Territory mapping is extensively used in Britain to monitor farmland avifauna (O'Connor and Shrubb 1986). In North America, territory mapping is used in the breeding bird census program to collect habitat specific information. The point count, or "Indice Ponctuel d'Abondance, IPA" method (Blondel and others 1970, 1977), has been widely used in Europe and North America. However, few attempts have been made to use it extensively in open landscapes. Within the larger framework of a Canadian Wildlife Service project to evaluate the impacts of agricultural practices on the avifauna (Rogers and Freemark 1991), a modified point count method was used to enable a larger number of plots to be surveyed (Freemark and Rogers, in this volume, Verner 1981).

This paper compares species composition, richness, and abundance estimates of cropland point counts at varying survey distances. Territory mapping is used to provide complete census data for comparison.

Methods

Three 40-ha plots were chosen in the agricultural landscape of the Municipality of Wotton (lat. 45°45'N., long. 71°45'W.) in the province of Quebec, Canada. The surveys were conducted between 0500 and 1000 (e.s.t.), between June 1 and July 13, 1990. One observer performed all surveys. The surveys were conducted in good weather with wind equal or lower than Beaufort 3, no heavy or lasting rain.

Visits to plots were scheduled so that surveys on each began at different times in the morning on consecutive visits to reduce biases related to time of day or season. For the territory mapping, each plot was visited for about 1.5 hours, eight or nine times each plot, for a total of 38.25 person-hours. Observations were accurately reported on plot maps. The number of territories was calculated at the end of the season by studying the composite maps of all visits for each species. A territory was counted as one when its boundaries were within the plot; it was counted as 0.5 when about one-half was within the plot, and 0.25 when found only along the edge of the plot. Bird abundance was equal to the total number of territories delineated.

Three half-circle point counts were located in each of the three plots (Freemark and Rogers, in this volume). The three point count locations per plot were selected to represent the crops and edge habitat of each plot and were at least 250 m apart on each plot (*table 1*). Point counts were conducted from the edges of fields (Freemark and Rogers, in this volume). All birds seen or heard within a 150-m radius semicircle were counted during 10 minutes, with data subdivided into radii of 50 m, 100 m and 150 m from the observer. Three to five point counts were surveyed each day during mapping surveys, the data of which were also included to generate the maps. Each point was visited five to seven times for a total of 50 point counts, or 8.33 person-hours.

The number of territories at each point-count location (hereafter referred to as mapped points) was determined from the composite maps of each plot using the same conventions as above. Since the points covered 31.77 ha of the 120 ha, the amount of time spent for territory mapping on the points can be estimated as 10.13 person-hours.

For accumulation curves, the data included all points within the three plots as well as those from eight comparable extra point counts from another study on a different farm located in hay (six points) and oat (two points) fields in Coaticook (*fig. 1*). The extra points were added to increase sample size. The points were counted during the same season as above without territory mapping. The calculations were as follows: the number of new species or individuals on subsequent visits were calculated then averaged for all points. For any visit, the number of individuals is the summation of individuals of each species above the previous number of individuals on any previous visit. Thus, the cumulative summation for each point corresponds to the summation of the maximum number of individual birds per species throughout all surveys for that point.

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Table 1--*Number of species detected with territory mapping and point count methods on half circles of different radii.*

		Number of Species					
	Radius:	0-50 m		0-100 m		0-150 m	
	Method:	Map	Point	Map	Point	Map	Point
Points	Crop		Counts		Counts		Counts
A1	Hay	10	8	15	13	20	19
A2	Hay	7	7	10	8	14	13
A3	Barley	10	8	15	14	17	15
B1	Hay and barley (50-50)	8	6	12	11	19	14
B2	Hay and pasture (50-50)	10	9	17	14	27	21
B3	Hay	7	5	15	12	23	20
C1	Hay	11	9	16	11	17	14
C2	Hay and barley (50-50)	3	2	8	6	18	17
C3	Hay and mixed cereals (50:50)	6	5	16	10	26	16
Paired t-test (n=9)		5.9648*		4.8564*		3.550*	
Mean		8.0	6.6	13.8	11.0	20.1	16.6
Total		27	23	35	31	49	39
Ha surveyed/point		0.39		1.57		3.53	
Mean difference/ha		3.6		1.78		0.99	
Total difference/ha		10.2		2.5		2.8	

* indicates $P < 0.05$

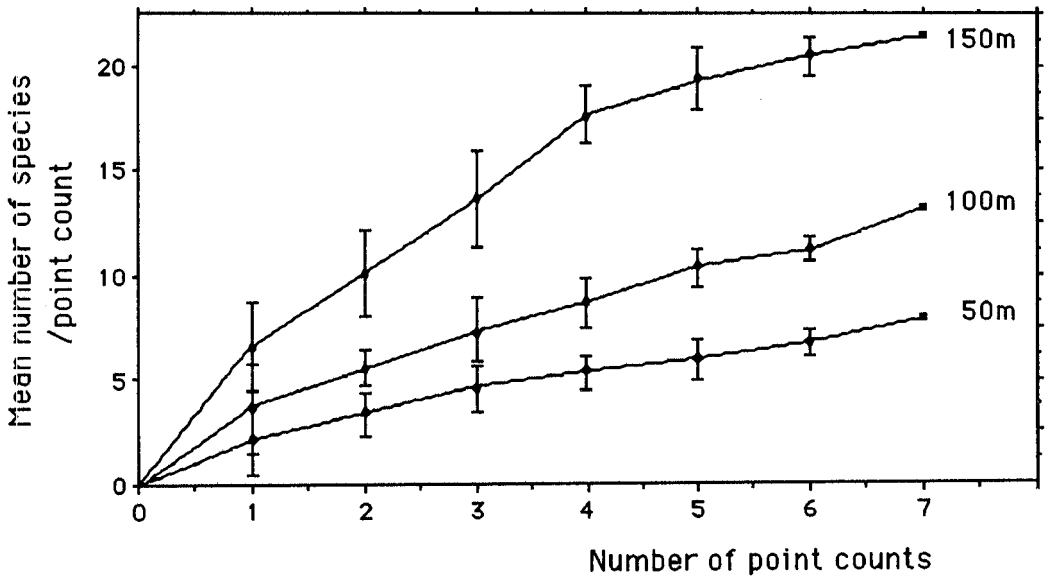

Figure 1--Species accumulation curves for point count include 8 point counts on an additional farm. See text for details.

We compared species richness, composition, and abundance between point counts and mapped points of different radii. We also compared absolute and relative abundance per hectare (proportion in percent of the total number of individuals of all points counted or territories mapped belonging to each species of a point or of a plot) between point counts and mapped points or between mapped points and the plots.

We used paired *t*-tests ($p < 0.05$) to compare the densities at different radii. Statistical comparisons are confounded to some degree because the same data are used in point counts of different radii.

Results

Species Richness

Territory mapping at point count locations detected more species than point counts on 50-m, 100-m and 150-m radius semicircles (*table 1*). The number of species detected increased with greater distance from the observer for the

point counts or larger area for territory mapping. More species were detected by territory mapping compared to point counts at different radii (*table 1*). Comparing the species number between methods per hectare surveyed by each radius, the methods were most similar on a point-by-point basis for the 150-m radius (mean difference/ha = 0.99) and in total for the 100-m radius.

After seven point counts, the number of species per point was approaching an asymptote for only the 150-m radius (*fig. 1*). At seven counts, the numbers of species for the 50-m and 100-m radii were only 40 percent and 68 percent of that for the 150-m radius. During the first four counts, species number increased most rapidly for the 150-m radius. After four counts, more than 80 percent of its total number of species had been detected for the 150-m radius, 66 percent of its total number of species had been detected for the 100-m radius, and 68 percent of its total number of species had been detected for the 50-m radius.

Species Composition

At the 150-m radius, 10 species detected by territory mapping were not detected by point count (*table 2*). These species tended to have large territories (e.g., Turkey Vulture (*Cathartes aura*)), to breed in adjacent edge habitats (e.g., Gray Catbird (*Dumetella carolinensis*)) or off-site habitats (e.g., Black-capped Chickadee (*Parus atricapillus*) and Ring-billed Gull (*Larus delawarensis*)), and to have low abundance (<<1 territory per point).

Abundance

Although more birds per species were observed with territory mapping at the 150-m radius than with point counts, the differences were not large in most cases (*table 2*). Relative abundances of species were even less different between methods (*table 2*). For most species, the number of territories on the points is larger than the mean number of birds counted per point. For eight species, the reverse is true, the four most abundant ones being Song Sparrow (*Melospiza melodia*), Common Yellowthroat (*Geothlypis trichas*), Common Snipe (*Gallinago gallinago*), and Cedar Waxwing (*Bombycilla cedrorum*). During any count, groups of birds might be seen that increase the mean number of counts without providing useful data for mapping territories.

After seven point counts, the number of birds per point was approaching an asymptote for all radii. At seven counts, the number of birds for the 50-m and 100-m radii were only 35 percent and 68 percent of that for the 150-m radius. During the first four counts, the number of birds increased most rapidly for the 150-m radius. After four counts, more than 80 percent of all birds had been detected for the 150-m radius, 71 percent for 100-m, and 57 percent for 50-m.

Ten species for which territories could be clearly defined were selected for comparison of point count bird density between radii, because mapping on semicircle locations included only parts of many territories and provided only a rough approximation of abundance for most species. For these 10 species, point count bird density (mean number of birds per 10 ha) differed significantly between 50-m and 100-m,

Table 2--*Species composition and abundance surveyed by point counts or territory mapping within a 150-m radius of the observer.*

Species (n=49)	Point counts		Mapped points	
	Mean number birds/ point[1]	Percent of total	Total number of territories	Percent of total
Bobolink	41.39	24.59	52.50	24.65
Savannah Sparrow	30.54	18.14	43.75	20.54
Red-winged Blackbird	12.47	7.41	16	7.51
Horned Lark	6.66	3.96	13	6.10
Song Sparrow	14.7	8.73	12.25	5.75
American Crow	7.57	4.5	11.25	5.28
European Starling	7.83	4.65	8	3.76
Common Grackle	7.34	4.36	7.50	3.52
Common Yellowthroat	8.27	4.92	7	3.29
Common Snipe	4.33	2.57	3.50	1.64
Killdeer	3.43	2.04	3.50	1.64
Rock Dove	2.70	1.60	3.50	1.64
Alder Flycatcher	2.19	1.30	3.25	1.53
American Goldfinch	1.31	0.78	2.25	1.06
American Robin	1.2	0.71	2.25	1.06
Upland Sandpiper	1.77	1.05	2.25	1.06
Yellow Warbler	1.33	0.79	2	0.94
Le Conte's Sparrow	1.17	0.70	1.50	0.70
Cedar Waxwing	2.97	1.76	1.25	0.59
Barn Sparrow	0.85	0.50	1	0.47
Brown-headed Cowbird	0.77	0.46	1	0.47
Cliff Sparrow	0.4	0.24	1	0.47
Mourning Dove	0.8	0.48	1	0.47
Tree Swallow	0.73	0.43	1	0.47
Black-capped Chickadee	0	0	1	0.47
Northern Goshawk	0.20	0.12	1	0.47
Eastern Kingbird	1.14	0.68	0.75	0.35
Bank Swallow	0.82	0.49	0.75	0.35
Northern Harrier	0.57	0.34	0.50	0.23
American Kestrel	0.40	0.24	0.50	0.23
Chipping Sparrow	0.37	0.22	0.50	0.23
Pine Siskin	0	0	0.50	0.23
Red-eyed Vireo	0.57	0.34	0.50	0.23
Blue Jay	0.20	0.12	0.25	0.12
Brown-capped Chickadee	0.17	0.10	0.25	0.12
Brown Thrasher	0.20	0.12	0.25	0.12
Black and white Warbler	0.2	0.12	0.25	0.12
Evening Grosbeak	0	0	0.25	0.12
Gray Catbird	0	0	0.25	0.12
Greater Yellowlegs	0.2	0.12	0.25	0.12
Lincoln Sparrow	0.2	0.12	0.25	0.12
Mourning Warbler	0.2	0.12	0.25	0.12
Northern Flicker	0	0	0.25	0.12
Purple Finch	0	0	0.25	0.12
Rose-breasted Grosbeak	0	0	0.25	0.12
Ring-billed Gull	0	0	0.25	0.12
Turkey Vulture	0	0	0.25	0.12
Yellow-bellied Sapsucker	0	0	0.25	0.12
Yellow-rumped Warbler	0.17	0.10	0.25	0.12
Total	168.33	100	213	100

[1] totaled for all points

Table 3--*Mean bird density per 10 hectares on point counts for species for which territory could clearly be established. See* table 1 *for area* of *each radius.*

Species	Radius (m)		
	50	100	150
Alder Flycatcher	1.41	0.71	0.69
Bobolink	24.11	17.43	13.01
Common Snipe	1.04	0.58	1.36
Common Yellowthroat	5.29	2.34	2.60
Eastern Kingbird	1.13	0.38	0.36
Horned Lark	6.37	3.58	2.09
Red-winged Blackbird	5.66	4.97	3.92
Savannah Sparrow	27.42	15.49	9.60
Song Sparrow	11.60	5.06	4.62
Upland Sandpiper	1.41	0.71	0.56
Total	85.44	51.24	38.81
Paired t-test (n=10)			
0-50-0-100 m	2.828	$P < 0.05$	
0-50-0-150 m	2.543	$P < 0.05$	
0-100-0-150 m	1.800	$P > 0.05$	

50-m and 150-m, but not 100-m and 150-m radii (*table 3*). Density decreased by 40 percent from 50 m to 100 m, 55 percent from 50 m to 150 m, and by 24 percent from 100 m to 150 m. Bird density is probably best estimated within a 100-m radius, being overestimated at 50 m and underestimated at 150 m because of lower detectability at greater distances for many species. Nine species had their highest density at the 50-m radius. The density of eight species declined continuously between radii of 50 m to 150 m. Only the Common Snipe, a species with a relatively large territory, had the highest density at 150 m.

On most 150-m radius points, point counts detected fewer birds than. territory mapping for each of the 10 species with clearly defined territories. Common Snipe, Common Yellowthroat, and Song Sparrow showed respectively five, four, and three of nine points with more birds on point counts than on territory mapping. Relative abundances were not very different between methods, but was larger in two plots for Common Snipe and three for Song Sparrow (*table 4*). Point count locations were representative of each plot for at least these 10 species, since relative abundances from territory mapping on plots and points were not significantly different (*table 4,* paired *t*-test $t = 0.0052$, $n = 27$, $P > 0.05$).

Discussion

Both point counts and territory mapping at point count locations led to comparable results in terms of species composition and number of individuals per species. Since the data collected during point counts were also transcribed on the maps, this might be one reason for such links in the results. This also resulted in more time spent for mapping on the points, and it might explain the slightly higher densities on mapped points. This result is not in agreement with Edwards and others (1981) who detected more species with the variable circular-plot method, a modified point count method, than with mapping on plots. Point counts in open landscape are also known to yield larger counts of rare species if distance of the plot is unlimited (Edwards and others 1981); thus 150 m should yield better results in such cases than shorter distances. Some species had low abundance on all points or did not use the site, such as ducks, some hawks, swifts, raven, orioles, and some warblers; others used it only for feeding and not for breeding, such as vultures, hawks, ducks, gulls, and many swallows. Many others used mainly the edges and thus required the presence of a different habitat or an ecotone which will be more or less important for nesting, or will be used as a perch for singing and territory maintenance.

The number of counts from four upward did not affect significantly the number of species detected per habitat in a study by Morrison and others (1981). Four counts per point seemed adequate since about 80 percent of all individuals per species have been accounted for in our study.

Absolute densities of territorial birds on the points compare well to the mean number of birds per point count. The mean number of individuals per species for any one point is about equal to the number of territories a point may support for most species, as long as they represent the actual number of birds the habitat could support. Relative densities of territorial birds obtained on mapped points match very well the relative mean number of individuals per point count and could be more useful than actual counts.

Our results suggest that point counts spanning at least 100 m are best suited for counting birds in agricultural landscapes. Four visits allow the detection of at least 80 percent of all species and birds. More visits would add more information, but the amount of work effort might impair the attainment of a good sample size on enough different points. Anderson and Ohmart (1981) also showed that more than three visits detected few additional birds.

Thus far, it appears that the point count method seems accurate enough to reflect "mapping based" true densities for comparison purposes between farm types in agricultural habitats. Blondel and others (1981) consider that the species

Table ***4-Number of territories on the plots and on 150-m radius points, and mean number of birds on 150-m radius point counts. See table 1 for crop types in each point.***

Species	Total territories on plots	Mapped points Number of territories			Total	Point counts Mean number of birds			Total
		A1	**A2**	**A3**		**A1**	**A2**	**A3**	
Bobolink	34.5	6	9	1.5	16.5	4.8	9	0.67	14.47
Common Snipe	4.5	0.25	0.5	0.75	1.5	0.6	0.8	0.5	1.9
Common Yellowthroat	2.5	0	0.25	0	0.25	0	0.8	0	0.8
Eastern Kingbird	1.5	0.25	0.25	0	0.5	0.6	0.4	0	1
Horned Lark	11.5	2	0.25	6	8.25	1	0.2	3.83	5.03
Red-winged Blackbird	23.5	2.25	8	2.5	12.75	1.6	6.6	1.83	10.03
Savannah Sparrow	36.0	5	2	5	12	2.8	1	4	7.8
Song Sparrow	11.0	1	2.25	0.25	3.5	0.8	2.4	0.67	3.87
Upland Sandpiper	3.0	0.5	0	1.5	2	0.2	0.4	1.17	1.77
		B1	**B2**	**B3**		**B1**	**B2**	**B3**	
Alder Flycatcher	2	0.25	0	0.25	0.5	0.29	0	0.4	0.69
Bobolink	36.5	6	6	5	17	6.29	4.8	2.8	13.89
Common Snipe	2	0.25	0.5	0.5	1.25	0.29	0.8	0.8	1.89
Common Yellowthroat	7	1	1	1	3	0.71	1.6	0.4	2.71
Eastern Kingbird	1	0.25	0	0	0.25	0.14	0	0	0.14
Horned Lark	6	2	2.25	0	4.25	0.86	0.4	0.2	1.46
Red-winged Blackbird	3	0.25	1	1	2.25	0.14	0.8	0.8	1.74
Savannah Sparrow	39.5	6	5.75	3.5	15.25	5.57	5	1.6	12.17
Song Sparrow	18	1.25	2	1.5	4.75	1.43	2.2	1.2	4.83
Upland Sandpiper	0.5	0.25	0	0	0.25	0	0	0	0
		C1	**C2**	**C3**		**C1**	**C2**	**C3**	
Alder Flycatcher	5.5	1.5	0.5	0.75	2.75	1.17	0.33	0	1.5
Bobolink	55	14.5	2.5	2	19	6.83	3	3.2	13.03
Common Snipe	0.75	0.25	0.25	0.25	0.75	0.17	0.17	0.2	0.54
Common Yellowthroat	12	2	0.25	1.5	3.75	1.83	1.33	1.6	4.76
Horned lark	1	0	0.25	0.25	0.5	0	0.17	0	0.17
Red-winged Blackbird	1	0.25	0.5	0.25	1	0.17	0.33	0.2	0.7
Savannah Sparrow	39.5	6	4.5	6	16.5	2.67	3.5	4.4	10.57
Song Sparrow	15.5	1.5	0.5	2	4	2.5	1.5	2	6

richness is a reliable index for total abundance in the community, the two being highly correlated in Oak forests. DeSante (1981) found that the variable circular-plot method tends to overestimate densities when species are rare and underestimate them when they are dense. Ideal workable distance for a fixed radius in agricultural landscapes seems to be at around 150 m, although less accuracy in the number of individuals is to be expected between 100 and 150 m from the observer, especially for species with smaller territories and for more abundant species. Many species can be easily detected in an open landscape, well up to 150 m. It would not seem advantageous to use a plot with a radius smaller than 150 m in such habitats.

A note of caution is important in regard to the expectation that the comparison would be feasible for all the species encountered. In fact, because many species use edges as their prime habitat, the value of the analysis might be altered if not enough care is taken to reduce the effect of surrounding habitats bordering the points. This by itself might affect the species composition more than the choice of method to collect the data. This is especially important because a majority of the species encountered are breeding outside of the habitat under consideration.

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Modification of Point Counts for Surveying Cropland Birds[1]

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Abstract: As part of a comparative study of agricultural impacts on wildlife, modifications to the point count method were evaluated for surveying birds in, and adjacent to, cropland during the breeding season (May to early July) in Ontario. Location in the field, observation direction and distance, number of visits, and number of study sites per farm were examined using point counts of 5-minute duration in 1989 and 10-minute duration in 1990. Bird species number and abundance were not significantly different between point counts conducted from field-edge and field-interior (100 m or less from the edge) locations at the same study site (median field size = 6 ha). At each field-edge location, semicircular counts detected significantly fewer, but still about 85 percent of species and 80 percent of individuals detected in circular counts. We attributed the poor performance of circular counts to poor visibility through wooded field-edges, poor habitat quality, and an edge-effect on bird activity. Limited-distance (within 100 m of observer) point counts detected significantly fewer, and only 59 percent and 69 percent of species and individuals detected with unlimited-distance (but still on farm) point counts per study site in 1989 and 1990. Species number of each study site was still increasing significantly for all point count methods after three visits in 1989 and four visits in 1990. Bird abundance at each site was not significantly different among visits in 1989 or among the last three of four visits in 1990. We argue these results reflect spatial dynamics in the distribution of birds and species in cropland throughout the breeding season. Our study farms appeared to be well-sampled by field-edge, semicircular, unlimited-distance point counts at a sampling intensity of one study site per 26 ha based on comparisons with point counts from a larger number of study sites, search (walk-about) surveys of study sites, and noncrop areas on farms. Relevance of our results to recommended point count standards is discussed.

The extensive use of commercially synthesized pesticides and fertilizers in modern agriculture has significant implications for farmland wildlife (Freemark and Boutin 1995, Fry 1991, O'Connor and Shrubb 1986, Sheehan and others 1987). The Canadian Wildlife Service has used the recent trend toward alternative agriculture (NRC 1989) to develop a comparative field study for evaluating the ecotoxicological impact of agrichemical use. A point-count based study by Brae and others (1988) in Denmark indicated the potential usefulness of comparing avifauna on organic and chemical farms. In adapting the Danish approach for Canada, we evaluated point counts as a method for surveying birds potentially exposed to agrichemicals in, and adjacent to, cropland (Rogers and Freemark 19911).

The point count method has not often been used for bird surveys on farms. Of 43 studies reviewed by Freemark and others (1991) to document bird use of croplands and field-edge habitats (excluding woodlots) in the Great Lakes-St. Lawrence region, only two (Stone and others 1974, Conover 1982) used off-road point counts, and a third study used a combination of field transects and point counts (Ashton and Jackson 1983). More recently, Bryan and Best (1991) used point counts to survey birds in Iowa farmland. Despite limited use, we selected point counts over other survey methods for the following reasons:

(1) Study sites were to be paired between farm types on the basis of habitat similarity to separate habitat effects from other agrichemical effects. With only one observer in 1989 and two in 1990, a larger sample of paired sites could be surveyed by point counts than by more intensive methods, such as territory mapping, which require more time per visit and more visits per study site.

(2) Brae and others (1988) found that point counts recorded similar differences in birds between farm types as those shown by territory mapping. Since then, Cyr and others (in this volume) have also found that point counts and territory mapping provide similar results for farmland birds.

(3) Survey sites could be more easily paired for habitat similarity at a point than along a transect in a field.

(4) Lastly, a stationary observer could follow bird movements more closely and was less likely to disturb birds or damage crops compared to the territory mapping and field transect methods in which the observer moves through the area.

Given limited use of point count methodology in the existing literature, we needed to evaluate conduct of point counts in croplands. In addition, we needed to evaluate how well cropland birds at each study site were sampled by point counts at a set of study sites that were paired between organic and chemical farms for habitat similarity. In this paper, we compare results between point counts conducted from the field edge versus the field interior to evaluate the importance of location of sample points in the field. Results are also compared between circular and semicircular (hereafter 360° and 180°, respectively) point counts in which the diameter was oriented along field edges. We considered this comparison necessary because many field edges in our study area and on our study sites were wooded. At most study sites, the observer had only an unobstructed view into fields in the 180° toward the field. Results for a limited versus an unlimited (but still on farm) distance from the observer are also compared. Patterns in bird species richness and mean abundance at each study site with replication of counts over the breeding season are also compared to evaluate the precision of point count samples at that temporal scale. Lastly, we evaluate the number of study sites required to adequately sample bird species composition on farms by comparing results among different sets of point count sites and search surveys of study sites and noncrop areas (e.g., farmsteads, woodlands, and riparian) on each farm.

Methods

In 1989, 20 study sites were established in cropland on three organic and three conventional (chemical) farms within 200 km of Ottawa, Ontario. Farms averaged 87 ha (s.d. = 39 ha) in size. Study sites on organic farms were paired with

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study sites on chemical farms on the basis of habitat similarity. There were three or four study sites at each farm for an average sampling intensity of one study site per 26 ha (range 13-41 ha) with woodland areas included. Fields at study sites averaged 16 ha (s.d. = 14 ha). The minimum distance between study sites averaged 474 m (s.d. = 378 m, range 150-1410 m). An additional five unpaired study sites (one on each of five farms) were established in cropland to evaluate how well point counts at paired sites sampled birds.

By 1990, we had established a total of 72 study sites in cropland paired between 10 organic and 10 chemical farms in eastern (same farms as 1989) and southwestern Ontario. Farms averaged 84 ha (s.d. = 45 ha) in size. Two to six study sites were established on each farm. Fields at study sites averaged 18 ha (s.d. = 14 ha). The minimum distance between study sites averaged 374 m (s.d. = 218 m, range 120-1410 m).

In both years, one farm pair was surveyed per observer on each day to minimize weather effects in our comparative data. In 1989, each farm pair was surveyed three times between June 13 and July 7 by a single observer. In 1990, each farm pair was surveyed twice in May and twice in June with observers alternating. On alternate visits, the order of visitation was reversed for the farms in the pair and for the study sites on each farm to minimize effects related to time of day.

Birds were surveyed by point counts conducted between dawn and 0930 (in 1989) or 1015 (in 1990). The weather was good (i.e., no rain, winds <13 mph) for most surveys.

Point counts were conducted from field edges. In 1989, bird registrations were mapped such that they could be separated into 180° and 360° directions (as defined above) and limited (100 m radius) and unlimited distances from the observer (but still on farm). During each point count, the observer rotated slowly to face all directions. In 1990, birds were surveyed by 180°, limited- and unlimited-distance point counts only.

In 1989, point counts were conducted from field edges and from field interiors at seven study sites to compare levels of bird activity. Five study sites were visited three times; two study sites only twice. Field-interior point counts were conducted at locations 100 m from the edge for larger fields (32 and 35 ha) at two study sites, and at the center for smaller fields (3-11 ha) at five study sites. The 180° recording direction for field-edge and field-interior point counts overlapped.

In 1989, we used point counts of 5-minute duration. Point count durations of 5 minutes (Bryan and Best 1991), 10 minutes (Ashton and Jackson 1983, Brae and others 1988) and 15 minutes (Conover 1982, Stone and others 1974) have all been used to survey cropland birds. In five trial point counts, we found that 50 percent to 86 percent (mean = 70 percent) of species and 53 to 92 percent (mean = 73 percent) of the individuals detected in 10 to 20 minutes had been observed within 5 minutes. Our choice of count duration, though based on. the limited data available at the time, is consistent with the recommendation by Ralph and others, in this volume, to use 5-minute point counts as a compromise between greater accuracy at a study site and increasing the number of study sites sampled. In 1989, point counts of longer duration were not practical given the number of study sites which had to be surveyed by midmorning by one observer. In 1990, fewer study sites were surveyed on each farm, but travel times between study sites and farms were often longer than 15 minutes. Given these logistical constraints, point count duration was extended to 10 minutes to improve sampling efficiency (particularly for species, see below).

All birds seen or heard were mapped during point counts. Birds in, and adjacent to, croplands or feeding over fields were included because they are potentially affected by agrichemical use. Birds flying over fields were excluded. After a point count visit, each species observed at a study site was given an index of abundance. For a given species, birds had to be seen and/or heard simultaneously to score as different individuals. A bird exhibiting territorial behavior, such as a singing male, was scored as 2; a male or female seen or heard calling scored as 1. This method follows the conventions currently being used by the Ontario Forest Bird Monitoring Program (Welsh, in this volume). The number of species per study site was accumulated over visits. The number of individuals per study site was averaged over visits.

In 1989, three search (walk-about) surveys were also conducted at each study site to help evaluate how well point counts sampled birds. Only species and individuals not detected during point counts at the site were recorded. Three search surveys were also conducted in noncrop areas (e.g., woodlands, farmsteads, and riparian areas) on each farm to provide data which might explain any differences in point count and search survey results between a farm pair. Most study sites and noncrop areas were searched after point counts for the farm pair had been completed (typically 0930-1230). A few study sites and noncrop areas were searched while the observer was en route from one point count to the next. Each search survey on a farm lasted about 1.5 hours. Search effort at each point count site and noncrop area within a farm was proportional to the amount of bird activity.

The Wilcoxon matched-pairs signed-ranks test was used to determine whether the number of species or individuals differed between field-edge and field-interior point counts at the same study site. The number of species detected on each study site was compared between point count methods and between visits by calculating the 95 percent confidence interval on the square root of the difference with upper and lower bounds back-transformed by squaring. The square root transformation was used to stabilize the variance of the count data. The mean number of individuals on each study site was compared between point count methods by calculating the 95 percent confidence interval for the difference. The differences in species number (square-root transformed) and mean number of individuals between visits were further analyzed in a one-way ANOVA with repeated measures ($P = 0.05$) and with posterior comparisons using Tukey HSD (Keppel 1982) to detect significant differences among time periods.

Results and Discussion

In 1989, 64 bird species were observed on study farms (see Appendix for species composition). Forty-nine species (77 percent) were recorded in, and adjacent to, cropland during unlimited-distance point counts. The other 15 species (23 percent) were recorded only during search surveys in noncrop areas on farms. In 1990, 68 species were observed during

unlimited distance point counts on study fauns. Species composition was similar to 1989.

Bird species number and abundance were not significantly different for point counts conducted from field-edge and field-interior locations at the same study site (*table 1*). At least for fields of this size (median = 6 ha), bird activity within crops can be adequately surveyed from field edges. Since bird activity is often greatest at the field edge (Best and others 1990; personal observation), it is perhaps best to survey from this vantage point, particularly for evaluating effects of farming practices such as pesticide use. Given a significant edge effect, the results of surveys conducted from field edges should be less affected by differences in field sizes among study sites than results of surveys conducted from the inside of fields (especially the center). In contrast, field-edge surveys will be more affected by differences in edge habitat among study sites (Best and others 1990). An observer backed by field-edge habitat (e.g., woody plants or fenceposts) may be less disruptive to bird activity than an observer standing in the crop proper. Others have tried to minimize observer effects on cropland birds by conducting point counts from sites located away from experimental plots (Bryan and Best 1991, Conover 1982). Lastly, surveys conducted from the field edge have the added advantage of minimizing observer damage to crop plants.

At field-edge locations, 180° point counts detected significantly fewer, but still about 85 percent of species, and 80 percent of individuals detected in 360° point counts at each study site (*table 2*). The following factors may account for the few additional species and individuals in 360° point counts:

(1) At one-half of the study sites, point counts were conducted from woody fencerows between fields. Because only the 180° view was unobstructed, the remaining part of the 360° point count was based solely on vocal cues. In our experience (but not quantified), many birds in1, and adjacent to, cropland are detected by visual rather than vocal cues.

(2) At an additional 25 percent of our sites, bird abundance in the remaining area of the 360° point count may have been depressed by two-lane gravel roads adjacent to the field-edge location.

(3) Birds detected along the field edge from which point counts were conducted were included in the 180° results. Because bird activity is highest along edges (particularly wooded edges), fewer birds (and therefore species) are likely to be detected in the remaining area of the 360° point count, even if visibility is good in all directions.

For comparing between farm types, we used 180° point counts as a compromise between slightly lower sampling efficiency and greater flexibility in locating study sites on farms (particularly farms that were small or narrow) and matching habitat characteristics between farm types. By using 180° point counts, we were also able to visually survey bird activity more intensely. In more open farmland or in studies with fewer design constraints, 360° point counts may be a more viable method.

In 1989, limited-distance point counts detected significantly fewer and only about 59 percent of species, and individuals detected with unlimited distances at each study site (*table 2; see Appendix for species*). Even with more visits of longer duration in 1990, limited-distance point counts still detected significantly fewer and still only 69 percent of species and 70 percent of individuals detected with unlimited distances at each study site. For comparing between farm types, we used unlimited-distance (but still on farm) point counts because of their higher sampling efficiency. At our study sites, an unlimited distance typically spans 200 m or less because of spatial constraints imposed by farm size, field size, or the detectability of many species. Ralph and others (in this volume) briefly discuss the use of limited-distance point counts to estimate abundance for among species comparisons. The limited distance of 50 m they recommended is not likely far enough for the open environments in farmland, given the drop in sampling efficiency we observed at 100 m (see also Cyr and others in this volume).

In 1989, species number per study site increased significantly between visits for all point count methods (*fig. la*). The number of species added between visit 1 and 2 versus

Table 1--*Results for point counts conducted from field-edge and field-interior locations at the same study site. Based on 1989 surveys using limited-distance (LD) and unlimited-distance (ULD), 180° and 360° point counts.*

	Mean (± 1 s.d.)			
	LD180°	LD360°	ULD180°	ULD360°
n Species[1]				
Edge	5.4 (2.2)	6.7 (2.4)	8.6 (2.6)	10.6 (2.0)
Interior	4.3 (2.8)	6.4 (3.3)	9.4 (3.4)	11.1 (3.2)
Mean *n* Individuals[1]				
Edge	7.9 (2.1)	10.0 (2.3)	12.8 (3.9)	17.9 (3.7)
Interior	6.9 (2.5)	8.8 (2.4)	12.3 (2.2)	16.3 (2.1)

[1] Paired Wilcoxon $P > 0.05$ for edge vs. interior

Table 2--*Comparisons of different point count methods on each study site. Based on field-edge, 180° and 360° point counts at a limited-distance (LD) and unlimited distance (ULD) from the observer at the study sites paired between farm types.*

Methods compared	Mean % (± 1 s.d.)			
	n Species		Mean *n* Individuals	
	1989	1990	1989	1990
180° vs. 360°				
LD	85*(17)	-	79*(17)	-
ULD	86*(13)	-	80*(11)	-
LD vs. ULD				
180°	58*((18)	69*(12)	59*(11)	70*(17)
360°	59*(17)	-	61*(13)	
n study sites	19	72	19	72
n visits/site	3	4	3	4
n minutes/site	15	40	15	40

* Significant difference between methods. See Methods for test details.

visit 2 and 3 was not significantly different within methods; 95 percent confidence intervals ranged from 0.3 to 3.7 additional species at each study site. Bird abundance at each study site was not significantly different among visits (*fig. 1b*). To improve sampling efficiency (particularly for species), we increased the number of visits to four (two each in May and June) and extended the point count duration to 10 minutes in 1990. After four visits, species number at each study site was still increasing significantly for both limited-distance and unlimited-distance point counts (*fig. 2a*). Significantly more species per study site were added between visit 1 and 2 (CI = 2.4-4.8 additional species) than between subsequent visits (CI = 0.6-2.1 additional species). Bird abundance at each study site increased significantly between visit 1 and 2 but was not significantly different between subsequent visits (*fig. 2b*). In Ontario, many species are still migrating in early May when our first visit was conducted. This, coupled with typically cool and wet weather, likely accounted for the significantly fewer species and birds seen during our first visit. Cyr and others, in these Proceedings, found that after four visits, 10-minute point counts had detected more than 80 percent of the species and birds observed in seven visits. Species number per site had not reached an asymptote, however, even after seven visits. It is unlikely that the continued increase in species number was simply because of insufficient sampling since bird species composition and relative abundance detected by their point counts were similar to results from more intensive territory mapping. More likely, these results reflect spatial dynamics in the distribution of birds and species in cropland throughout the breeding season.

Our study farms appeared to be well-sampled by field-edge, 180°, unlimited-distance point counts at the set of 20 study sites paired between farm types (representing a sampling intensity of 3 to 4 study sites per farm or one study site per 26 ha, including woodland). The field-edge, 180°, unlimited-distance point counts at these study sites detected 86 percent of

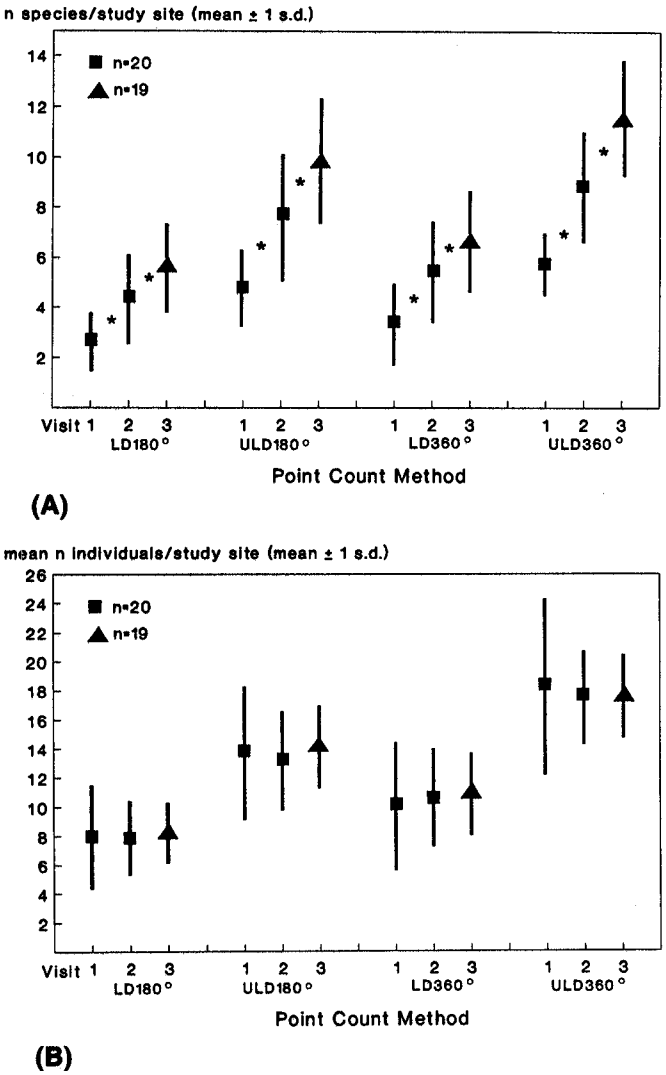

Figure 1--(A) Number of species and (B) number of individuals detected during 5-minute, limited-distance (LD) and unlimited-distance (ULD), 180° and 360° point counts conducted from field edges at 1989 study sites paired between farm types (number of study sites (*n*) as shown). * indicates a significant ($P < 0.05$) difference between visits.

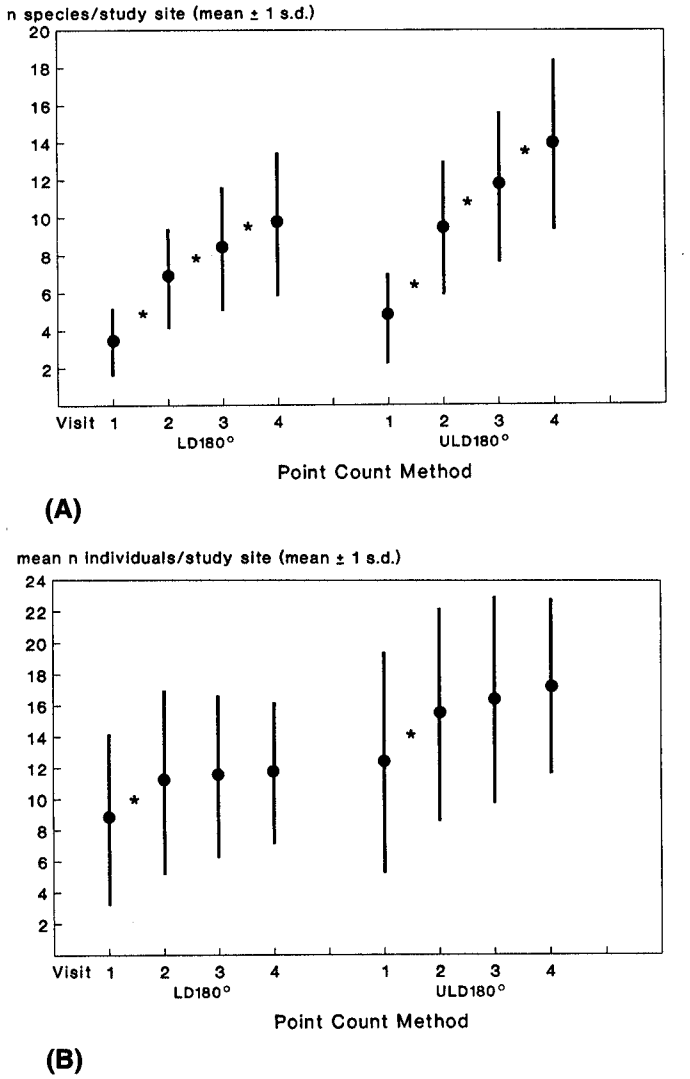

Figure 2--(A) Number of species and (B) mean number of individuals detected using 180° limited-distance (LD) and unlimited-distance (ULD), 10-minute point counts conducted from field edges at 72 study sites in 1990. * indicates a significant ($P < 0.05$) difference between visits.

species detected by all point count methods combined. Extending point counts to 360° added only four more species. Point counts at five study sites, riot paired between farm types, added only two more species. A single species was observed only during field-interior point counts (*Appendix*). Search surveys of study sites did not add any new species. The minimum distance between study sites paired between farm types averaged 474 m in 1989 and 374 m in 1990. At these distances, we did not have a problem with double counting of birds between study sites (personal observation). We agree with Ralph and others, in these Proceedings, that distances greater than 250 m between study sites are needed to ensure statistical independence of point counts in open environments. In our opinion, the 500-m distance recommended for roadside counts is also appropriate for offroad point counts in farmland.

Acknowledgments

We thank Myriam Csizy, Christine Ribic, Brian Collins, and Peter Blancher for their assistance in data analyses, and Dan Welsh for presenting the paper for us at the workshop. Pierre Mineau, Peter Blancher, André Cyr, and all three editors provided valuable comments on earlier drafts. Funding was provided by the Pesticide Evaluation Section, Canadian Wildlife Service, National Wildlife Research Centre, and the Canadian Wildlife Service-Ontario Region (Joe Carriero and Chip Weseloh). Logistical support was provided by the Canadian Wildlife Service Regional office in London, Ontario (Gary McCullough). Finally, we thank the farm families who generously participated in the study and gave us perspective on their way of life.

Appendix--*Bird species composition from point count and search surveys of six farms in the 1989 Ontario field study.*

Species		Point Count[1]		Search[2]
Common Name	Scientific Name	180°	360°	
American Bittern	*Botaurus lentiginosus*			r
Great Blue Heron	*Ardea herodias*			r
Red-tailed Hawk	*Buteo jamaicensis*	e+	e+	
American Kestrel	*Falco sparverius*	e+	e+	
Ruffed Grouse	*Bonasa umbellus*			w
Killdeer	*Charadrius vociferus*	e	e	
Spotted Sandpiper	*Actitis macularia*		e+	
Upland Sandpiper	*Bartramia longicauda*	e	e	
Common Snipe	*Gallinago gallinago*	e+	e+	
American Woodcock	*Scolopax minor*		i	
Ring-billed Gull	*Larus delawarensis*	e+	e+	
Rock Dove	*Columba livia*	e	e	
Mourning Dove	*Zenaida macroura*	e	e	
Black-billed Cuckoo	*Coccyzus erythropthalmus*	e+	e+	
Yellow-bellied Sapsucker	*Sphyrapicus varius*	e+	e+	
Hairy Woodpecker	*Picoides villosus*			w
Northern Flicker	*Colaptes auratus*	e	e	
Eastern Wood-Pewee	*Contopus virens*	e	e	
Least Flycatcher	*Empidonax minimus*	e+	e+	
Eastern Phoebe	*Sayornis phoebe*	e+	e+	
Great Crested Flycatcher	*Myiarchus crinitus*	e+	e+	
Eastern Kingbird	*Tyrannus tyrannus*	e	e	
Horned Lark	*Eremophila alpestris*	e	e	
Tree Swallow	*Tachycineta bicolor*	e	e	
Barn Swallow	*Hirundo rustica*	e	e	
Blue Jay	*Cyanocitta cristata*	e	e	
American Crow	*Corvus brachyrhynchos*	e	e	
Black-capped Chickadee	*Parus atricapillus*			w,f
Red-breasted Nuthatch	*Sitta canadensis*			w
White-breasted Nuthatch	*Sitta carolinensis*			w

continued

Appendix--*continued*

Species		Point Count[1]		Search[2]
Common Name	Scientific Name	180°	360°	
Brown Creeper	*Certhia americana*			w
House Wren	*Troglodytes aedon*	e+	e+	
Eastern Bluebird	*Sialia sialis*			f
Veery	*Catharus fuscescens*	e+	e+	
Hermit Thrush	*Catharus guttatus*			w
Wood Thrush	*Hylocichla mustelina*			w
American Robin	*Turdus migratorius*	e	e	
Gray Catbird	*Dumetella carolinensis*			w
Brown Thrasher	*Toxostoma rufum*	e+	e+	
Cedar Waxwing	*Bombycilla cedrorum*	e	e	
European Starling	*Sturnus vulgaris*	e	e	
Warbling Vireo	*Vireo gilvus*		ue	
Red-eyed Vireo	*Vireo olivaceus*	e	e	
Yellow Warbler	*Dendroica petechia*	e	e	
Chestnut-sided Warbler	*Dendroica pensylvanica*		e	
Black-throated Green Warbler	*Dendroica virens*			w
Black-and-white Warbler	*Mniotilta varia*		e	
Ovenbird	*Seiurus aurocapillus*		e	
Mourning Warbler	*Oporornis philadelphia*	e+	e+	
Common Yellowthroat	*Geothlypis trichas*	e	e	
Northern Cardinal	*Cardinalis cardinalis*		ue	
Rufus-sided Towhee	*Pipilo erythrophthalmus*			w
Chipping Sparrow	*Spizella passerina*	e+	e+	
Savannah Sparrow	*Passerculus sandwichensis*	e	e	
Song Sparrow	*Melospiza melodia*	e	e	
White-throated Sparrow	*Zonotrichia albicollis*			w
Bobolink	*Dolichonyx oryzivorus*	e	e	
Red-winged Blackbird	*Agelaius phoeniceus*	e	e	
Eastern Meadowlark	*Sturnella magna*	e	e	
Common Grackle	*Quiscalus quiscula*	e	e	
Brown-headed Cowbird	*Molothrus ater*	e	e	
Northern Oriole	*Icterus galbula*	e	e	
American Goldfinch	*Carduelis tristis*	e	e	
House Sparrow	*Passer domesticus*	e	e	

[1] Point count survey:
180° = unlimited-distance semicircle
360° = unlimited-distance circle
e = paired field-edge (i.e., at study sites paired between farm types for habitat similarity, n = 20)
i = inside-field (100 m or less from the field edge, n = 7)
ue = unpaired field-edge (i.e., study sites not paired between farm types, n = 5)
+ = detected at >100 m only

[2] Search (walk-about)survey of point count sites (n = 25) and the following noncrop areas on farms:
r = near river
w = woodlot
f = farmstead

Design of a Monitoring Program for Northern Spotted Owls[1]

Jonathan Bart and Douglas S. Robson[2]

Abstract: This paper discusses methods for estimating population trends of Northern Spotted Owls (*Strix occidentalis caurina*) based on point counts. Although the monitoring program will have five distinct components, attention here is restricted to one of these: roadside surveys of territorial birds. Analyses of Breeding Bird Survey data and computer simulations were used to develop recommendations for design of the roadside surveys. An approach known as "lattice sampling," in which some stations are visited annually and other stations are visited less often, may offer some advantages over the more common practice in wildlife surveys of visiting every station once per year. The analyses suggest that an adequate sample of the roadside surveys could be obtained with less than one person-year of effort per year per state, an expenditure well within current efforts for surveying Northern Spotted Owls, and that a minimum of 8 years, and probably at least 10 years of survey data will be required to obtain reliable estimates of long-term population trends.

The Northern Spotted Owl was listed as a threatened species under the Endangered Species Act on July 23, 1990. During the following months, a Recovery Team was appointed and began meeting to discuss the design of a monitoring program to provide reliable information on population trends of Northern Spotted Owls throughout their range. Northern Spotted Owls live in older forests in western Washington and Oregon and northwestern California. They occur at very low densities (median home range size varies across the range from 2,000 to 12,000 acres) and thus are difficult to survey. Substantial resources will probably be expended on the monitoring program and, because the results it produces will provide the basis for making decisions of considerable economic and biological importance, a detailed study of the design is warranted.

The proposed monitoring program was divided into five parts: (1) roadside surveys; (2) studies of floaters; (3) monitoring of activity sites; (4) transmitter studies; and (5) coordination. Here we discuss design of the roadside surveys. The other segments are discussed in the Recovery Plan (USDI 1992).

Two studies, one based on Breeding Bird Survey data (Robbins and others 1986: Sauer and Droege 1990) and the other based on a computer simulation, were used to investigate how frequently stations should be visited, how many should be visited per year, and how long the survey should be continued before attempting to estimate long-term trends. Particular attention was given to a design in which some of the stations are visited annually and the rest are visited every t years with $t > 1$. Such a design may be useful when the trend is small and when high within-site autocorrelation in successive years exists. An illustration of this approach is shown in *table 1* where some of the sites are visited only every third year while others are visited annually; such a design falls into the class known as "lattice sampling designs" (Yates 1960). Although the results were developed for Northern Spotted Owls, the methods could be applied with little alteration to many other species.

Methods

Analyses of Breeding Bird Survey Data

Breeding Bird Survey data from a 25-year period (1966-1990) for hawks and owls were used as surrogate pilot data for long-term Spotted Owl data in our analysis of optimal sampling for owl trends. We used the following procedure to select several data sets, each consisting of the count data on all routes for all years for one species within one state or province. We asked the Fish and Wildlife Service (FWS) for up to five data sets per species, each having ≥30 routes surveyed per year. They provided us with 31 data sets. We then discarded routes covered in fewer than 20 of the 25 years (inclusion of poorly covered routes can seriously bias trend estimates), and we discarded data sets in which this reduced the number of routes below 20. This process produced 15 data sets for analysis.

The 15 data sets included 7 species and 9 states or provinces (*table 2*). We calculated the mean number of birds per route recorded each year and plotted these means. Periods during which the changes in mean counts were approximately linear were then delineated by eye, and these intervals were used in the analysis. Most intervals were ≥20 years, but 2 intervals were 17 years. The average number of routes per year, during the intervals used from each data set, varied from 20 to 57; the average number of birds per route varied from 0.7 to 5.2. Average annual trend (referred to below as lambda, λ) was calculated by fitting an exponential function to the data using regression on logarithms of counts. We expressed the results as percent changes (i.e., a λ of -1 percent meant that the population declined at an average annual rate of about 1 percent during the interval). The trends varied from -1.6 percent to 6.9 percent (*table 2*) and had an average value of 2.0 percent. Autocorrelation, as indicated by the Durbin-Watson test, was absent in all but one data set.

To determine how many years were needed to obtain reliable estimates of the long-term trends, we selected all possible sets of k sequential years (k = 3-15) from each period in each data set, calculated the estimated percent change per year, and stored the error (estimated trend-true trend). The data were summarized by determining the minimum interval length such that 80 percent of the errors were <0.02, <0.03, and <0.04. The rationale for this procedure was that the main source of concern in using this survey method is that the true trends not be overestimated. Our analyses give

[1] This paper was not presented at the Workshop on Monitoring Bird Populations by Point Counts but is included in this volume because of its interest and value.

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Table 1--*Example of a lattice design in which four sets of routes are visited each year, one annually and the rest every third year*

	Year											
Route	1	2	3	4	5	6	7	8	9	10	11	12
1	X	X	X	X	X	X	X	X	X	X	X	X
2	X			X			X			X		
3		X			X			X			X	
4			X			X			X			X

Table 2--*Description of Breeding Bird Survey data sets used to estimate number of years required to obtain reliable estimates of long-term trends.*

Species	State	Years	Average number of routes	Average count/ route	Estimate percent change
Turkey Vulture	Florida	1966-90	22	5.2	-1.4
	Maryland	1966-90	43	4,7	3.3
	Ohio	1966-89	24	1.5	3.1
	Oklahoma	1967-90	23	4.0	[a]0.2
Black Vulture	Alabama	1966-90	28	2.1	2.1
	Florida	1966-90	21	4.7	0.1
Red-tailed Hawk	Kansas	1967-90	29	2.1	1.1
	Oklahoma	1970-90	23	1.6	3.1
	Wisconsin	1966-90	57	0.7	4.5
Red-shouldered Hawk	Florida	1971-90	23	2.0	0.9
American Kestrel	New York	1974-90	46	1.4	-1.6
	Ohio	1974-90	24	1.3	1.4
	Ontario	1968-90	25	1.0	3.0
Osprey	Florida	1966-85	20	1.0	6.9
Great Horned Owl	Kansas	1967-90	29	0.7	2.2

[a] auto-correlation present, based on Durbin-Watson test with $\alpha = 0.05$.

estimates of the sample size requirements when "overestimated" is defined as error of 0.02, 0.03, or 0.04, and the probability of avoiding this error is 80 percent. The rationale for selecting the threshold values 0.02, 0.03, and 0.04 is given below (magnitude of trend that should be detectable).

The procedure is illustrated with data from Red-tailed Hawks (*Buteo jamaicensis*) in Wisconsin. This data set showed an increasing trend throughout the 25-year period (*fig. 1*). The average annual change was 4.5 percent or 0.045. In the 25-year interval, there are 23 different intervals of 3 years each. An estimate of the "true," long-term trend (0.045) was calculated from each of these samples (*table 3*). Row 1 of *table 3* indicates that 57 percent of these estimates were <0.02 higher than the true value (i.e., 57 percent were <0.065); 57 percent were <0.03 higher than the true value, and 61 percent were less than 0.04 higher than the true value. At the opposite extreme, 91 percent of the estimates based on 15-year intervals were <0.02 higher than the true value, and all of these estimates were <0.04 higher than the true value.

Computer Simulations

Computer simulations based on models of population change can also be used to investigate sampling efficiency. Our investigation required specification of an autocorrelation model describing the process by which the survey data would be obtained. We used an analytically tractable Markov chain model.

Model Details

The model in simplest form is defined by the probability ø that a site is initially occupied, the probability *p* that a site which is occupied in one year will be occupied the next year, and the probability *r* that a site which is not occupied in one year will be occupied the next year. These define a Markov chain on the two states of nature, "1" for occupied and "0" (*table 4*).

The expected proportion of occupied sites converges to a limiting value, $r/(1\ p+r)$, independent of the initial fraction ø of occupied sites, so if the initial occupancy rate is less than this equilibrium value, then an upward trend occurs. As an illustration of this phenomenon, the trend over an 8-year peri-

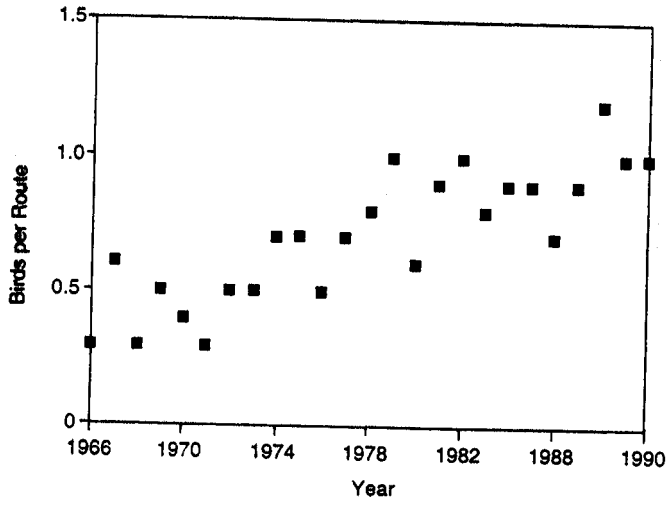

Figure 1--Mean population counts by year for Red-tailed Hawks in Wisconsin as indicated by Breeding Bird Survey data.

Table ***3-Reliability of trend estimates λ for Red-tailed Hawks in Wisconsin as a function of interval length.***

Number of years in sample	Percent of samples in which the error $\hat{\lambda} - \lambda$ was:		
	<0.02	<0.03	<0.04
3	57	57	61
4	64	68	68
5	67	81	86
6	65	75	85
7	63	68	74
8	67	78	89
9	76	88	88
10	75	81	94
11	73	73	93
12	71	79	93
13	62	92	100
14	67	100	100
15	91	91	100

Table 4--*Transition probability matrix for Markov chain model*

Initial probability of site occupancy	Condition	Condition[1]	
		1	0
ø	1	p^2	1-p
1-ø	0	r^3	1-r

[1] 1: site occupied, 2: site not occupied

[2] p: probability that site remains occupied in second year

[3] r: probability that a site that is not occupied in first year will be occupied in second year

od was calculated for the case $p = 0.9$ and $r = 0.01$, giving a limiting value of .01/.11 = .090909 for the fraction occupied after a large number of years (*table 5*). The initial fraction was chosen to be 30 percent smaller than this; namely, ø = .070. During the 8-year interval, this fraction increased 17 percent to 0.082, which is equivalent to an annual, proportional change of 1.019626, or 1.96 percent (i.e., 1.019626^8 = 1.17, or 17 percent). In the analyses below, we would describe such a change by stating that the population grew at an average annual rate of 1.96 percent.

Detectability bias and noise were introduced into the model by assuming that an occupant is detected with probability *d,* and "detection" is independent from site to site and year to year. Only "false negatives" are allowed; i.e., a true 0 is always recorded as 0, while a true 1 is sometimes (with probability 1-*d*) recorded as 0. This has the effect of (1) reducing the expected slope by the factor *d,* (2) reducing the variance by the factor d^2, but (3) adding a noise variance component.

Stochasticity in the transition probabilities *p* and *r* was introduced as random multiplicative effects. A year-specific, site-specific *p* became a product of a random year factor α, say, and a random site component τ, say; thus, $p = \alpha\tau$ at where α is common to all sites that year and τ is common to all years at that site. Randomness in *r* was introduced by assuming that *r/p* is a random variable θ, $0 < \theta < 1$, for α fixed $p = \alpha\tau$; on; the distribution of α and τ were selected (from the beta family), for convenience of simulation, to be that of the largest order statistic of a sample from a uniform distribution on the unit interval. The uniform sample size was chosen separately for α and τ to force the expected value of *p* to be a specified value (namely, the same value as before when *p* was a constant). Similarly, the distribution of θ was taken to be that of the smallest order statistic from a uniform sample of a size determined by the previously assumed constant value of *r*. Such distribution choices enable the ready use of probability transforms in simulating values for α, τ and θ while also permitting some analytic calculations to be readily performed; e.g., the calculation of the vector (*a*) of expected innual occupancies.

Table 5--*Illustration of a Markov chain approach toward stochastic equilibrium when r/(1-p+r) is 30 percent higher than the initial fraction ø.*

Year	Expected proportion of sites occupied
1	0.069930
2	0.072238
3	0.074292
4	0.076120
5	0.077746
6	0.079194
7	0.080483
8	0.081630

Simulation Analysis

A computer program based on the model permitted power calculation for any combination of values for Ø, p and *r* and for alternative lattice designs. It was used to generate 34. data sets. In each, a population changing in size at a specified rate was monitored for either 8 or 12 years, the probability of detecting the trend (i.e., power) was determined with different sampling designs and sample sizes. The level of significance was set at 10 percent in all tests. Rates of change varied from a decline of 4.8 percent per year to an increase of 4.5 percent per year; numbers of owls recorded per station varied from 0.03 to 0.14; detection rates varied from 0.5 to 1.0; and stochastic year and site effects were present in some analyses and absent in others. The number of stations visited per year varied from 200 to 1000, and from none to all of them were on a 4-year cycle. Power varied from 0.21 to 1.00.

Magnitude of Trend That Should Be Detectable

A decision must be made about how large a trend the survey should be capable of detecting. One step in making this decision is estimating the magnitude of fluctuations that night be expected in Spotted Owl populations that were stable and "healthy." No data for such calculations are available for Spotted Owls, but the estimates are important because we would not expect trends to be exactly zero, even if a population were fully recovered. In any given period it would probably be increasing or decreasing slightly and would thus have roughly a 50-50 chance of declining slightly. Thus some effort must be made to understand the magnitude of trend that might be considered normal and to incorporate this information into sample size guidelines for the monitoring program.

We examined the Breeding Bird Survey data sets described above to help determine natural levels of variation in populations that are stable or close to stable. Four of the 15 populations showed both positive and negative trends during the 25-year period. We estimated both trends in these cases, obtaining a total of 19 trends. Five were negative and 14 were positive. About one-half (42 percent) of the absolute trends exceeded 3 percent per year and two-thirds exceeded 2 percent per year. The preponderance of positive values may have been caused by a slight overall increase in these populations at the regional or national level (Droege, S., telephone conversation) or perhaps by a general increase in surveyor skill (Peterjohn, B., telephone conversation). We can shift the distribution so that it is approximately centered on zero by subtracting 2 percent from all values. Nine of the 19 trends (i.e., about one-half) are then negative and 10 are positive. In this case, 37 percent of the absolute trends exceed 3 percent per year, and 42 percent exceed 2 percent per year. These results suggest that average annual changes, over periods of up to 25 years, in state-wide populations of raptors, are commonly as large as 2.5 percent or 3 percent. Smaller populations probably exhibit somewhat larger fluctuations, so annual changes in a single physiographic province of 3.5-4 percent may be common.

Another factor to consider in deciding how large a trend should be detectable is how the estimate of trend will be combined with other information in determining whether populations are recovering. We believe that conclusions about the long-term stability of the population should not depend solely, or even primarily, on empirical estimates of trend. On the contrary, these data should probably play a minor role, compared to efforts based more on *understanding the causes* of trends (i.e., population modeling). We believe the latter efforts (which are described in the Recovery Plan [USDI 1992]) will provide a more reliable and cost-effective way to estimate or predict trends.

The points above suggest that the roadside surveys should have adequate (i.e., 80 percent) power to detect annual changes of 2.5 percent at the statewide level or 3.5 percent at the province level. Changes of smaller magnitude would probably be hard to interpret, even if they were detected, since such changes may occur commonly in healthy populations. The cost of obtaining higher power would also be hard to justify given that other measures will play at least as important a role in the overall estimation of population trends as will the roadside surveys. We therefore calculated the sample sizes required for 80 percent power of detecting annual changes in the 2-4 percent range.

Results

Analyses of Breeding Bird Survey Data

The average amount of time (and range) required for 80 percent probability that errors in estimating trend were <0.02 was 11.9 years (range: 8 to >15 (*table 6*)). The corresponding figures for errors of <0.03 and <0.04 were 9.5

Table 6--*Number of years required to obtain reliable estimates of long term trends from sample Breeding Bird Survey data sets.*

Species	State	Minimum Number of years for 80 pct Probability that $\hat{\lambda} - \lambda$ was <0.02	<0.03	<0.04
Turkey Vulture	Florida	>15	9	80
	Maryland	12	7	6
	Ohio	15	15	15
	Oklahoma	11	10	9
Black Vulture	Alabama	>15	13	10
	Florida	10	10	10
Red-tailed Hawk	Kansas	8	7	4
	Oklahoma	14	8	7
	Wisconsin	15	13	6
Red-shouldered Hawk	Florida	8	7	6
American Kestrel	New York	8	6	5
	Ohio	8	8	8
	Ontario	13	10	8
Osprey	Florida	9	8	7
Great Horned Owl	Kansas	14	11	9
Average	--	11.9	9.5	7.9

years (range: 6-15) and 7.9 years (range: 4-15), respectively. (In these calculations, estimates from table 6 of ">15" were counted as 17 years.)

Computer Simulations

Power increased with increasing value of the following five variables: absolute trends, numbers of birds recorded per 100 stations, number of stations per year, number of years, and fraction of the station on a 4-year cycle. Detection rate and presence or absence of random factors in the simulation had little effect on power. The large number of factors having a substantial influence on power made it difficult to specify conditions required to achieve a specified power. In general, however, few simulations produced power of 80 percent when only 8 years of monitoring data were available. With annual population changes of <3 percent and number of owls recorded per 100 stations of <10, power never reached 80 percent even when 1000 stations were visited per year and all were on a 4-year cycle (power was about 79 percent in this case). Higher absolute trends, or numbers of birds reported per 100 stations, increase power to levels above 0.80. For example, surveying 1000 stations per year and recording 6.5 birds per 100 stations, when the population was declining 4.1 percent per year, produced power equal to 80 percent when 30 percent of the stations were replaced annually. It produced power of 85 percent when all the stations were replaced annually. Despite these examples, in general, it was expensive, and sometimes virtually impossible, to achieve power of 80 percent with only 8 years of monitoring data.

With 12 years of data, many more situations were found in which power was above 80 percent, sometimes by a substantial margin. For example, with a 2.5 percent decline per year, and 6.2 birds recorded per 100 stations, power was 0.82 with 1000 stations, all replaced annually. With 10 birds recorded per 100 stations, power exceeded 80 percent if 70 percent of 800 stations, or all of 600 stations, were replaced annually. With larger trends, smaller samples were sufficient. For example, with a 3.6 percent decline per year and 7.7 birds recorded per 100 stations, power exceeded 80 percent if 60 percent of 600 stations, or all of just 400 stations, were replaced annually. By contrast, if none of the stations were replaced, then 1000 per year were necessary to achieve power of 80 percent.

Results from the simulations were analyzed with a general linear models program in which power was the dependent variable. The simplest equation with high explanatory power was:

$$power = -1.18 + 0.04stns + 0.18chg + 0.04recs + 0.05yrs + 0.16repl$$

where *stns* = number of stations surveyed per year in 100's (e.g., 800 stations per year was coded as 8)
chg = annual absolute percent change per year (e.g., if the population decreased 3.2 per cent each year, then *chg* was 3.2)
recs = average number of birds recorded per 100 stations
yrs = length of monitoring period in years
repl = fraction of the stations on a 4-year cycle

The r^2 for this equation was 0.87. All variables were highly significant. Slight improvement was obtained by applying a square root transformation to several of the variables and including a few interaction terms, but the gain (r^2 equalled 0.92 in the best model) did not seem worth the increased difficulty in interpreting the model. Adding detection rate and presence of random effects did not improve the fit of the model. The standard deviation and coefficient of variation of the residuals were 0.08 and 16 percent, indicating that the model revealed general trends, but did not make individual predictions very well.

The coefficients above describe the general relationship between the variables and power. The general trend was to obtain an increase in power of about 0.04 for each of the following: (1) increasing the number of stations per year by 100; (2) increasing the annual trend in the population by 0.25 percent (e.g., from 3 percent to 3.25 percent); (3) increasing the number of birds recorded per 100 stations by 1; (4) increasing the number of years on which the estimate was based by 1; and (5) putting an additional 25 percent of the stations on a 4-year cycle.

Obviously, these statements hold only for powers well below 1.0 and for appropriate ranges of the variables, and as noted above, the specific predictions of the regression model were often in error by 0.08 to 0.10 or even more. Nonetheless, the results above provide at least a rough guideline to the ways that power is affected by altering the variables.

Discussion

Analyses of Breeding Bird Survey Data

In 11 of the 15 data sets, 7 to 11 years were required before estimates of the long-term trend were within 3 percent of the true values. There is little basis, at present, for deciding which of our data sets most closely resemble the data that will be collected for Northern Spotted Owls. We studied the analyses to determine effects of density, sample size, outliers, and autocorrelation but were unable, with this small sample size, to reach definitive conclusions. Even if we had, it would probably be difficult to predict the form of the Northern Spotted Owl data set. For example, survey data on diurnal raptors such as the Red-tailed Hawk that inhabits open landscapes might be considerably different from survey data for Northern Spotted Owls.

Computer Simulations

These analyses suggested that a minimum of 8 years will probably be required for 80 percent probability of detecting trends in owl populations unless such trends exceed 3 percent and >10 owls are recorded per 100 stations. Such a program would probably require that >1000 stations be visited per year. If 12 years of data are available to estimate trends, then 600 stations per year, if visited on a 4-year cycle, might be sufficient to detect annual trends in the 2-3 percent range, particularly if ≥8 birds are recorded per 100 stations. Obviously these conclusions are based on the assumptions inherent in the model, and these assumptions can be refined and improved as data from the monitoring program are collected. Furthermore, it must be remembered that these surveys do not

detect trends in the total population, but provide information only about the territorial population (nonterritorial birds are almost never detected on these surveys).

The analyses bring out the value of increasing the length of the monitoring period. For example, increasing the period from 8 to 12 years increases power by approximately .16 (4 years x a gain of .04/year). If power were sufficient initially, then the number of stations visited per year could be decreased by 400 (4 years x a loss in power of .04 per year). Thus, even this simple analysis shows the great value of extending the monitoring period.

The analyses also illustrate the possible advantage of the lattice design over a design in which each station is visited once each year. The regression equation suggested that, for each 25 percent of the stations put on a 4-year cycle, 100 fewer stations could be visited per year without losing power, or power would increase by about 0.04 if the same number of stations was visited. Specific analyses using the computer simulation (rather than the linear model) also indicate the potential value of the lattice design. For example, in one simulation, a population declining at an annual rate of 3.4 percent was surveyed for 8 years. With 600 stations visited per year, power was 66 percent when all stations were visited each year and increased to 75 percent when all stations were visited every fourth year. The potential value of the lattice design is also evident by comparing sample sizes required to achieve a given level of power. For example, power was about the same with 800 stations, all visited on a 4-year cycle, as with 1000 stations all visited each year. Thus, the lattice-design, in this case, would permit a 20 percent reduction in the number of stations surveyed per year without any loss in power to detect the trend. Note, however, that the lattice design in this case would require the identification of 3200 stations, rather than the 1000 stations needed if all stations were visited each year. The lattice design thus requires that more routes be selected, but permits a smaller number to be surveyed in each year (to achieve a given power) than a design in which each route is surveyed each year.

The decision on whether to adopt a lattice design can be postponed until the second year of monitoring. At that time, a decision must be made to revisit every route surveyed in the first year or to temporarily drop some routes and introduce a corresponding set of new routes. If the new set were spatially interpenetrating with those that were dropped, then the logistics of the program would not be compromised by this tactic and the geographic dispersion of the sample would remain essentially the same. (Such a spatially interpenetrating design on a 4-year cycle is being implemented by the Environmental Protection Agency in their newly instituted Environmental Monitoring and Assessment Program (EMAP)).

Calibration of Roadside Surveys

The discussion above assumes that the roadside surveys will be a typical index in which results would be expressed as birds recorded per station or some other measure of effort, and investigators would assume that this measure had an approximately constant relationship to true density in the surveyed area. Under this assumption, changes in the index reflect changes in the population being surveyed. This assumption, however, might be incorrect for many reasons as noted by numerous researchers (e.g., Robbins and others 1986; Sauer and Droege 1990). Furthermore, many areas, including several of considerable size, will probably be searched thoroughly for territorial birds each year regardless of whether index or plot-type methods are employed in the monitoring program. These data provide a basis for "calibrating" the index data by using the technique known as double-sampling. With this approach, the index data may be adjusted to provide estimates of density (of territorial birds). We describe this method below.

A double-sampling approach for monitoring territorial Northern Spotted Owls might proceed as follows. First, areas to be searched thoroughly would be selected and delineated on maps. The main criterion for selecting these areas would be availability of surveyors willing to search the areas thoroughly (defined, for example, as searching according to protocols that have been developed by the USDA Forest Service). The areas could be large (e.g, demographic study areas) or small (e.g., single patches of old-growth) and would not have to be selected randomly, though random selection might be advantageous in some cases. Presence of a bird within the area would be defined as occurring when the bird's activity center was within the thoroughly searched area. The assumption would be made that such searches constituted censuses of the territorial birds in the areas. The results would thus provide "true densities" for each area. Of course, in reality some birds would be missed, but such errors would probably have little effect on the estimate of trend if fewer than, say, 10 percent of the birds were missed, and this figure did not vary greatly between years. The thoroughly searched areas would be regarded as one stratum.

The next step in developing the program would be the delineation of additional strata. Strata could be defined to include owl conservation areas and other high-interest areas, areas in which density is anticipated to be high, areas in which density is anticipated to be low, etc. The strata would not have to be contiguous; thus one stratum might consist of all the areas in a given region dominated by old-growth, another stratum might consist of all the areas with moderate amounts of old-growth, and so on. Each year, randomly selected routes in all of the strata would be visited. Sampling intensity could vary between these strata so that more stations were located within areas of high interest, easy access, or high density. Sampling intensity in these strata could be determined subjectively or by using formulas for maximizing statistical efficiency.

Intensive work within the thoroughly studied stratum would reveal the actual densities in these areas. Two estimates would thus be available: the results from the roadside routes and the actual density. The ratio of these two results would be used to "calibrate" the index in other strata. For example, if the mean number of birds per roadside route was 2, and the true density of owls per 100 km^2 was 3, then the results for roadside routes in other strata would be multiplied by 1.5 to obtain an estimate of actual density per 100 km^2. The multiplier might differ between years and areas.

One problem with this approach is that in double-sampling methods, the sample of sites searched thoroughly is usually a random sample from the entire population. This permits unbiased estimation of actual densities. In the case of Northern Spotted Owls, the thoroughly searched areas have not been randomly selected. This may not cause serious problems and, even if problems do arise, various ways can be imagined for resolving them. The issue, however, needs to be addressed before the final design is determined.

Conclusion

The analysis of Breeding Bird Survey data and the computer simulations suggest that the roadside survey should include visits to approximately 750 stations per year in each of the three states, and that data collection will have to continue for at least 8-10 years before reliable estimates of long-term trends can be obtained. An average of about 15 stations are usually visited per person-night, so the fieldwork would require 50 person-days per state, or about 15 days per physiographic province, a modest expenditure of effort that could easily be continued for many years.

Although these are preliminary estimates and will need revision after the first few years of data have been collected, the analyses above identify some of the most important design considerations, suggest methods that appear feasible and efficient, and indicate that the needed data can be collected at reasonable cost. In combination with the demographic and population modeling studies recommended in the Recovery Plan (USDI 1992), these methods will provide comprehensive information about trends in different areas and habitats and should provide a sound basis for refining the recovery program and ultimately for delisting the subspecies.

Acknowledgments

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Monitoring Birds in a Regional Landscape: Lessons from the Nicolet National Forest Bird Survey[1]

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Abstract: The Nicolet National Forest Bird Survey represents one of the first systematic bird monitoring programs in a USDA National Forest. Volunteers visit approximately 500 permanently marked points biennially (250 each year) during a single weekend of mid-June. Results from the first 6 years provide a general inventory of the Forest's avifauna, documentation of geographic gradients, and evidence of significant bird-habitat relationships. The point count method has been designed to accommodate flexibility in data analysis. Birds are recorded in 0- to 3-, 3- to 5-, and 5- to 10-minute intervals to permit adjustment of count duration. Two sets of samples have been established, one (approximately 300 points) representing major habitat categories, the other (200 points) consisting of randomly chosen points along roadsides. Mean counts from the two sampling schemes are statistically different from one another, whereas results from the same sets of sites during different years are not significantly different. Birds of localized habitats such as wetlands are less abundant in the randomized samples. Our method departs most significantly from recommended standards by allowing several observers to participate in each point count. We recommend a modification of the original method to permit observations by only a single experienced observer during the formal point count.

Large-scale monitoring programs like the North American Breeding Bird Survey (BBS) provide critical information about the status of bird populations across their ranges (Robbins and others 1986). Such programs, however, cover only a minute fraction of the area inhabited by most bird populations. Additional monitoring needs exist on a local level, where land managers often wish to know more specific information about species distributions, critical habitats, and the effects of prescribed management activities. The supervisor of a wildlife refuge, for example, might want to know which habitats should be protected for the benefit of rare species. The staff of a public park might want to identify areas of particularly high species diversity for the enjoyment of visitors. Biologists in a National Forest might want to know whether viable populations of avian indicator species persist within the forest boundaries.

Controversies about National Forest management in northern Wisconsin (Kuhlmann 1990) have underscored the need for better information about local animal and plant populations. Because they are familiar and relatively well-studied elsewhere, birds have figured prominently in recent public debates over forest management policies. Indeed, of 32 management indicator species in the Nicolet National Forest, 25 are birds (USDA Forest Service 1986). In 1987, the Northeastern Wisconsin Audubon Society and USDA Forest Service staff organized a volunteer inventory to improve information about the status and habitat preferences of birds in the 270,000-ha Nicolet National Forest. Point counts are used to monitor approximately 300 habitat-based and 200 randomized points. Results are intended to guide ecologically sound decisions by Forest Service authorities and to help document the long-term effects of management practices.

A secondary aim of the Bird Survey is to provide an opportunity for people to become familiar with the Nicolet National Forest and its biota. This purpose leads to compromises from an ideal sampling scheme, insofar as field sampling teams include both highly skilled and less skilled observers. In the long-run, however, less skilled observers gain expertise for future bird surveys and help build an informed public constituency for participation in National Forest planning.

In this paper we present some results from the first 6 years of the Bird Survey and describe how the point count method is applied toward three specific objectives: (1) a geographic inventory of bird species, (2) an assessment of species' habitat associations, (3) long-term monitoring of regional bird population trends. These objectives are likely shared by many land managers, and therefore we hope that our experiences will provide direction for future (and perhaps even existing) bird monitoring programs.

Methods

Point Selection

Sample points were chosen to represent major habitat types within the Forest (*table 1*). Six habitat types defined by dominant tree species represent 77 percent of all points. An additional 44 subcategories provide a more detailed description of each site. For example, forest subcategories are based on age and tree species (e.g., "young red pine," "mature mixed hardwoods"). Other categories are subdivided on the basis of size and widely-recognized habitat definitions ("open bog," "large upland opening," "shrub swamp"). Whenever possible, these *habitat-based* survey points were established 100 m or more within the target habitat type in order to reduce contact with adjacent habitat types or open road corridors.

The number of sample points during the first 2 years was determined by the number of qualified observers (*table 2*). In order to maximize coverage, only one-half of the forest is sampled during a given year. Since 1989, we have established a sample of approximately 310 permanent habitat-based points (150 in the southern half of the forest, 160 in the northern

[1] An abbreviated version of this paper was presented at the Workshop on Monitoring Bird Population Trends by Point Counts, November 6-7, 1991, Beltsville, Maryland.

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Table *1-General habitat groupings and subcategories used to describe survey points in the Nicolet National Forest Bird Survey. In some cases, subcategories are further divided to indicate the relative age of the forest, size of opening, or special habitat feature. Sites labeled South are located in the southern half of the forest; sites labeled North are located in the northern half of the forest.*

Habitat groupings	Sub-categories	Number of sites	
		South	North
Aspen and birch	4	24	24
Spruce and fir	6	8	9
Conifer (Pine and Hemlock)	9	26	30
Hardwood	4	37	44
Oak	2	7	3
Lowland conifer	4	13	17
Treeless wetland	4	17	10
Pond	2	2	3
Lake riparian	5	6	9
Stream riparian	2	3	2
Rural town	1	4	4
Upland opening	1	6	7
Total	44	153	164

half). All of these points and their road access are marked to ensure that the same points are sampled from year to year. This permits flexibility in habitat definitions for alternative classification schemes or as habitat conditions change over time.

Selection of the habitat-based sample points was biased by our desire to include a wide range of habitat types (some of which are geographically rare) and the requirement that the habitat surrounding each point is extensive enough (ideally >15 ha) to adequately represent the target habitat type. Extrapolation of results to the entire forest is complicated by this nonrandom method of point selection. In order to provide a more unbiased sample of regional bird populations, we selected an additional 100 *randomized* points during 1992 in the northern half of the Forest and another 100 randomized points during 1993 in the southern half of the Forest. Each of these new permanent points is located at the road nearest randomly selected geographic coordinates, without respect to habitat type or other geographic features. All locations have been incorporated into the National Forest's Geographic Information System (GIS) in Rhinelander, Wisconsin.

Field Methods

The annual Bird Survey takes place during a single weekend in mid-June. Volunteers work in teams, led by a skilled bird observer who is designated on the basis of: (1) past participation in the North American Breeding Bird Survey, (2) current research or professional experience with birds, or (3) bird identification skills that have been demonstrated to the project organizers through recommendations or personal experience. The leader is responsible for all bird identifications. Lack of a systematic testing process for group leaders can be seen as a weakness of the project and is a legitimate concern regarding the identification of rare or easily confused species. Fortunately, the program has attracted some of the State's best birders.

Many people who wish to participate in the Bird Survey are not skilled enough in bird identification to conduct point counts on their own. In order to include these volunteers, the establishment of field teams was seen as a practical alternative. This approach has the secondary benefit of providing experience for nonleaders who eventually might acquire the expertise needed to lead a group of their own. We recognize that the use of field teams (rather than single observers) creates difficulties for comparisons with other studies, although in practice few bird detections are contributed by nonleaders.

Each morning, teams are assigned 5 to 6 habitat-based survey points and 3 to 4 randomized roadside points. Point counts are conducted between dawn and approximately 9 a.m. (Approximately 10 wetland or riparian sites, accessible only by canoe, are occasionally sampled during early evening if the number of observers is inadequate to cover them earlier.) At each point all birds seen or heard are recorded during a 10-minute period or, in the case of randomized points, a 5-minute period. With the help of preprinted data forms (*fig. 1*), the first detection of each bird (individual) is recorded within one of three time intervals (0 to 3 minutes, 3 to 5 minutes, 5 to 10 minutes) and one of two status categories: (1) within the target habitat or (2) flying over, or within an adjacent nontarget habitat. These distinctions permit flexibility in data analysis to conform with other studies or

Table 2--*Summary of general results from the Nicolet National Forest Bird Survey. Cumulative numbers of species include all birds recorded during the Bird Survey point counts through the year indicated*

	1987	1988	1989	1990	1991	1992
	South	North	South	North	South	North
Total number of points	65	116	151	159	150	156
Total number of species	95	120	108	118	103	114
Total number of species recorded in >1 count	65	89	89	89	87	85
Number of species recorded at >10 percent of sites	34	23	32	25	26	23
Mean number of individuals/count	15.5	12.4	14.0	14.0	14.1	14.2
Cumulative number of species	95	133	140	149	150	153

NICOLET NATIONAL FOREST BIRD SURVEY

FORM A

Site #:_____ Habitat Type:_____ Date:_____

Group Expert(s):_____ Marker Located? Yes No Time:_____

Wind: calm light moderate strong Temp.: <40 41-50 51-60 61-70 >70

Sky Conditions: clear partly cloudy mostly cloudy overcast foggy lt. rain/drizzle

w/in target habitat type	not in habitat (flying over, in adjacent habitat)
3 min.	
5 min.	
10 min.	
Species encountered to/from site:	

CENSUS SUMMARY

(birds in target habitat only)

Species	Code	3	5	tot.	seen?		Species	Code	3	5	tot.	seen?

Notes:

Figure 1--Sample data form used in the Nicolet National Forest Bird Survey. Horizontal blocks indicate time when individuals were first detected (3 minutes = 0 to 3 minutes, 5 minutes = 3 to 5 minutes, 10 minutes = 5 to 10 minutes).

to compare counts from habitat-based points with the randornized 5-minute counts. Bird detections also are recorded on a circular map to help estimate the abundance of common species.

Data Management

Completed data forms are returned to site envelopes and eventually filed at the Nicolet National Forest headquarters in Rhinelander. Forest Service personnel or volunteers enter the results in a computerized data base which is interfaced with the Nicolet National Forest's Geographic Information System (GIS). Each survey locality has been digitized in the GIS, where it is supplemented by information about vegetation features, site history, and geographic characteristics. Bird records are entered as observations of individual species at individual points during a single year. For example, the observation of two Red-eyed Vireos (*Vireo olivaceous*) at Site 135 during 1991 would represent a single record in the data base. This scheme permits us to sort the data by species, site, year, or any combination of these categories. Counts for each species are entered into fields representing the time of observation (0 to 3 minutes, 3 to 5 minutes, or 5 to 10 minutes) and whether or not the bird occurred in the target habitat.

Results

Inventory

Before this Bird Survey no systematic inventory of breeding birds in the Nicolet National Forest had been reported. Information was available from local experts and Breeding Bird Survey routes within the Forest, but none of these sources could give a comprehensive picture of Forest birds.

As of 1992, 153 species had been recorded during the point counts, and additional species were reported at other times during the survey weekends. Results (*table* 2) show that the majority of breeding bird species are uncommon, encountered during fewer than 10 percent of the point counts. During individual counts, most species (66 percent of 5758 detections) have been represented by only one individual; only 12 percent of all species recorded during a given point count were represented by three or more individuals. These proportions are nearly identical for both the northern and southern halves of the Forest (*fig. 2*).

Early morning point counts might be expected to underrepresent or miss certain species altogether. Nocturnal species, for example, are rarely recorded. Nevertheless, over the course of 6 years and 910 point counts, even some of the

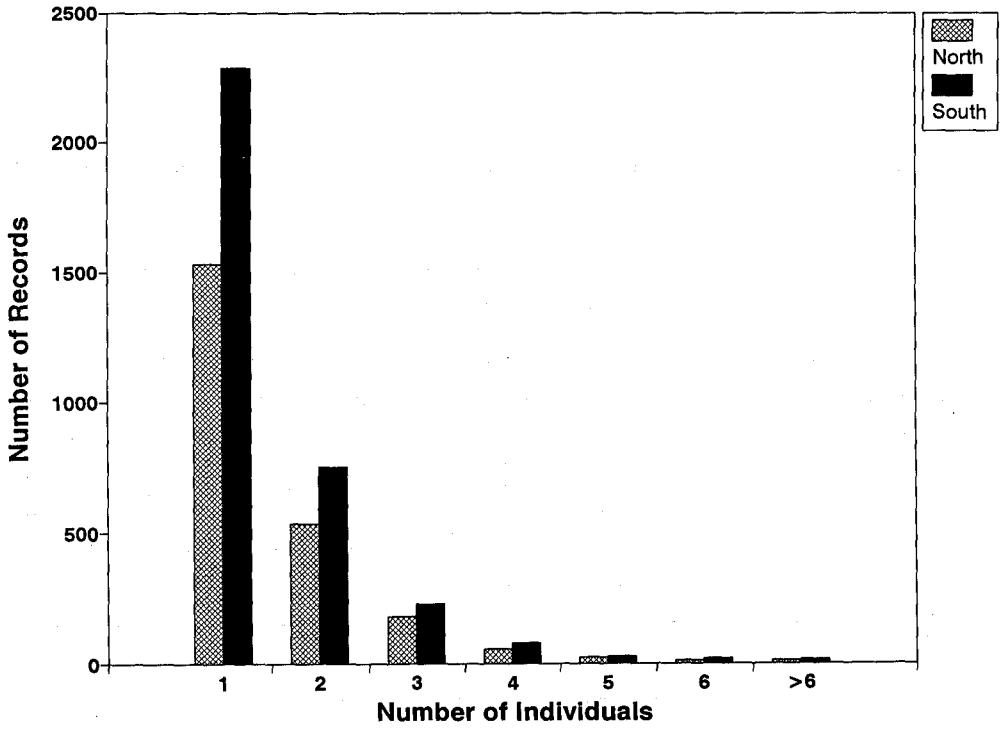
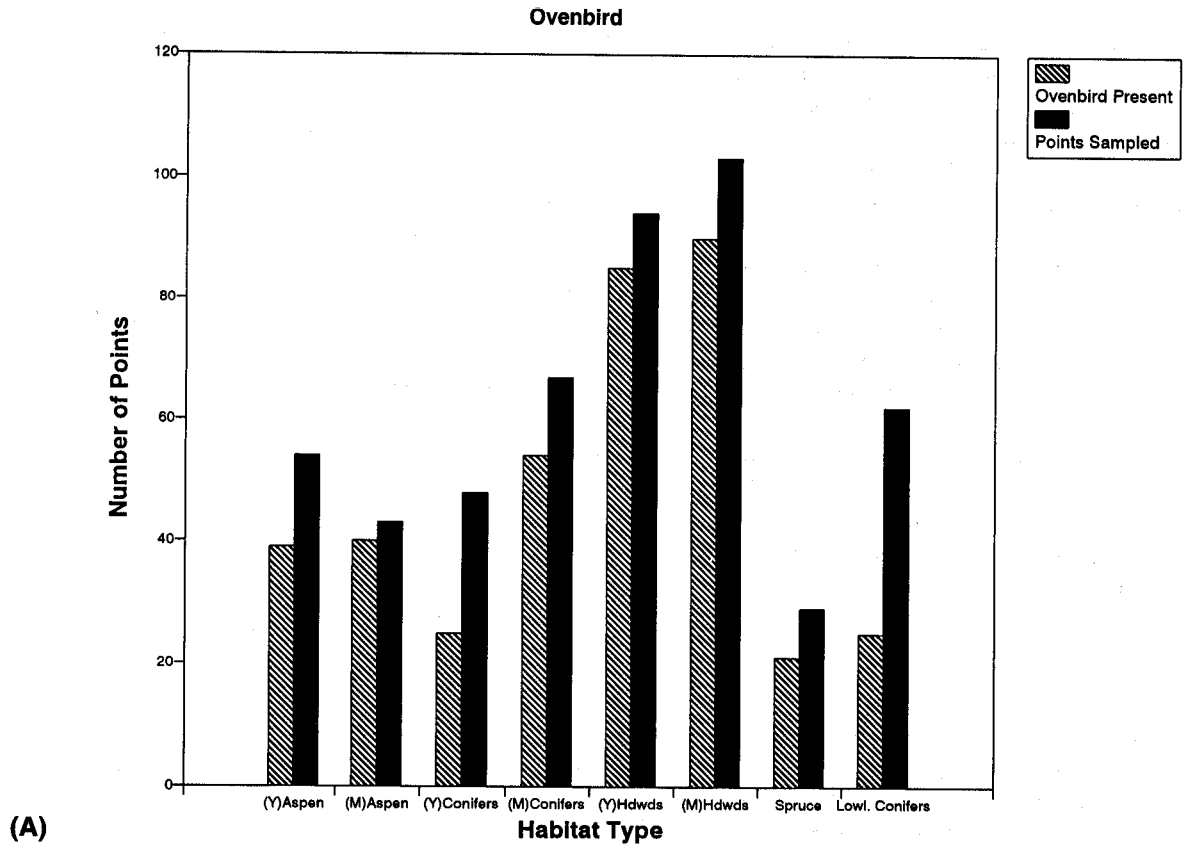
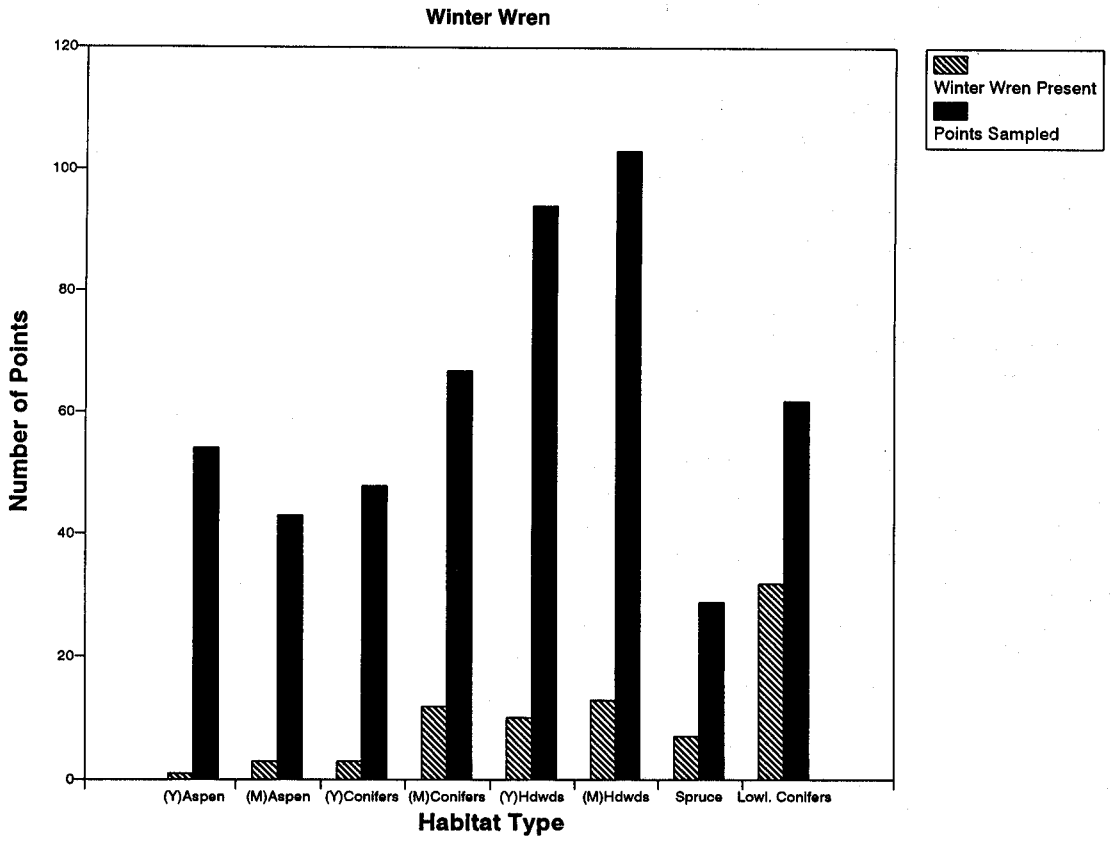


Figure 2--Relative abundance of species detected during point counts of the Nicolet National Forest Bird Survey (1987-1991). Number of records refers to the number of species detections represented by 1, 2, 3, 4, 5, 6, or >6 individual birds. Detection of three Ovenbirds in a single point count, for example, would add one record to the column labeled 3



(A)



(B)

Figure 3--Distribution of Ovenbirds (A) and Winter Wrens (B) among major forest habitats in the Nicolet National Forest. Sites are characterized by the habitat categories given in *table 1* with separation into young (*Y*) and mature (*M*) stands

Forest's rarest species have been encountered, including Northern Saw-whet Owl (*Aegolius acadicus*), Red-shouldered Hawk (*Buteo lineatus*), Northern Goshawk (*Accipiter gentilis*), Yellow Rail (*Coturnicops noveboracensis*), Black-backed Woodpecker (*Picoides articus*), and Connecticut Warbler *(Oporornis agilis*). Several species such as Whip-poor-will (*Caprimulgus vociferus*), Merlin (*Falco columbarius*), and Spruce Grouse (*Dendragapus canadensis*) are known to reside in the Forest but have yet to be recorded during the 10-minute point counts; all of these have been observed at least once by participants going to or from their survey points, however, and their presence has been noted in a qualitative list of species observed during the Bird Survey weekend. Only a handful of species likely to breed in the area, including Great Gray Owl (*Strix nebulosa*), Red Crossbill (*Loxia curvirostra*), and White-winged Crossbill (*Loxia leucoptera*), have never been recorded during the Bird Survey weekends.

Habitat Associations

With the exception of aquatic birds, no species recorded consistently during the Bird Survey has been restricted to a single habitat category (as we have defined them). Most species occur in a rather wide range of structurally similar vegetation types. Habitat associations can be tested by comparing observed frequencies of birds with expected frequencies based on the numbers of point counts in the respective habitat types. Ovenbirds, the most widespread species in the Forest, have been recorded regularly in every forest habitat category (*fig. 3a*). Nevertheless, the observed distribution is statistically nonrandom (χ^2 = 19.1, df = 7, P <0.025). Winter Wrens (*Troglodytes troglodytes*) (*fig. 3b*) show a highly nonrandom distribution among habitat types (χ^2 = 67.8, P <0.001, n = 83) because of their affinity for lowland conifers where individuals were recorded at 32 of 62 sites, compared with an expected frequency of 9.22. Scarlet Tanagers (*Piranga olivacea*), on the other hand, show no statistically significant habitat preferences among major forest types (χ^2 = 7.98, P >0.25, n = 81).

Geographic Patterns

Forest Service biologists and planners are interested in the bird species composition at specific localities for assessing the effects of timber harvest or other management activities. Presence or absence of bird species at these sites can be predicted by patterns of habitat association. These predictions are not always reliable, however, because species sometimes occur in atypical habitats or are missing from habitats which are otherwise characteristic. Pine Warblers (*Dendroica pinus*), for example, show a clear preference for pine forests (χ^2> 3;84, P <0.05, 2x2 contingency test), but over the first 6 years of the Bird Survey, Pine Warblers have been recorded at only 13 of 55 points in pine-dominated forests. Predictions of local bird species composition can be improved by considering geographic patterns in addition to habitat associations. Results of our Bird Survey document two types of geographic patterns:

1. Over a distance of only 100 km, 16 species show statistically significant geographic trends in abundance (χ^2> 3.84, P <0.05, 2x2 contingency test). Yellow-billed Cuckoo (*Coccyzus americanus*), Great Crested Flycatcher (*Myiarchus crinitus*), Northern Oriole (*Icterus galbula*), Purple Finch (*Carpodacus purpureus*), Indigo Bunting (*Passerina cyanea*), Scarlet Tanager, Brown Thrasher (*Taxostoma rufum*), and Wood Thrush (*Hylocichla mustelina*) occur more frequently in the southern half of the forest; Mallard (*Anas platyrhynchos*), Olive-sided Flycatcher (*Contopus borealis*), Least Flycatcher (*Empidonax minimus*), White-throated Sparrow (*Zonotrichia albicollis*), Song Sparrow (*Melospiza melodia*), Black-throated Blue Warbler (*Dendroica caerulescens*), Chestnut-sided Warbler (*Dendroica pensylvanica*), and Black-throated Green Warbler (*Dendroica virens*) occur more frequently in the northern half of the Forest. Based on this information, protection of bogs in the northern half of the Forest, for example, will have a more positive effect on Olive-sided Flycatchers than will protection of bogs in the southern half of the Forest.

2. In addition to latitudinal patterns, results from the Bird Survey help identify centers of abundance for certain species. Northern Waterthrushes (*Seiurus novaboracensis*) typically favor wet lowland or riparian forests (Robbins 1991), but they are absent from many such areas in northern Wisconsin (*fig. 4*). Where they have been found, waterthrushes often are one of the most conspicuous and locally abundant species. Management efforts for such species obviously will be most effective if they are aimed at, or near, areas where the birds have been documented, not simply areas of appropriate habitat.

Population Trends

Overall abundances of bird species (*table 3*) generally vary less than 5 percent between years; mean variation in frequency for the 20 most abundant species was 3.9 percent between 1989 and 1991 (southern half of the forest), and 5.5 percent between 1990 and 1992 (northern half of the forest). The most striking irregularities in abundance were unusually high numbers of Rose-breasted Grosbeaks (*Phaucticus ludovicianus*) and Scarlet Tanagers during 1989 and relatively high numbers of Red-eyed Vireos in 1992.

Despite consistency on a large scale, results from individual points show considerable variation over time. On average, only about one-half of the birds recorded during the first year are counted at the same locality 2 years later (mean similarity = 47.6 percent, s.d. = 19.7). This suggests that even 10-minute point counts offer only a snapshot of the local bird community and cannot substitute for intensive inventories if one is interested in the bird species composition at a specific site.

Other Findings

Several of our results have relevance for the design of bird monitoring programs. Like other authors in these Proceedings (e.g., Buskirk and MacDonald), we found that species are added to point counts according to a nonlinear function of diminishing returns (*fig. 4*). On average, 64 percent of the bird species recorded during our 10-minute counts in forest habitats were detected during the first 3 minutes (n = 217, 1989 and 1991); 63 percent were recorded during

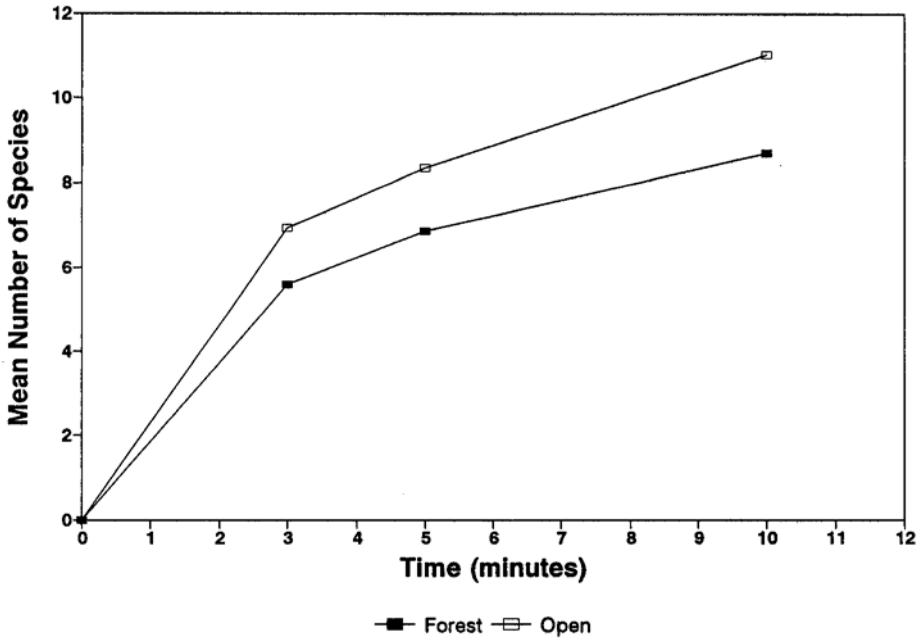


Figure 4--Increase in the number of species detected as duration of point count time increases from 3 to 10 minutes. Data are derived from 1987 and 1991 counts in the southern half of the Nicolet National Forest (*n* = 217 for forest habitats, 53 for open habitats, including treeless wetlands and grasslands).

the first 3 minutes in open habitats (*n* = 53). During the first 5 minutes, 79 percent and 76 percent of the species were recorded in forest and open habitats, respectively. As the count duration is increased, samples become complicated by movements of birds into the detectability range. We found that wide-ranging species like American Goldfinch (*Cardeulis tristis*), American Robin (*Turdus migratorius*), Cedar Waxwing (*Bombycilla cedrorum*), Scarlet Tanager, and woodpeckers were detected more frequently in the second 5 minutes of our 10-minute counts than expected according to the proportion of all species encountered (χ^2> 3.84, P < .05, 2x2 contingency test). Species like Red-eyed Vireo, Black-throated Blue Warbler, Least Flycatcher, and Winter Wren were disproportionately more abundant in the first 5 minutes. This implies that two 5-minute counts at separate points are not equivalent to a single 10-minute count, even if bird distributions are uniform in space, because the 10-minute counts will include a higher proportion of wide-ranging birds.

The distribution of species in the randomized sites (*figure 5*) differed significantly from the distribution of species in the original habitat-based sites during 1992 (χ^2 = 37.10, P <0.05, df = 19, 2x2 contingency test comparing frequencies of the 20 most abundant species). Comparisons of species distributions from year to year (1988 versus 1990, 1990 versus 1992) at the habitat-based sites showed no corresponding difference (χ^2< 17.0, P >> 0.05). Our original site selection process was biased to ensure representation of localized habitats such as wetlands and openings. As a result, species like Song Sparrow, Common Yellowthroat (*Geothlypis trichas*), and Swamp Sparrow (*Melospiza georgiana*) were represented much less frequently among the randomized sites than they were among the habitat-based sites. Typical forest species like Red-eyed Vireo, Ovenbird (*Seiurus aurocapillus*), Black-throated Green Warbler, Yellow-bellied Sapsucker (*Sphyrapicus varius*), and Scarlet Tanager were more frequent in the randomized sample. Interestingly, birds of forest edges or openings-like American Robin, Chestnut-sided Warbler, Mourning Warbler (*Opornis philadelphia),* American Crow (*Corvus brachyrhynchos*), Common Raven (*Corvus corax*), and Indigo Bunting-also were significantly more frequent in the randomized samples (χ^2 > 3.84, P < 0.05, 2x2 contingency test), suggesting that the location of randomized sites along roads affected the relative abundance of species in our results.

Discussion

The Nicolet National Forest Bird Survey was designed without the guidance of national or international standards such as those presented in this volume. Although flexibility was built into our methods to allow analysis of 3-, 5-, or 10-minute counts, several features of our Bird Survey depart from the newly recommended standards. Multiple observers were permitted because many nonexperts were interested in taking part in the project. The effects of extra observers are not known, although in practice most if not all detections of

Table 3--*Species recorded most frequently in Nicolet National Forest Bird Survey. Percent of occurrence indicates the percentage of all points sampled during a given year in which the species was recorded. Sites labeled South are located in the southern half of the forest, sites labeled North are located in the northern half of the forest*

	Percent occurrence					
	South			North		
Species	1987	1989	1991	1988	1990	1992
Ovenbird	71	69	69	54	61	56
Red-eyed Vireo	51	57	61	48	43	64
American Robin	26	30	31	34	35	37
Rose-breasted Grosbeak	32	48	29	23	27	32
Blue Jay	43	35	28	15	25	21
Hermit Thrush	20	38	31	17	27	33
White-throated Sparrow	29	26	25	37	37	39
Black-capped Chickadee	23	27	27	19	21	20
Black-throated Green Warbler	32	21	20	28	35	32
Chestnut-sided Warbler	6	13	18	19	33	26
Least Flycatcher	16	16	18	27	26	20
Nashville Warbler	19	21	17	12	26	22
Song Sparrow	23	17	17	21	25	33
Veery	15	21	18	11	16	12
Great Crested Flycatcher	29	23	19	9	10	8
Eastern Wood-Pewee	20	19	19	18	13	15
Mourning Warbler	14	18	13	13	15	21
Common Yellowthroat	25	14	15	16	17	19
Cedar Waxwing	14	17	22	9	10	16
Scarlet Tanager	11	24	15	8	9	10

birds are identified by the single group leader. Extra observers have stimulated a broad level of interest and camaraderie that has helped sustain the volunteer project over 6 years.

Selection of sites based on habitat has introduced a bias in the relative abundance of species among sample points. This procedure was employed because forest managers were interested in predicting the effects of logging and other management activities on bird populations of specific habitat types. For the same reason, our original sample points are generally located away from roads at least 125 m within the target habitat. Despite our intentions, the highly heterogeneous nature of the Forest and the small size of many forest stands have meant that many of our habitat-based sample points actually represent a mixture of habitat types. The inaccuracy of mapped forest descriptions also has introduced some complications. More detailed descriptions of habitats surrounding our sample points are needed; at least one such study is underway and others are facilitated by the fact that points are permanently marked and mapped within a computerized geographic information system.

During 1992, the addition of approximately 100 randomized points along roads proved to be well within the capacity of available volunteers and time. The addition of 100 more sites during 1993 gave us two parallel samples (habitat-based sites versus randomized sites) for comparisons with other studies. Comparison of these two alternative sampling schemes shows that selection of sample points can have a statistically significant influence on the documented relative abundances of birds. Species of rare or localized habitats like wetlands are underrepresented in the random samples. Since these species are significant for management considerations, we will continue to sample both habitat-based sites and randomized points.

Other departures from recommended standards are relatively minor or can be corrected by analysis of existing data. For example, census duration can be adjusted from 10 to 5 minutes by simply excluding birds first detected during the second 5 minutes of our counts. Evening counts have been permitted for inaccessible wetlands, but these sites comprise such a minor part of our data base that they can be ignored if desired. We will continue to sample the inaccessible sites whenever possible because they contribute to the inventory function of the survey by covering habitats that would not otherwise be represented.

From the very start, planners of the Bird Survey hoped that the project would not only provide information for local

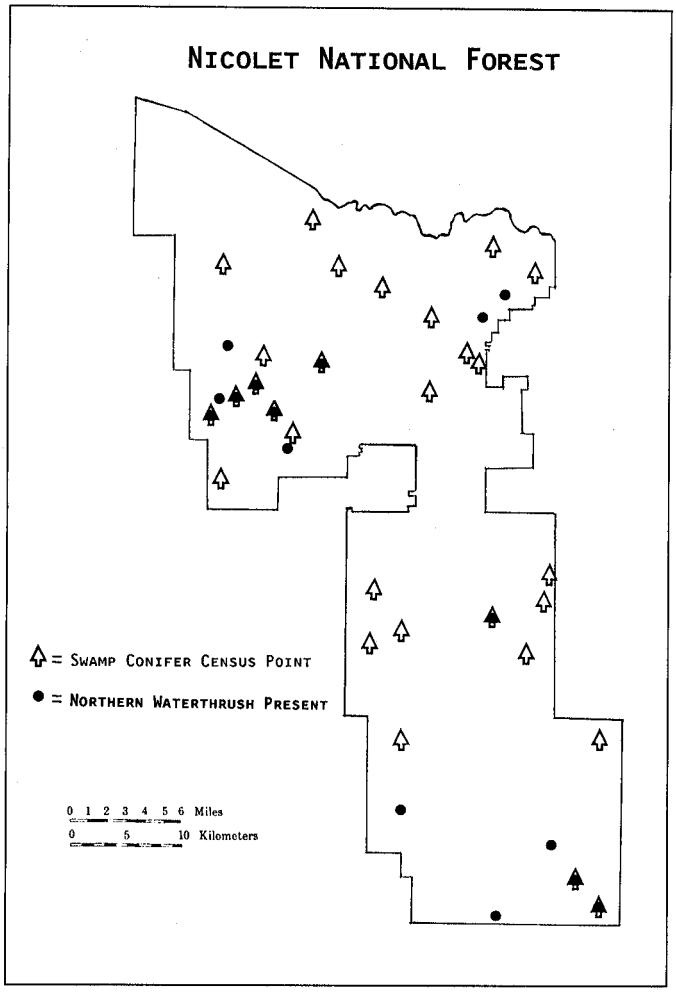


Figure 5--Geographic distribution of Northern Waterthrushes and swamp conifer habitats in the Nicolet National Forest. Solid circles that are not associated with a tree figure represent occurrences of Northern Waterthrushes in other habitats, including shrub swamp,

applications, but would also contribute to larger scale bird monitoring programs. We have succeeded in maintaining flexibility of census duration and already have modified the site selection process. We expect to introduce other changes that will facilitate comparisons with other surveys. Complications due to multiple observers, for example, might be minimized by the following: detections by only a single observer can be included in the formal point count. Observations by other participants can be added to a separate list, just as we separately record birds that are seen before and after the formal 10-minute count period. These extra records will help characterize local bird assemblage for local considerations but will not affect larger scale comparisons between point counts.

If we assume that birds can be detected within an average 150 m (Wolf and others, in this volume), the Bird Survey covers about 1.3 percent of the 270,000 ha Nicolet National Forest, more than 10 times the coverage of larger scale programs like the North American Breeding Bird Survey (Robbins and others 1986). Overall the Forest's common diurnal birds are now well documented and their observed relative abundances (*table 4*) are consistent with results from other recent studies (Hoffman and Mossman 1990, Keller, unpublished data, Mossman and others 1990, Robbins 1991, Schneider 1992). The Bird Survey also has adequately documented north-south patterns of abundance for numerous species. Patterns of habitat association also have been demonstrated, but in many cases they are less obvious than geographic patterns. In some cases (e.g., Scarlet Tanager), no habitat association has been documented beyond the species' obvious preference for forests. A finer analysis of bird-habitat associations certainly is appropriate for meeting the Bird Survey's objectives.

Only about one-half of the species recorded at a given site (on the average) have been recorded during the next visit 2 years later. Such a high degree of variation makes it difficult to establish the resident status of species at specific sites. Many sources are likely responsible for this variation, including the fact that different observers may visit sites during different years; the exact locality, prior to establishment of permanent markers, might have been different from one count to the next; and, of course, the birds themselves move to and from sites in the course of their daily activities and population dynamics. As a result of these factors, our point counts do not provide adequate descriptions of birds at specific localities, but results from many years provide at least general sketches

Table 4--*Comparison of frequencies for the 20 most abundant species in habitat-based sites versus randomized sets of point counts during 1992. The percent of occurrence indicates the percentage of all sample points where the species was recorded. For the sake of comparison, results include only species recorded during the first 5 minutes of the count.*

Species	Percent occurrence	
	Habitat-based	Randomized
Red-eyed Vireo	60	77
Ovenbird	51	83
White-throated Sparrow	36	43
Hermit Thrush	29	37
Song Sparrow	29	19
Black-throated Green Warbler	26	41
American Robin	25	56
Least Flycatcher	25	29
Chestnut-sided Warbler	24	47
Rose-breasted Grosbeak	24	39
Nashville Warbler	19	22
Mourning Warbler	17	30
Black-capped Chickadee	16	23
Blue Jay	15	24
Common Yellowthroat	15	6
Winter Wren	14	18
Eastern Wood-Pewee	13	16
Swamp Sparrow	12	3
Yellow -rumped Warbler	11	14
Cedar Waxwing	10	12

of local avifaunas. For example, presence of Winter Wrens during four of five biennial counts would argue that the species is typically resident at that site. Observations of birds before or after the formal count period can be very important also in describing the local bird community. This information should not be discarded because many applications (e.g., environmental impact analysis, site planning, etc.) require only a description of the birds at sites of interest. Such results, however, cannot be considered a substitute for detailed site inventories.

In summary, point counts of 5- or even 10-minute duration provide only a snapshot of the local bird community. Like a photograph, longer exposures (count durations) permit finer resolution of these bird communities, but the image becomes increasingly vulnerable to blur caused by movements of birds into or out of the count area. The most significant contribution of monitoring programs like the Nicolet National Forest Bird Survey is the documentation of larger scale patterns, which produce a clearer overall picture of the avifauna; these patterns, in turn, can be used to predict the composition of birds at sites of interest. As the project is continued over many years, the large-scale picture will become clearer and the reliability of site-specific predictions will almost certainly improve.

Acknowledgments

The Nicolet National Forest Bird Survey has been developed through the efforts of many individuals, including John Braastad, Denise Friedrick, Michael Grimm, Terrie Howe, Joseph Kastenholz, Gerald Lemerond, Thomas Matthiae, Jennifer Nieland, William Reardon, Michael Reed, Michael Peczynski, John Probst, Gary Zimmer, and more than 100 volunteer participants. Funding for the project, including data analysis, has come from the Nicolet National Forest and the North Central Forest Experiment Station of the USDA Forest Service and the University of Wisconsin-Green Bay.

An Overview of the Forest Bird Monitoring Program in Ontario, Canada[1]

Daniel A. Welsh[2]

Abstract: In 1987, the Canadian Wildlife Service (Ontario Region) initiated a program to inventory and monitor trends in forest birds. The Forest Bird Monitoring Program (FBMP) was designed to describe changes in numbers over time for all forest songbirds, to develop a habitat-specific baseline inventory of forest birds (species composition and relative abundance), and to develop regionally accurate habitat association profiles for all common forest birds. It was intended to build upon and augment the broad regional base of the Breeding Bird Survey (BBS). The program relies on volunteers for annual surveys to monitor trends, supplemented by salaried observers to establish sites and conduct baseline inventories. This paper provides an overview of procedures and methodology and some general comments on habitat-specific surveys and volunteers. The paper is intended as a description of the program and does not contain extensive data justifying the protocol. The initial selection of procedures for FBMP was based primarily on scientific literature, field experience, and the opinion of experienced volunteers. An additional section comparing 3-, 5-, and 10-minute counts based on 1992 data has been added to the paper since the 1991 workshop.

History of Project

In 1987, forty volunteers surveyed 310 stations (62 sites) in a pilot project to examine the feasibility of a volunteer-based program to monitor forest bird trends. The methodology was similar to that currently used, except that observers recorded birds found within an imbedded 50-m radius fixed-distance plot as well as for the unlimited-distance plot. Distance estimation difficulties led to abandoning the 50-m inner plot. The pilot year was successful, and the program has operated at a modest scale of about 200 to 300 stations every year since, expanding somewhat in 1991. The 5-year database is presently being analyzed for trends and to better understand the data set characteristics.

Related projects using the same methodology have concentrated on inventory and habitat associations of bird communities in the boreal forest in relation to forest ecosystems. Over the past 4 years, about 3000 stations have been sampled, and a model to predict bird species composition and abundance in relation to forest type has been developed for Northwestern Ontario.

Site Selection and Station Layout

Forest stands representative of the major forest habitats of Ontario are selected as study sites. Specific site selection is usually made jointly by the volunteer, Canadian Wildlife Service (CWS), and other agencies and incorporates consideration of permanence and access as well as representativity. CWS has also established more than 100 sites in protected areas during forest bird inventories that volunteers are encouraged to take over. The goal is to have adequate sampling in all major habitat types, and the overall sampling design is controlled by CWS.

Five sampling locations called stations are established in each forest site. Stations are located at least 100 m from the edge of the forest type and at least 250 m apart. Although the actual size of the stand is not specified, an area of at least 25 ha is necessary to locate five stations meeting the guidelines. In exceptional circumstances, stations are located in more than one forest fragment. All stations are clearly marked to facilitate relocation in subsequent surveys, and most bear permanent markers and have linking trails between stations which are flagged as well.

Bird Survey Procedures

The survey procedure used is an unlimited-distance point count based, in general, on the approach described by Blondel and others (1970) and used by numerous other investigators (Fuller and Moreton 1987, Robbins and others 1989). Our procedure is as follows:

(1) Counts begin as soon as possible after observers arrive at the station. Normally they require a short 10- to 30-second rest to get their breathing slowed down and their ear "attuned."

(2) Observers record all birds seen and heard during a 10-minute sample period, ensuring that each individual is counted only once. Counting is done by mapping all records on the map sheets provided, keeping track of movements as best they can, and paying particular attention to simultaneous records. We find that mapping (marking the exact location and noting movements) is the best way to minimize duplicate records. Data mapping forms used are similar to those included in *Field Methods for Monitoring Landbirds* (Ralph and others 1993) and in the Monitoring Avian Productivity and Survivorship (MAPS) program instructions (DeSante 1992). Standardized species abbreviations are used, and different symbols record the status of each bird (e.g., singing male, pair, female, nest, calling bird, etc.). We emphasize that it is critical to record status symbols accurately because they determine the assigned breeding evidence; some levels assume a pair, others only a single bird. A special effort is made to record all species by guarding against "tune-out." Tune-out

[1] An abbreviated version of this paper was presented at the Workshop on Monitoring Bird Population Trends by Point Counts, November 6-7, 1991, Beltsville, Maryland

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is missing an individual or species even though it is singing clearly. It seems to occur most often when the observers are having problems identifying one bird and concentrate so hard that they miss others. Common, constantly singing birds, like Red-eyed Vireo (*Vireo olivaceous*), seem to be the easiest to tune out.

All participants have a high skill level in bird identification, and observers are encouraged to eliminate species-identification errors by tracking down problem birds. We recommend that a count-down timer be used to eliminate the difficulty of watch-checking during the count period. Wind direction and the orientation of the map sheet are recorded.

(3) Counts are done early in the morning from soon after dawn until approximately 4 hours after dawn. Observers conduct surveys only in weather that is unlikely to reduce count numbers, similar to the guidance given to Breeding Bird Survey (BBS) participants. Generally, the better the weather, the better to count. We request that birds be counted when winds are calm to light (<15 km/h) and that counts not be conducted in the rain. All stations for each site are completed in one day to make them as comparable as possible.

(4) Observers may have as many helpers as they require for navigation and data-recording purposes, but there must be only one listener per station. In trend analysis, we use only data from the same observer in subsequent years on the same site.

(5) Each site is sampled twice during the season; once during the end of May or early June (approximately May 27 to June 12) and once during the latter part of June (approximately June 14 to June 24). The number and date of counts we use are based on regional phenology and may have to be adjusted for other areas.

(6) Data coding is done soon after the survey, ideally on the same day. The observers transcribe the mapping data onto a coding sheet. The level of breeding evidence determines whether a bird is assumed to indicate a pair or a single; a singing male, observed pair, occupied nest, and a family group are all considered a pair. All other individuals seen or heard calling are counted as singles. Observers return the map and coding sheet for each series to CWS for verification and processing.

Data Analysis

The higher value for each species during the breeding season is used as the station estimate. Station values can be summed to obtain site values which must be used to relate bird abundance to some forest variables that are only available on a stand basis.

The number of stations required to develop significant trends is difficult to specify precisely. The magnitude of change and the variance patterns of individual species dramatically affect the sample size required for statistical significance. There could theoretically be a different sample size value for each species, taking into account the amount of change we want to detect over a certain time period. Using BBS route regression methodology (Collins and Wendt 1990, Geissler and Noon 1981), statistically significant trends, in cases of dramatic change, occur with as few as 20 stations over the 1987-to-1991 5-year period, and frequently with 40 or more stations.

Habitat-Specific Surveys

The decision of whether to stratify surveys by habitat must always be based on the nature of the data required. Some general comments based on our experience may be useful.

(1) Habitat-based approaches are most valuable at local and regional levels and obviously become more difficult to design effectively as scale increases, the major problem being geographic changes in forest vegetation patterns.

(2) Habitat information can be ignored in analysis if not needed, but is often difficult and expensive to collect a posteriori. Habitat-specific data can produce forest-specific as well as aggregated regional, provincial, and national roll-ups (but could be subject to bias if not complete-see Item 4).

(3) Habitat-based sampling protocols should be viewed from a statistical perspective as stratification to deal with heterogeneous distribution. Bird species turnover across forest stand gradients is high, so there are considerable statistical benefits in examining trend within similar habitats.

(4) To effectively estimate population size, all habitats in which a species occurs must be adequately sampled, and the extent of each habitat should be known. To monitor trends, changes in both bird species abundances within habitats and the extent of the habitats must be monitored.

(5) Results and conservation recommendations (where and perhaps why) can be related to forest management and other land use plans. Bird trend data can thus provide effective input into land management decisions. Many landscape changes, both natural and human-induced, are habitat-specific, so information is often most valuable when expressed in terms of landscape units.

(6) Volunteers and volunteer organizations are more ready to cooperate and provide financial support to data collected on a locally interpretable basis as well as integrated to a larger scale. For example, data could be collected on sugar maple stands for townships and also used on a provincial basis, as long as local sampling is adequate and relative habitat proportions are known.

(7) Habitat-specific data can also meet the strong requirement for inventory and habitat association information as well as for monitoring.

Volunteer Observer Considerations

The use of volunteers dramatically expands the potential scope of monitoring programs and provides potential for long-term continuity of observers. They do introduce a number of additional considerations such as:

(1) The program should have clear overall conservation goals, as people want to contribute to worthwhile conservation efforts that they understand.

(2) It should have rigorous methodology that recognizes habitat differences. Naturalists tend to be suspicious of "average" values from very different habitats.

(3) The survey should give an impression of completeness, as the volunteer observers often have a strong interest in the site they survey and want it done properly. I have noticed that the volunteer observers distrust samples in which they feel rushed while collecting the data. They like to know that they have successfully recorded all birds during the count period. For instance, they are far happier with 10-minute rather than 3-minute counts.

(4) Since volunteers provide long-term continuity, it is important that the methodology be satisfying to them and fun-it is their free time!

(5) Communication is extremely important for long-term support. Volunteer observers need regular feedback on program progress and results. Newsletters seem to work well in this regard.

Point Count Standards and the Forest Bird Monitoring Program

In design and approach Forest Bird Monitoring Program (FBMP) is highly compatible with the recommended standards of Ralph and others (in this volume). The program is now in its sixth year of operation using volunteers and seems unlikely to change substantially. Over time it will be adjusted as necessary to fit with integrated North American programs as they are developed.

Some of our practices warrant comment as they appear to differ from the standards:

- FBMP is intended to inventory and monitor on a habitat-specific basis. The landscape pattern of forest habitat distribution and land use have dictated an emphasis on off-road sampling in the regions where FBMP has been implemented to date. In other regions, adequate sample size may well be achieved along roadsides. When overall integrated characterization of the avifauna is a goal, as well as habitat-specific data, particular attention must be directed to ensuring adequate sampling of a full range of habitat units within the study region.

- FBMP is based on a 10-minute count period, and limited data suggest that between-station travel time for volunteers varies from 5 to 25 minutes depending on terrain and the observer's physical condition and schedule. Volunteer observers tell us that they want a sample period long enough to have an impression of completeness. In general, most birds are detected in the first 5 minutes by experienced observers, and although a significant number of new species can be added in the second 5 minutes, they usually occur in low abundance.

  The major difficulty in selecting an optimum period for a volunteer-based program is broad variability in the speed at which they record observations. It is my impression that participants conducting only one or two surveys a year often need more than 5 minutes to record an acceptable number of cues, but they perform well over a 10-minute count period. The results of a 3-, 5-, and 10-minute count comparison are presented in the following section.

- As described in the history overview, FBMP initially used a 50-m fixed-radius plot and unlimited distance, but it was found that problems existed in comparability of distance estimates, making it difficult to use the data effectively.

Comparison of 3-, 5- and 10-Minute Counts

The specific interest in counts of 3-, 5- and 10-minute duration in the North American Point Count Standards (Ralph and others, in this volulme) prompted us to conduct a small-scale comparison in 1992. Using our standard survey procedure, a highly experienced observer mapped the count information using different colored pens for each time period. We recorded the period when each bird was first detected and noted if it continued to be detected in subsequent periods.

We conducted 180 songbird surveys in 18 stands in eastern Ontario in the Great Lakes-St. Lawrence forest region (Rowe 1972). Most stands (12) were white pine (*Pinus strobus*) and white pine mixed woods, and several stands (6) were dominated by tolerant hardwoods. Each site (comprised of five stations) was visited twice. The first visit was done June 2 to June 11, and the second was done June 23 to July 11. Surveys ran from 0500 to 1015, and approximately 3 sites (15 stations) were sampled per day.

The length of the travel time between sample points strongly affects the number of counts that can be conducted per hour (Ralph and others, in this volume). If we assume a 5-minute travel period (a reasonable time to walk 250 m in open forest), then an observer could theoretically conduct 7.5 counts of 3 minutes, 6 counts of 5 minutes or 4 counts of 10 minutes an hour. *Table 1* presents calculated results for 1 hour of survey based on the average of three random draws from the 1992 data.

Table 1--*The number of individuals and number of species of birds detected per hour using point counts of 3-, 5-, and 10-minute duration.*

	Duration of Count (minutes)		
Parameter	3	5	10
Individuals per hour	105	99	78
Species per hour	32	31	29

Table 2--*Bird species occurrence in 3-, 5-, and 10-minute count periods. Species with significantly different distributions from the average overall distribution are presented by count period, with direction of bias.*

Species	Significance	Duration of Count (minutes)		
		3	5	10
Downy Woodpecker	**	Lower[1]	Lower	Higher
Great Crested Flycatcher	*	Lower	Lower	Higher
Yellow-rumped Warbler	*	Lower	Higher	Higher
Yellow-bellied Sapsucker	**	Lower	Higher	Higher
Black-capped Chickadee	*	Lower	Higher	Higher
Red-breasted Nuthatch	*	Lower	Higher	Higher
Golden-crowned Kinglet	**	Lower	Higher	Higher
Pine Warbler	*	Lower	Higher	Higher
Red-eyed Vireo	*	Higher	Lower	Lower
Least Flycatcher	**	Higher	Lower	Lower
Ovenbird	**	Higher	Lower	Lower
Hermit Thrush	*	Higher	Higher	Lower

[1] Counts were significantly lower or higher during this time period than expected.

* $P<0.05$

** $P<0.01$

In addition to knowing if the number of species per count changes, it is also important to determine if species are equally likely to occur in counts of different lengths. We examined this question by comparing the distribution of the number of detections of each species in the 3-, 5- and 10-minute counts with the distributions for each other species. Only species that occurred at more than 15 sample points were included in the analysis. Of these 36 species, 24 had similar overall distributions, whereas the overall distributions for 12 species were significantly different from the others. The results for species with significantly different distributions are summarized in *table 2*. Of these, the probability that the overall distribution was significantly different was <0.01 for 5 species (Downy Woodpecker (*Picoides pubescens*), Golden-crowned Kinglet (*Regulus satrapa*), Least Flycatcher (*Empidonax minimus*), Ovenbird (*Seiurus aurocapillus),* and Yellow-bellied Sapsucker (*Sphyrapicus varius*)) and <0.05 for another 7 (Black-capped Chickadee (*Parus atricapillus*), Great-crested Flycatcher (*Myiarchus crinitus*), Hermit Thrush (*Catharus guttatus*), Pine Warbler (*Dendroica pinus*), Red-breasted Nuthatch (*Sitta canadensis*), Red-eyed Vireo, and Yellow-rumped Warbler (*Dendroica coronata*)).

Although most species follow expectations, numbers of vocal long-distance migrants (e.g., Ovenbird, Least Flycatcher) are disproportionately high in the first 3 minutes, whereas several resident and short-distance migrants (e.g., Downy Woodpecker, Golden-crowned Kinglet), mostly cavity nesters, are detected less frequently than expected in the first 3 minutes. For example, Ovenbird, which had a significantly different distribution (χ^2 = 20.1, df = 2, $P<0.005$) from the others, had counts higher in the first 3 minutes and lower in the 5- and 10-minute counts than expected.

One of the purposes of our program is to describe species-habitat associations. It is, therefore, interesting to compare the species accumulation curves for the different count period lengths. Using the 1992 data (90 stations with two visits, treating each as a sample), we randomized the observations and drew the species accumulation curves. Using the maximum number of species observed overall (75 species) as 100 percent, we could expect to observe 90 percent of the species (a proportion often considered acceptable) in 45 samples of 10 minutes, 63 samples of 5 minutes, and 80 samples of 3 minutes.

The principal benefit of a shorter count period should be increased statistical power due to an increased number of samples and a higher number of birds counted per hour. In general, it is assumed that longer counts are more precise so that the benefits of more short counts depend on how variable they are relative to the potential improved power obtained by increasing the number of samples.

One possible way to examine the question is to calculate the Coefficient of Deviation (CD = standard error/mean) for each count period, and then calculate the sample ratio at which they are equal (the break point) for the two methods to be compared. This approach assumes that standard deviation is correctly estimated for the population. *Table 3* presents some sample values from the 1992 data. For the overall data the CD for 3 minutes is 0.024 and for 10 minutes it is 0.013. The break point ratio for 3- and 10-minute samples is 0.200. We can, therefore, conclude that five times as many 3-minute as 10-minute counts would be required to obtain a comparable standard error. Comparison of the 5-minute and 10-minute values gives a break point ratio of 0.299, thus 3.3 times as many 5-minute as 10-minute counts would be required. Using the earlier example, with a 5-minute travel period, 4 counts of 10 minutes should be comparable to 13 counts of 5 minutes and 20 counts of 3 minutes in precision.

If we examine the data for migratory habit groups (*table 3*), the results would be different than those calculated

for the

Table 3--*Selected summary results from 3-, 5-, and 10-minute counts.*

		Duration of Count (minutes)					
		3		5		10	
Parameter	n	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Overall	1684	0.91	0.89	1.12	0.88	1.40	0.77
Long-distance migrant	994	1.11	0.99	1.32	0.99	1.58	0.90
Short-distance migrant	437	0.73	0.64	0.92	0.62	1.18	0.48
Resident	205	0.47	0.56	0.71	0.56	1.11	0.31

overall data. Grouping species by migratory habit seems desirable, since we have differing expectations of detecting these groups, depending on the duration of the count period (*table 2*). For example, the ratio for long-distance migrants is 0.389 and for residents it is 0.006 between 3-minute and 10-minute counts. Therefore, 260 counts of 3 minutes would compare to 100 counts of 10 minutes for long-distance migrants; but for residents, 1670 counts of 3 minutes would be comparable to 100 counts of 10 minutes.

Table 4--*Results of a calculated typical morning's survey effort of 5 hours using point count periods of 3, 5, and 10 minutes in length. Numbers are the average of three values obtained by taking random samples of all stations visited.*

	Duration of Count (minutes)		
Parameter	3	5	10
Samples	23	20	15
Individuals	319	335	299
Species	49	52	53
Time counting (minutes)	69	100	150
Distance walked (km)[1]	5.75	5.00	3.75

[1] Based on one-way travel, walking a minimum of 250 m between stations.

The appropriate values will vary from place to place, but could be roughly estimated from a preliminary test.

In our program we attempt to maximize the number of 10-minute samples per morning, whenever possible surveying 3 sites of 5 stations each (15 samples). On average this requires 5 to 5.5 hours. For our survey circumstances, the average time between stations is, therefore, 10 to 12 minutes. The time between stations will vary enormously between regions, depending on the amount of driving and walking required, the ease of travel, and the design of the program. Several important aspects of the relative merits are summarized in *table 4,* which represents calculated results of a typical morning of surveying for 5 hours with 10 minutes between stations.

Overall for our region, the lower variability coupled with the improved counts of residents and more complete species profiles suggests that 10-minute counts are better. While the precision with 5-minute counts is higher than with 3-minute counts, the 10-minute counts are preferable for this data set. In other regions with different song frequency and phenology patterns, the relative merits of short versus long counts may be different. It is clearly important to carefully calculate how many samples can be taken in a morning and consider their variability when making a decision about length of count period.

Evaluation of Bias in Roadside Point Count Surveys of Passerines in Shrubsteppe and Grassland Habitats in Southwestern Idaho[1]

John T. Rotenberry and Steven T. Knick[2]

Abstract: Breeding passerine abundances in Great Basin shrubsteppe and grassland habitats were surveyed in southwestern Idaho by using 73 pairs of 200-m radius circular point counts. Points were placed along roads and paired with points 400 m away from roads but in similar habitat. Grassland species such as Horned Larks (*Eremophila alpestris*) and Western Meadowlarks (*Sturnella neglecta*) accounted for 65 percent and 21 percent of the total number of individuals counted in both habitat types. Typical shrubsteppe bird species such as Sage (*Amphispiza belli*) and Brewer's sparrows (*Spizella breweri*), and Sage Thrashers (*Oreoscoptes montanus*) were less common (11 percent of the total counted). Except for Western Meadowlarks ($P < 0.05$), all comparisons between the number of individuals of a species counted at points on- versus off-roads were statistically insignificant ($P > 0.20$). Meadowlarks were likely over-sampled along roads because of the presence of adjacent fences, which provide conspicuous song perches.

Passerine birds are a conspicuous element of Great Basin shrubsteppe habitats (Rotenberry and Wiens 1978, 1980; Smith and others 1984; Wiens and Rotenberry 1981). Because of several important ecological attributes that these species exhibit, monitoring their abundances over relatively large spatial scales can be of interest. For example, because their position is relatively high in the food chain, and because several species may exhibit rather narrow habitat associations, songbirds may serve as sensitive indicators of ecosystem disturbance or other habitat changes.

Before any monitoring scheme can be implemented, however, its methodology must be verified. One sampling method widely used throughout North America is the USDI Fish and Wildlife Service's Breeding Bird Survey (BBS) (Bystrak 1981, Droege 1990). Each survey route is a series of 50 3-min point counts conducted along a 25-mi (40-km) stretch of road. One potential bias of surveying from roads, however, is the inevitable edge, or discontinuity in habitat, created by the road itself. The potential difference between the species and their abundance detected from roads and those detected in similar habitat away from roads ("roadside bias") has only rarely been examined (Hutto and Hejl, Keller and Fuller, Ralph and others, in these Proceedings).

We systematically surveyed breeding passerine abundances at paired on- and off-road sites throughout the Snake River Birds of Prey Area (SRBOPA) in southwestern Idaho. We asked if abundances of species surveyed along roads were the same as those surveyed in similar habitat but away from roadsides. Our results provide estimates of any bias due to sampling along roads associated with BBS or similar large-scale surveys conducted in shrubsteppe habitats.

Methods

Study Area

The 195,325-ha SRBOPA, located south of Boise and west of Mountain Home on the Snake River Plains of southwestern Idaho, contains a mosaic of native shrubsteppe and grassland habitat types interspersed with large patches of disturbed (mostly burned) areas dominated by exotic annual plants (*fig. 1*). Common shrubby species include big sagebrush (*Artemisia tridentata*), winterfat (*Ceratoides lanata*), shadscale (*Atriplex confertifolia*), and russian thistle (*Salsola iberica*). The dominant grasses are *Bromus tectorum, Poa secunda, Sitanon hystrix,* and *Vulpia octoflora.*

Point Selection

During the April-June 1991 passerine breeding season, we established 73 pairs of points scattered throughout the SRBOPA. One member of each pair was located ≤25 m from a road, and each was matched with a companion point >400 m away from the road but in similar habitat. One point in the pair was selected first from existing vegetation survey transects randomly located throughout the SRBOPA (Knick 1990), then matched with a companion. All points were permanently marked and their location determined within ±2-5 m with a Global Positioning System. Habitat within a 200-m radius of each point was classified into a discrete type (grassland or shrubsteppe), based on the physiognomy of the dominant vegetation. If necessary, the final location of a sampling point was adjusted to maintain homogeneity of major habitat type within a 200-m radius. Road types ranged from paved to two-tracked, well-traveled dirt roads.

Survey Methods

At each point, counts were made of all birds [excluding Common Ravens (*Corvus corax*) and falconiforms] seen or heard within a 200-m radius during a 3-minute period. Previous experience indicates good delectability of most shrubsteppe passerines out to this distance. All surveys were conducted between 0600 and 1000 on mornings with little wind (0 to 5 km/h) and no rain. On days when two observers were used, on- and off-road sampling responsibilities were randomly assigned to avoid bias.

Statistical Analysis

A datum was the number of individuals of a species counted within a 200-m radius of a sampling point (12.57 ha) during 3 minutes. Differences in species abundances between on- and off-road counts were compared using a nonparametric

[1]This paper was not presented at the Workshop on Monitoring Bird Populations by Point Counts but is included in this volume because of its relevance.

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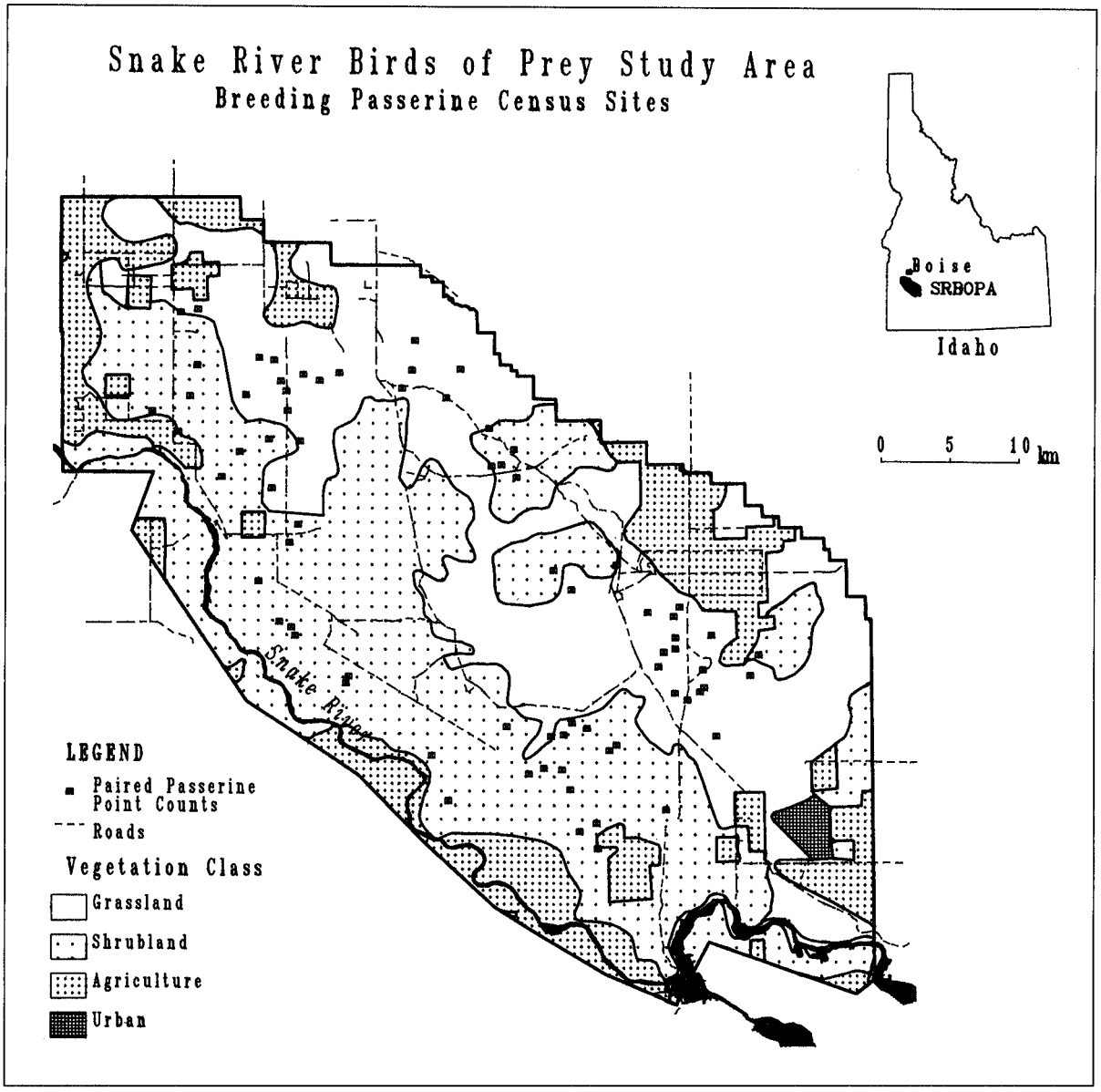

Figure 1--Distribution of paired passerine point counts throughout the Snake River Birds of Prey Area. For clarity, only graveled roads are shown.

paired Wilcoxon test, whereas associations in abundances between on- and off-road counts were assessed using a nonparametric Spearman rank correlation (Sokal and Rohlf 1981). All analyses were performed on untransformed data.

Results

General Patterns

We conducted 73 pairs of point-count censuses (146 total censuses) between April 30 and June 21, 1991. Of these, 27 pairs were in grassland habitat and 46 in shrub habitat (*table 1*). Only five species in this low-diversity ecosystem occurred on counts frequently enough to make statistical analyses meaningful. By far, the most abundant and widely distributed birds were Horned Larks; they accounted for 65 percent of the total number of individuals counted (n = 1,534) and appeared on 138 of 146 point counts. Western Meadowlarks were also common, accounting for 22 percent of the total number of individuals and occurring on over 70 percent of the counts.

Although most counts were conducted in shrub-dominated habitat types (*table 1*), typical shrubsteppe bird species such as Sage and Brewer's sparrows, Sage Thrashers, Rock Wrens (*Salpinctes obsoletus*), and Lark Sparrows (*Chondestes grammacus*) were much less common, representing only 11 percent of the total counted. Of the group, only Brewer's Sparrows occurred on more than 10 percent of the shrub habitat counts (54 of 92).

On-Road and Off-Road Comparisons

Except for Western Meadowlarks, all comparisons between the number of individuals of a species counted at

Table 1--*Numbers of individuals seen on 3-minute, 200-m radius-point counts on- versus off-roads in different habitat types on the SRBOPA, April-June, 1991. Entries are the average (and standard deviation) of numbers of individuals counted. Values <0.05 are not shown.*

	Shrublands (n = 46 pairs)		Grasslands (n = 27 pairs)		Total (n = 73 pairs)	
Species	On-road	Off-road	On-road	Off Road	On-road	Off-road
Grassland Species						
Horned Lark	5.9	6.2	8.1	8.4	6.7	7.0
	(3.31)	(3.98)	(3.77)	(4.27)	(3.62)	(4.21)
Western Meadowlark	2.7	2.5	2.1	1.5	2.5	2.1
	(2.25)	(2.32)	(1.82)	(1.78)	(2.10)	(2.17)
Shrubland Species						
Brewer's Sparrow	1.4	1.4	0.2	0.1	0.9	0.9
	(1.57)	(1.57)	(0.79)	(0.32)	(1.44)	(1.41)
Sage Sparrow	0.2	0.2	-	-	0.1	0.1
	(0.66)	(0.70)	-	-	(0.53)	(0.56)
Sage Thrasher	-	0.I	-	-	-	0.1
	-	(0.31)	-	-	-	(0.25)

points on- versus off-roads (*table 1*) were statistically insignificant (paired Wilcoxon test; all $P > 0.20$). These comparisons were made both throughout the SRBOPA as a whole and within each of the two major habitat types. Additionally, the Spearman rank correlations between the number of individuals counted at each location on- versus off-roads were highly significant for all species except Sage Thrashers (Horned Lark $r_S = 0.46$, Brewer's Sparrow $r_S = 0.69$, Sage Sparrow $r_S = 0.57$, all $P < 0.001$; Sage Thrasher $r_S = -0.03$, $P = 0.8$; all df = 71), indicating a good agreement between the two.

The number of Western Meadowlarks differed significantly between on- versus off-road counts only when pooled over both habitat types. However, the Spearman rank correlation between the two sets of counts was highly significant ($r_S = 0.69$, df = 71, $P < 0.001$), implying that on-road counts were likely a reliable index to meadowlark abundances determined from off-road ones.

Discussion

The absence of a "road effect" (except for Western Meadowlarks) may have several explanations. For one, roads likely represent much less of a habitat discontinuity in grasslands and shrubsteppes than they do in more physiognomically developed woodlands or forests. This may be particularly true in the SRBOPA where many of the roads are unpaved and have relatively narrow associated rights-of-way. For another, many shrubsteppe species have relatively large territories and may be more able to incorporate small patches of unsuitable habitat than species with smaller territories (Wiens and others 1985). Finally, for Sage Thrashers, which were encountered only infrequently, our sample size is likely too small to generate sufficient statistical power to detect any but the most obvious of differences.

We suspect that the "road effect" associated with Western Meadowlarks is really more of a "fence effect." Many roadway rights-of-way in western rangelands are delimited by fences to reduce access by livestock, and many tertiary roads are developed along pre-existing fencelines. The posts and wires of these fences, which usually protrude above the average vegetation height in these short-statured habitats, provide elevated song perches favored by this species, thus increasing their conspicuousness (Lanyon 1957).

In summary, our analysis suggests that point counts distributed alongside secondary and tertiary roads in Great Basin shrubsteppe and grassland habitats tend to overrepresent abundances of Western Meadowlarks compared to points located away from roads, but otherwise appear to be unbiased surveys of other common species. Even for meadowlarks, the numbers counted off-road and on-road at a site were highly correlated and thus may provide a suitable index. We conclude that a network of roadside point counts can serve adequately to monitor regional population abundance patterns for common passerine species in Great Basin shrubsteppe and grassland habitats.

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A Comparison of Bird Detection Rates Derived from On-Road versus Off-Road Point Counts in Northern Montana[1]

Richard L. Hutto, Sallie J. Hell, Jeffrey F. Kelly and Sandra M. Pletschet[2]

Abstract: We conducted a series of 275 paired (on- and off-road) point counts within 4 distinct vegetation cover types in northwestern Montana. Roadside counts generated a bird list that was essentially the same as the list generated from off-road counts within the same vegetation cover type. Species that were restricted to either on- or off-road counts were rare, suggesting that restricted occurrences were a consequence of small sample sizes and not a product of habitat differences surrounding on-versus off-road points. Nevertheless, there were significant differences in the mean number of individuals detected between on- and off-road points for a number of species. Some of these differences appear to be a product of habitat changes associated with the presence of roads, and those differences appear to be less pronounced on narrower roads. Therefore, we recommend that, if one wishes to extrapolate results from on- to off-road areas, care should be taken to select smaller, secondary or tertiary roads as transect routes.

Numerous private, state, and federal land management agencies are beginning to recognize the practicality of using information about the health of songbird populations as an effective tool in meeting part of their legal and ethical requirements to monitor the populations of all vertebrate species. With the desire of most agencies to develop an extensive, rather than intensive, monitoring system, and with the already-existing roadside North American Breeding Bird Survey (BBS) in place, it appears likely that many of these agencies will choose to supplement the BBS with some sort of roadside monitoring method. Before expanding our efforts to obtain roadside data, we must evaluate the possible biases associated with roadside counts. Specifically, if roadside data are to be used to monitor bird populations, we need to know: (1) if the sample is representative of off-road samples in the same habitat and (2) whether population trends of on-road birds mirror those of off-road bird populations.

While it may be difficult, if not impossible, without long-term data sets to compare trends of bird populations based on on-road versus off-road counts, it is relatively simple to test how well roadside counts sample the more broadly defined habitats through which they pass. It is, therefore, surprising that there are no published studies related to this issue (Keller and Fuller, and Ralph and others, in this volume). If on-road counts are similar to off-road counts, there is a strong chance that population trends would be similar as well. If, however, on- and off-road counts differ substantially due to the distinct habitat conditions created by the presence of a road, those distinct conditions might also affect the population dynamics of occupants, resulting in different population trends as well.

The objective of our study was to test whether the abundances of various bird species differ significantly between on- and off-road point counts. We categorized our data by bird species, vegetation type, and road width to gain insight into possible causes of any observed differences.

Methods

We conducted 550 point counts along secondary roads within the Flathead National Forest—Big Fork and Glacier View Ranger Districts—and Glacier National Park, Montana, from May 31 to July 12, 1991 (peak breeding season). Counts were paired (275 pairs), with one on the road and the other perpendicular to and 200 m away from the road. Both on- and off-road points were located within the same vegetation cover type, and neither was within 200 m of an abrupt vegetation edge or another road. To find locations that had continuous vegetation cover of a single type (see vegetation categories below) for at least 400 m on both sides of the road, the vegetation context of a given stretch of road was determined beforehand from SPOT Image Corporation (SPOT) satellite images and from conversations with land managers. Before we conducted the actual point counts, we also confirmed that the points would be in continuous habitat by walking or driving through the site.

We conducted point counts within each of 4 vegetation cover types: recently burned forest (n = 44 pairs), early successional forest (n = 34 pairs), open forest (n = 52 pairs), and closed forest (n = 145 pairs). In the burned sites, virtually all of the trees were dead, and standing trees had not been removed since a 1988 fire. The understory was composed primarily of forbs, but some shrubs had begun resprouting. Early successional sites were regenerating from clear-cutting and were covered with shrubs, generally less than 3 m tall; occasionally, there were a few large trees present. Open forests included sites where the canopy was not continuous, either because the trees had been thinned through logging, or because a considerable number of standing trees were dead from natural causes. The understory in the open sites varied from sparsely scattered to moderately dense shrubs and saplings. The size and density of trees in the closed forest varied from large, well-spaced "old-growth" trees to smaller, more densely packed trees. The understory within the closed forest sites also varied greatly, from open to very dense shrub and sapling cover.

In association with each on-road point, we estimated the width of the road by pacing the distance from one edge of the

[1] An abbreviated version of this paper was presented at the Workshop on Monitoring Bird Population Trends by Point Counts, November 6-7, 1991, Beltsville, Maryland.

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graded portion to the other. The distribution of road widths was distinctly bimodal, with the majority being less than 10 m wide. Roads less than 10 m wide were classified as "narrow," and those greater than 10 m wide were classified as "wide."

Two observers used 10-minute, fixed-radius plots to record all birds detected within each of two distance categories: within 50 m, and between 50 and 100 m. Visual cues, calls, and songs were used to identify bird species. Point counts were begun about 15 minutes after sunrise and ended before the midday lull in bird activity, generally before 1030. Points were placed at 200-m intervals along roads, and observer bias was controlled by alternating the two observers between on- and off-road counts.

To compare on- and off-road bird communities, we used the Wilcoxon matched-pairs signed-ranks test on measures of overall abundance (mean number of individuals per point) and species richness (mean number of species per point). To compare detection rates of individual species, we used the Wilcoxon test on the mean number of individuals per point, and the *G*-test on frequencies of on- versus off-road detection (Sokal and Rohlf 1981). Tests were considered significant at $P < 0.05$. All analyses were conducted with SPSS-PC computer software.

Results

We detected a total of 64 species within a 50-m radius (*table 1*). Fifty-one (80 percent) of those species were detected on both on-and off-road counts. Nine were detected only on the on-road counts, and four were detected only on the off-road counts. The patterns were similar for 100-m-radius data: 68 species were detected, 59 (87 percent) on both on- and off-road counts, 9 were detected only on roads, and none were detected only off roads (*table 1*).

For either count radius, all species detected either only on-road or only off-road were rare; they were detected on 4 or fewer of the 550 point counts. For those species, the mean number of counts on which they were detected was 1.5 within a 50-m radius, and 2.0 within 100 m. In contrast, the average species was detected on 31.9 and 56.3 counts for the 50- and 100-m radius data, respectively.

The mean species richness at a given count point was significantly greater for on-road than for off-road counts (*table 2*). Most species (62-66 percent, depending on count radius and measure of abundance used) had either a greater frequency of detection, or a greater average number of detections per point, for on-road than for off-road counts (*table 1*). If we restrict analysis to the 31 species that were detected on at least 25 points (*table 1*), the frequency of detection was significantly greater on on-road counts for seven species, and no species was significantly more frequently detected on off-road counts. Similarly, the number of detections per point was significantly greater on on-road counts for nine species, whereas none had a significantly larger number of detections per point off road. These results held true regardless of the count radius used. The species that had either a significantly greater frequency of detection, or a significantly larger number of detections per point, represent a diverse cross-section in terms of their behavior and general feeding locations.

The proportion of detections that came from on-road versus off-road varied significantly among species ($G = 86.1$, $P = 0.000$ for 50-m radius data; $G = 63.3$, $P = 0.001$ for 100-m radius data). To contrast the kinds of species that were relatively more likely to be detected on roadside counts with those that were less likely to be detected, we simply tallied six species from each end of the spectrum (*table 3*). On the basis of our own field experience in northern Rocky Mountain forests, most of the species with the highest proportions of on-road detections can be safely classified as those that forage along either the forest opening or the shrubby vegetation associated with the presence of a road. In contrast, most of the species that cluster toward the lower proportion of on-road detections are forest interior species.

To determine whether the effect of roads was more pronounced in some vegetation types than in others, we tallied the total number of detections on and off roads for each bird species. We then calculated the absolute value of the on/off road difference in number of detections for each species. The averages of those differences for each of the four vegetation cover types vary significantly among cover types (*table 4*). For data from both count radii, the greatest average magnitudes of difference between the numbers of on- and off-road detections occurred in the forested cover types.

We used data from the heavily forested vegetation cover type to assess the effect of road width on detection rates (the other cover types had only a few wide-road samples). The mean number of birds detected per point on and off narrow roads did not differ significantly ($t = 0.64$, *NS* for 50-m-radius data; $t = 0.35$, NS for 100-m-radius data), while the mean number of birds detected per point on and off wide roads did ($t = 4.29$, $P < 0.001$ for 50-m-radius data; $t = 4.57$, $P < 0.001$ for 100-m-radius data); there were significantly more birds detected on than off wide roads (*fig. 1*).

The pronounced effect of road width suggested that the on- vs. off-road difference in the number of detections for most species might disappear if we restricted our analysis to narrow roads only. Of the 11 species whose average number of detections differed significantly between on- and off-road counts for at least 1 of the 2 count radii (*table 1*), 5 (Ruby-crowned Kinglet (*Regulus calendula*), American Robin (*Turdus migratorius*), Warbling Vireo (*Vireo gilvus*), Yellow-rumped Warbler (*Dendroica coronata*), and MacGillivray's Warbler (*Opornis tolmiei*)) still revealed a significant difference in the number of individuals detected per point after restricting the analysis to data from narrow roads only. Interestingly, by so restricting the analysis, the on- versus off-road difference in mean number of detections changed from insignificant to significant for one species, Varied Thrush (*Ixoreus naevius*).

Discussion

Roadside counts appear to be adequate for the generation of complete bird lists. Species that were restricted to either on- or off-road counts were rare, suggesting that restricted occurrences were a product of small sample sizes and not a product of habitat differences between on- and off-road points. Nevertheless, a number of the more common species were significantly more likely to be detected on on-road

Table 1--*The number of point counts on which a given species was detected, and the mean number of detections per point (x 100) for on-road (n = 275) and off-road (n = 275) counts within each of two count radii.*

	Frequency of occurrence				Mean number per point (x100)			
	50-m radius		100-m radius		50-m radius		100-m radius	
Species	On road	Off road	On road	Off road	On road	Off road	On road	Off road
Sharp-shinned Hawk *Accipiter striatus*	0	1	1	1	0.00	0.36	0.36	0.36
Red-tailed Hawk *Buteo jamaicensis*	0	0	3	0	0.00	0.00	1.09	0.00
American Kestrel *Falco sparverius*	2	1	5	2	0.73	0.36	1.82	0.73
Merlin *Falco columbarius*	0	0	1	0	0.00	0.00	0.36	0.00
Ruffed Grouse *Bonasa umbellus*	0	1	6	11	0.00	0.36	2.18	4.00
Common Snipe *Gallinago gallinago*	1	1	2	3	0.36	0.36	0.73	1.45
Calliope Hummingbird *Stellula calliope*	20	10	20	10	8.36	4.00[d]	8.36	4.00[d]
Rufous Hummingbird *Selasphorus rufus*	15	7	15	7	6.18	2.55	6.18	2.55
Red-naped Sapsucker *Sphyrapicus nuchalis*	16	15	30	27	6.55	6.55	11.64	12.00
Downy Woodpecker *Picoides pubescens*	2	0	2	0	0.73	0.00	0.73	0.00
Hairy Woodpecker *Picoides villosus*	4	5	8	16	1.82	2.18	3.64	6.55
Three-toed Woodpecker *Picoides tridactylus*	8	3	10	5	4.00	1.82	4.73	2.55
Black-backed Woodpecker *Picoides arcticus*	3	0	4	0	1.45	0.00	1.82	0.00
Northern Flicker *Colaptes auratus*	7	10	17	19	2.55	4.73	7.27	9.45
Pileated Woodpecker *Dryocopus pileatus*	0	1	5	6	0.00	0.36	1.82	2.18
Olive-sided Flycatcher *Contopus borealis*	5	1	24	22	2.18	0.36	9.09	8.36
Western Wood-Pewee *Contopus sordidulus*	2	5	10	13	0.73	1.82	5.09	5.45
Dusky and Hammond's Flycatchers *Empidonax* sp.[a]	32	17[c]	36	24	11.64	6.18[d]	13.09	8.73
Eastern Kingbird *Tyrannus tyrannus*	1	0	1	0	0.36	0.00	0.36	0.00
Tree Swallow *Tachycineta bicolor*	9	12	13	16	6.18	8.36	9.09	12.00
Gray Jay *Perisoreus canadensis*	18	12	40	36	13.09	7.27	24.73	18.55
Steller's Jay *Cyanocitta stelleri*	1	1	5	2	0.36	0.36	1.82	0.73
Clark's Nutcracker *Nucifraga columbiana*	0	0	1	0	0.00	0.00	0.73	0.00
Common Raven *Corvus corax*	3	3	24	21	1.45	1.09	10.18	8.00
Black-capped and Mountain Chickadees *Parus* sp.[b]	52	54	92	91	27.27	30.55	46.91	47.64
Boreal Chickadee *Parus hudsonicus*	2	0	2	0	2.18	0.00	2.18	0.00
Chestnut-backed Chickadee *Parus rufescens*	1	2	1	2	0.73	1.09	0.73	1.09
Red-breasted Nuthatch *Sitta canadensis*	59	50	132	136	25.82	20.73	58.18	62.91
Brown Creeper *Certhia americana*	7	12	8	13	2.55	4.73	2.91	5.09
House Wren *Troglodytes aedon*	1	0	1	0	0.36	0.00	0.36	0.00
Winter Wren *Troglodytes troglodytes*	3	10	4	12	1.09	3.64	1.82	4.36
Golden-crowned Kinglet *Regulus satrapa*	19	26	20	26	9.09	12.36	9.82	12.73

continued

Table 1-*continued*

Species	Frequency of occurrence				Mean number per point (x100)			
	50-m radius		100-m radius		50-m radius		100-m radius	
	On road	Off road	On road	Off road	On road	Off road	On road	Off road
Ruby-crowned Kinglet *Regulus calendula*	33	24	76	62	16.73	10.55	36.73	27.64[d]
Mountain Bluebird *Sialia currucoides*	4	3	12	8	4.36	1.82	8.73	5.82
Townsend's Solitaire *Myadestes townsendi*	6	3	19	10	3.27	1.09	8.73	4.36
Swainson's Thrush *Catharus ustulatus*	97	85	166	141[c]	41.09	38.55	92.00	86.91
American Robin *Turdus migratorius*	47	25[c]	91	82	21.82	11.64[d]	50.18	40.73
Varied Thrush *Ixoreus naevius*	9	4	30	22	3.64	1.45	12.73	9.45
Cedar Waxwing *Bombycilla cedrorum*	1	0	1	1	1.09	0.00	1.09	0.73
European Starling *Sturnus vulgaris*	0	1	2	1	0.00	1.09	1.82	1.09
Solitary Vireo *Vireo solitarius*	10	16	32	37	3.64	5.82	11.64	13.45
Warbling Vireo *Vireo gilvus*	40	19[c]	62	35[c]	17.09	7.64[d]	26.55	15.64[d]
Red-eyed Vireo *Vireo olivaceus*	2	2	2	4	1.09	0.73	1.09	1.45
Orange-crowned Warbler *Vermivora celata*	31	27	44	50	12.36	13.45	21.82	26.18
Yellow-rumped Warbler *Dendroica coronata*	75	62	116	84[c]	33.45	25.09[d]	56.73	39.27[d]
Townsend's Warbler *Dendroica townsendi*	70	81	102	112	31.27	35.64	56.00	60.36
American Redstart *Setophaga ruticilla*	7	1	11	3	2.55	0.73	4.00	1.45
Northern Waterthrush *Seiurus noveboracensis*	8	5	20	12	2.91	2.18	8.00	5.09
MacGillivray's Warbler *Oporornis tolmiei*	91	65[c]	122	96[c]	41.45	28.00[d]	61.09	42.18[d]
Common Yellowthroat *Geothlypis trichas*	8	5	14	11	3.27	2.18	6.55	4.36
Wilson's Warbler *Wilsonia pusilla*	30	15[c]	37	21[c]	14.91	6.18[d]	20.00	10.18[d]
Western Tanager *Piranga ludoviciana*	27	34	54	65	12.36	13.45	23.64	26.55
Black-headed Grosbeak *Pheucticus melanocephalus*	3	4	10	10	1.09	1.45	4.00	4.73
Lazuli Bunting *Passerina amoena*	2	1	4	1	1.09	0.36	1.82	0.73
Chipping Sparrow *Spizella passerina*	64	36[c]	104	87	38.55	18.91[d]	59.64	44.00[d]
Fox Sparrow *Passerella iliaca*	8	4	20	13	3.27	1.45	9.45	5.82
Song Sparrow *Melospiza melodia*	3	0	3	0	1.09	0.00	1.45	0.00
Lincoln's Sparrow *Melospiza lincolnii*	5	6	16	16	2.18	4.00	6.91	9.09
White-crowned Sparrow *Zonotrichia leucophrys*	4	2	9	5	2.18	1.45	4.73	2.55
Dark-eyed Junco *Junco hyemalis*	154	129[c]	199	179	96.00	71.27[d]	146.18	114.55[d]
Red-winged Blackbird *Agelaius phoeniceus*	1	0	4	4	0.36	0.00	2.18	1.82
Brown-headed Cowbird *Molothrus ater*	3	1	3	4	1.82	0.36	1.82	1.45
Pine Grosbeak *Pinicola enucleator*	1	0	2	3	1.09	0.00	1.45	1.45
Cassin's Finch *Carpodacus cassinii*	3	2	6	5	1.09	1.45	2.18	2.55

continued

Table 1--*continued*

Species	Frequency of occurrence				Mean number per point (x100)			
	50-m radius		100-m radius		50-m radius		100-m radius	
	On road	Off road	On road	Off road	On road	Off road	On road	Off road
Red Crossbill								
Loxia curvirostra	0	0	1	1	0.00	0.00	0.73	0.36
White-winged Crossbill								
Loxia leucoptera	4	3	6	5	1.82	6.55	4.73	7.27
Pine Siskin								
Carduelis pinus	55	42	91	73	40.73	29.09	69.09	51.64[d]
Evening Grosbeak								
Coccothraustes vespertinus	5	1	5	4	4.36	0.73	4.36	1.82

[a]Vocalizations of Dusky and Hammond's Flycatchers were difficult to distinguish, so data from the two species were combined.

[b]Vocalizations of Black-capped and Mountain Chickadees were difficult to distinguish, so data from these two species were combined.

[c]On- and off-road counts differ significantly (G-test, $P < 0.05$).

[d]On- and off-road detection rates differ significantly (Wilcoxon matched-pairs signed-ranks test, $P < 0.05$).

Counts than on off-road counts. The possible explanations fall into one of two categories: (1) habitat changes (because of vegetation changes or the presence of a road per se) cause differences in either actual population densities or in the detection probability (behavior) of on-road versus off-road birds; or (2) actual bird densities or behaviors do not differ, but there is a visual, auditory, or area-estimate bias associated with on-road and off-road counts. We can gain insight into the probable explanation by examining results from analyses that were categorized by bird species, habitat, and road width.

Because the bird species whose detection rates differed significantly represent a varied group in terms of their foraging locations and behaviors, it seems unlikely that a single form of habitat influence can be used to explain those differences. Nonetheless, most of the species that differed are generally associated with habitat conditions that are similar to those created by the presence of a road. For example, considering the species whose detection rates differed significantly between on- and off-road counts (*table 1*), it is easy to see how an increase in roadside shrub vegetation would be attractive to, and lead to higher counts of, Dusky Flycatcher (*Empidonax oberholseri*), Warbling Vireo, MacGillivray's warbler, and Wilson's Warbler (*Wilsonia pusilla*), because they each feed or nest, or both, in shrubby vegetation. In addition, the Calliope Hummingbird (*Stellula calliope*), American Robin, Chipping Sparrow (*Spizella passerina*), Dark-eyed Junco (*Junco hyemalis*), and Pine Siskin (*Carduelis pinus*) each feed primarily from the grass and forb layer, which is especially well developed along side roads. Finally, the Hammond's Flycatcher (*Empidonax hammondii*), Yellow-rumped Warbler and Ruby-crowned Kinglet occur commonly along natural forest edges and openings, and roadside edges may be used similarly. The argument that habitat changes associated with the presence of roads are causing the observed differences gains additional credence if we examine the list of species that had the relatively fewest detections on roadside counts (*table 3*). Most can be clearly recognized as forest interior specialists.

The large variety in kinds of species whose detection rates differ significantly between on- and off-road counts is also consistent with the idea that those differences are a product of some kind of sampling bias associated with either on- or off-road counts. For example, if we overestimated the area surveyed for on-road relative to off-road counts, we would have expected a diverse group of species to be affected. However, because the magnitude of any area-estimate bias would be expected to differ between data based on 50-m and 100-m radii, we should also have expected the number of significant on- versus off-road differences in detection rates

Table 2—*The mean number of species (± s.d.) detected per point on on-road and off-road counts for each of two count radii.*

Count radius	Point Location		*t*	*P*
	On road	Off road		
50 m	4.39 ± 2.1	3.53 ± 1.9	5.16	0.000
100 m	7.44 ± 2.5	6.53 ± 2.5	4.27	0.000

Table 3—*Six species with the relatively greatest and relatively least number of detections (expressed as a percentage of the total number of detections) on 50-m radius on-road (versus off-road) counts. The pool of species was restricted to those with at least 25 detections.*

Species	On road *n*	On road percent
Wilson's Warbler	58	70.7
Warbling Vireo	68	69.1
Calliope Hummingbird	34	67.6
Chipping Sparrow	158	67.1
Dusky and Hammond's Flycatchers	49	65.3
American Robin	92	65.2
Orange-crowned Warbler	71	47.9
Western Tanager	71	47.9
Townsend's Warbler	184	46.7
Tree Swallow	40	42.5
Golden-crowned Kinglet	59	42.4
Solitary Vireo	26	38.5
All 64 species	2948	56.4

Table 4--*Means* (± s.d.) *from absolute values of the differences between the on-road and off-road number of detections in each of four vegetation cover types. Data are from all species combined.*

Vegetation type	50-m radius[a]	100-m radius[b]
Burned forest	2.60 ± 3.1	3.91 ± 4.3
Early successional	2.24 ± 3.1	2.87 ± 2.7
Open forest	3.93 ± 5.1	4.48 ± 5.0
Closed forest	5.18 ± 7.3	7.22 ± 9.3

[a] Means vary significantly among vegetation types (ANOVA; $F = 3.17$, $P = 0.026$).

[b] Means vary significantly among vegetation types (ANOVA; $F = 4.36$, $P = 0.005$).

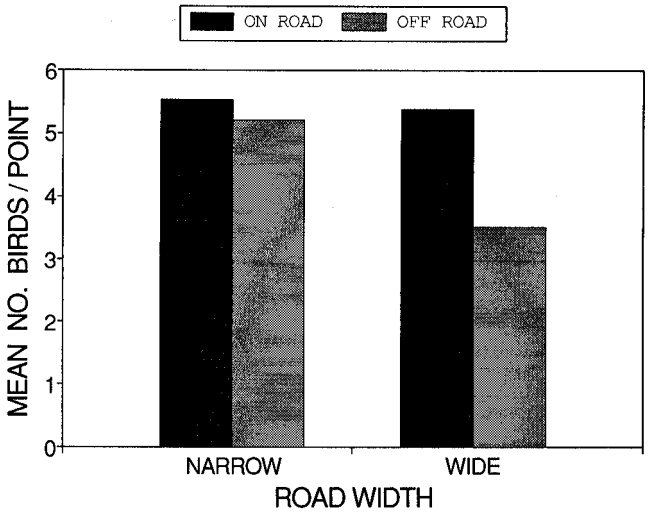

Figure 1--The mean number of birds detected per point within 50 m on on- and off-road counts for each of two road widths.

to change from one count radius to the next. In fact, the same number of species had significantly different detection rates under each sampling radius (nine species, based on mean numbers detected per point (*table 1*)). Thus, in the absence of other information, an evaluation of the identity of species affected would leave us with the impression that multiple habitat factors best account for the differences in detection rates between on- and off-road count points.

How can a breakdown by vegetation cover types help us interpret our results? If species are responding to the presence of an opening or to an increase in shrub cover, we might expect the on/off-road difference in the number of detections to be greater in closed forests because off-road points are surrounded by little early successional vegetation relative to the on-road points. This was indeed the case. The greatest average difference between on-road and off-road counts occurred in closed forest, followed by open forest, and then the early successional cover types (*table 4*). Nevertheless, the results are consistent with an area-estimate bias as well.

Finally, the observation that there was less difference between on- and off-road counts on narrow than on wide roads (*fig. 1*) is also consistent with either interpretation. The wider roads that we surveyed had associated with them an apron of grass along both edges, significant shrub cover and, of course, a wide forest opening. Those kinds of habitat changes associated with roads may explain the relatively large differences between on- and off-road counts. If this were the case, however, we would have expected the off-road counts to be similar for narrow and wide roads, and the on-road counts to be larger for wide roads. Instead, we found that the mean number of birds per off-road point was less on wide roads than on narrow roads, while the mean numbers of birds per point on roadside counts were nearly the same for wide and narrow roads (*fig. 1*). The difference in off-road detection rates between wide and narrow roads is probably a reflection of the fact that, even though we restricted analysis to the "closed forest" cover type, the paired points from wider roads were situated in predominantly lodgepole pine (*Pinus contorta*) forest, a notoriously bird-poor habitat type, while most of the paired points from narrower roads were situated in mixed conifer stands. Thus, the "baseline" detection rates for our wide road samples may be lower than for the narrow road samples, but the results are still consistent with the conjecture that habitat differences between on- and off-road points were greater in the areas with wide roads. Alternatively, because it is easy to underestimate distances in open areas, the more open conditions associated with wide roads may have resulted in the inclusion of a greater number of birds that were actually beyond the formal cutoff radius than was true for narrow roads.

In conclusion, consideration of information on species identity, vegetation cover type, and road width suggests that vegetation change associated with the presence of roads is an important factor contributing to a difference between on- and off-road count data. In addition, the particular kind of roadside vegetation change that affects the count data (whether it is the presence of an opening, a grassy area, or an increase in shrub cover) probably differs among species, and may not affect some species at all. In short, changes in a variety of habitat elements probably caused the patterns we observed, which is merely a reflection of the fact that every species is biologically unique. Thus, one must understand enough about the biology of each target species to make a decision about whether the exclusive use of roadside counts is appropriate for a particular study.

Because some species were almost certainly responding to the changed habitat conditions brought about by the presence of a road, we recommend that studies of habitat associations treat roadside conditions as unique "habitats" in and of themselves. This should be especially true for studies involving wide roads or heavily forested habitats, or both, because roadside effects appear to be most pronounced in those situations. Thus, counts restricted to primary roads will probably not assure a representative coverage of habitat types because, in effect, such counts do not include the off-road contexts of the habitat types through which they pass. By the same token, studies designed to use only off-road points would be missing samples from those special habitat conditions created by the presence of roads.

If the goal of one's study is to monitor bird population trends over a broad region, we recommend combining on- with off-road counts to avoid the possible bias of using either

exclusively. Our results also suggest, however, that off-road counts are more-or-less equivalent to on-road counts when the road is a small secondary or tertiary road. Therefore, if roads are to be used, perhaps the simplest design would call for use of smaller roads that have the same vegetation cover types within 100 m to either side and that appear to have resulted in little, if any, change in the vegetative conditions immediately adjacent to the road. Sample points can then be stratified by the habitat type through which the road passes.

Unfortunately, the issue of whether or not to use roadside counts is nearly a moot point on much of our public land. It was difficult to find any locations, especially in bottomlands, that were more than 200 m from an existing road (*fig. 2*). By

Figure 2--A scene typical of the roaded landscape found on forested public lands throughout much of the northern Rocky Mountains (USDA Forest Service photo 611030 1186-94).

default, we will be forced to sample bird populations over much of the public landscape in what are basically roadside environments. In those parts of the country where we are fortunate enough to still have sizable blocks of largely roadless areas, there should be a premium on establishing monitoring programs so that we will be able to better understand the effects of roads on not only count data themselves, but on trends of populations situated near versus far from roads.

Acknowledgments

Financial support for this study was provided by Region I of the USDA Forest Service (contract RFQ 1-865). Numerous forest wildlife biologists and silviculturists helped us find potential sites for the paired counts, and personnel at Glacier National Park provided the same service. To those individuals we express our gratitude. We also thank Cherry Keller, John Sauer, and C. John Ralph for reviewing the manuscript and offering comments that improved the final version.

Comparison of Birds Detected from Roadside and Off-Road Point Counts in the Shenandoah National Park[1]

Cherry M. E. Keller and Mark R. Fuller[2]

Abstract: Roadside point counts are generally used for large surveys to increase the number of samples. We examined differences in species detected from roadside versus off-road (200-m and 400-m) point counts in the Shenandoah National Park. We also compared the list of species detected in the first 3 minutes to those detected in 10 minutes for potential species biases. Results from 81 paired roadside and off-road counts indicated that roadside counts had higher numbers of several edge species but did not have lower numbers of nonedge forest species. More individuals and species were detected from roadside points because of this increase in edge species. Sixty-five percent of the species detected in 10 minutes were recorded in the first 3 minutes.

The USDI Fish and Wildlife Service's Breeding Bird Survey (BBS) has been monitoring bird populations from roadside routes since the 1960's. Each survey route is a series of 50 3-minute point counts conducted at 0.8-km intervals along secondary roads. The BBS now has over 3000 routes distributed across North America. The large geographic coverage of this survey would not be possible without using roads to expedite travel between points.

However, using secondary roads for survey routes has several potential biases. Geographic biases might occur because road density differs among regions. Large, undeveloped areas with few roads will be undersampled compared to more populated agricultural and urban areas. Road placement may also bias the habitats sampled by the route. For example, roadside surveys are less likely to sample marshes and bogs because roads are not easily constructed in these areas. These potential geographic and habitat biases must be considered when interpreting monitoring data based on road counts (Temple and Wiens 1989). But these sampling biases can be defined and may be addressed by adding routes in specific habitats or areas.

A more insidious bias of roadside counts may occur if the species detected from roads differ from those that would be encountered in the same habitat away from the road. The presence of a road in a forested area often creates a break in the canopy and a forest/road edge. Are we less likely to detect or even miss some forest birds and more likely to detect forest edge species from roadside points? Will roadside surveys give an adequate assessment of the bird community in the habitats encountered? To address these questions, we compared point counts of breeding birds conducted on and off the road in the Shenandoah National Park. We also examined any potential biases in the species sampled by staying 3 minutes versus 10 minutes at a count to guide future monitoring efforts using point counts.

Study Area and Methods

The Shenandoah National Park is located in the Blue Ridge Mountains of Virginia and is composed primarily of second growth forest that has developed on farmland abandoned in the early 1900's. Skyline Drive is a two-lane paved road with grassy margins 1-25 m wide and runs 169 km through the Park along the crest of the Blue Ridge Mountains.

We selected sites where three point count stations could be placed in a line perpendicular to the road with one point on the roadside and one each at 200 m and 400 m from Skyline Drive or any other road. Sites were constrained to areas where the same forest type occurred from the road to at least 500 m from the road, as delineated on the Park vegetation map (Teetor 1988), and the elevation change was not greater than 60 m among the 3 points. Sites had to be at least 0.8 km from another site. Eighty-one locations meeting these conditions were found along Skyline Drive, and we sampled all of these.

At each site, the same observer consecutively sampled the roadside at 200-m and 400-m points, reversing the order of coverage at alternating sites. Observers noted all birds detected in 3 minutes and continued recording for a full 10 minutes to enable comparisons of the number of species detected by increasing the length of the count. Counts were conducted only once at each point. Thus, within a site, the three point counts have the same forest type, elevation, observer, and general time-of-day.

For each species, the number counted from the roadside point was compared to the number counted from the 200-m point and the 400-m point in two paired-sample, one-sided, *t*-tests (Zar 1984). Because the two tests both use the roadside count and are thus not independent, our interpretation of statistical significance was conservative, and we used the Bonferroni adjustment (which halves the critical *P* value) and consequently accepted $P < 0.025$ to indicate significant differences between a species' abundance at roadside and off-road points (Miller 1981:15). The paired-sample *t*-tests were conducted using only the sites where the species was present on at least one of the counts.

Results and Discussion

Roadside and Off-Road Abundance of Species

Thirty-five species were observed on 10 or more sites. Greater numbers of species and individuals were detected at roadside points than at their paired 200-m or 400-m off-road points (*table 1*). Roadside counts had significantly more Chipping Sparrows (*Spizella passerina*), Indigo Buntings (*Passerine cyanea*), American Crows (*Corvus brachyrhynchos),* Gray Catbirds (*Dumetella carolinensis*), American

[1] An abbreviated version of this paper was presented at the Workshop on Monitoring Bird Population Trends by Point Counts, November 6-7, 1991, Beltsville, Maryland.

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Table 1--*Results of paired sample t-test comparing number of birds detected at roadside points to number detected at 200-m or 400-m off-road points. Analyses were conducted on the sites where the species was present on at least one of the 0-m, 200-m, or 400-m counts. Mean number per count is also calculated from these sites. Species are ordered by the ratio of roadside to off-road mean abundance.*

Species	Number sites species present	$\bar{x}$ Number/count if species present 0 m	200 m	400 m	0-200 m *P*	0-400 m *P*	Ratio of road/off-road abundance
Chipping Sparrow (*Spizella passerina*)	25	1.36	0.16	0.20	0.00 *	0.00 *	7.56
American Robin (*Turdus migratorius*)	13	1.23	0.23	0.31	0.02 *	0.08	4.56
Indigo Bunting (*Passerina cyanea*)	65	1.78	0.58	0.60	0.00 *	0.00 *	3.02
American Crow[a] (*Corvus brachyrhynchos*)	26	1.11	0.34	0.42	0.01 *	0.00 *	2.92
Chimney Swift (*Chaetura pelagica*)	11	0.73	0.09	0.45	0.13	0.57	2.70
Gray Catbird (*Dumetella carolinensis*)	20	1.15	0.40	0.50	0.02 *	0.05	2.56
Chestnut-sided Warbler (*Dendroica pensylvanica*)	21	1.00	0.42	0.52	0.04	0.14	2.13
Common Raven (*Corvus corax*)	38	0.79	0.50	0.32	0.11	0.01 *	1.93
American Goldfinch (*Carduelis tristis*)	36	0.64	0.25	0.50	0.01 *	0.42	1.71
Brown-headed Cowbird (*Molothrus ater*)	40	0.82	0.40	0.58	0.03	0.29	1.67
Northern Cardinal (*Cardinalis cardinalis*)	10	0.90	0.90	0.20	1.00	0.88	1.64
Cerulean Warbler[a] (*Dendroica cerulea*)	18	0.78	0.44	0.56	0.30	0.46	1.56
Pileated Woodpecker[a] (*Dryocopus pileatus*)	23	0.65	0.39	0.52	0.28	0.61	1.43
Wood Thrush[a] (*Hylocichla mustelina*)	62	1.13	1.05	0.74	0.59	0.02 *	1.26
Tufted Titmouse[a] (*Parus bicolor*)	32	0.81	0.56	0.75	0.16	0.75	1.24
Dark-eyed Junco (*Junco hyemalis*)	24	0.62	0.42	0.62	0.28	1.00	1.19
Red-eyed Vireo[a] (*Vireo olivaceous*)	64	1.27	1.06	1.09	0.19	0.29	1.18
Great Crested Flycatcher[a] (*Myiarchus crinitus*)	27	0.56	0.48	0.55	0.70	1.00	1.09
Solitary Vireo (*Vireo solitarius*)	38	0.68	0.68	0.58	1.00	0.61	1.08
Ovenbird[a] (*Seiurus aurocapillus*)	60	1.13	0.98	1.17	0.37	0.87	1.05
Scarlet Tanager[a] (*Piranga olivacea*)	76	0.88	0.89	0.91	0.91	0.85	0.98
American Redstart[a] (*Setophaga ruticilla*)	49	1.00	1.00	1.06	1.00	0.75	0.97
Blue Jay (*Cyanocitta cristata*)	19	0.42	0.26	0.63	0.33	0.33	0.94
Yellow-billed Cuckoo (*Coccyzus americanus*)	30	0.53	0.60	0.53	0.66	1.00	0.94
Eastern Wood-Pewee (*Contopus virens*)	76	0.93	1.04	0.97	0.46	0.78	0.93
Rufous-sided Towhee *(Pipilo erythrophthalmus*)	72	1.08	1.21	1.14	0.51	0.78	0.92
Downy Woodpecker (*Picoides pubescens*)	25	0.44	0.56	0.44	0.65	1.00	0.88
Red-bellied Woodpecker[a] (*Melanerpes carolinensis)*	10	0.40	0.30	0.70	0.68	0.34	0.80
Veery[a] (*Catharus fuscescens*)	40	1.42	1.77	1.92	0.13	0.10	0.77

continued

Table 1--*continued*

Species	Number sites species present	$\bar{x}$ Number/count if species present 0 m	200 m	400 m	0-200 m *P*	0-400 m *P*	Ratio of road/off-road abundance
Carolina Chickadee (*Parus carolinensis*)	20	0.40	0.65	0.55	0.37	0.57	0.67
Acadian Flycatcher[a] (*Empidonax virescens*)	25	0.52	0.68	0.88	0.41	0.14	0.67
White-breasted Nuthatch[a] (*Sitta carolinensis*)	44	0.48	0.61	0.82	0.44	0.08	0.67
Black-and-white Warbler[a] (*Mniotilta varia*)	11	0.27	0.34	0.54	0.55	0.27	0.61
Hooded Warbler[a] (*Wilsonia citrina*)	21	0.43	0.57	0.90	0.42	0.08	0.59
Rose-breasted Grosbeak[a] (*Pheucticus ludovicianus*)	27	0.33	0.52	0.78	0.34	0.03	0.51
Number of species	81	9.53	8.31	8.51	0.00 *	0.01 *	1.13
Number of individuals	81	14.50	11.67	12.30	0.00 *	0.00 *	1.21

[a] Considered to be area-sensitive (Robbins and others 1989).

* $P < 0.025$ and considered statistically significant.

Goldfinches (*Carduelis tristis*), and American Robins (*Turdus migratorius*) than paired counts 200 m from the road. Mean abundance of Chipping Sparrows on roadside points was over seven times the mean of its abundance at paired off-road points (*table 1*). The Common Raven (*Corvus corax*) and Wood Thrush (*Hylocichla mustelina*) were significantly more abundant on roadside points compared to 400-m points, but not compared to 200-m points. No species had a significantly greater abundance on off-road points than on the roadside point. Several area-sensitive species (Robbins and others 1989:25) were among those with the lowest roadside to off-road change in mean abundance (e.g., Rose-breasted Grosbeak (*Pheucticus ludovicianus*) and Hooded Warbler (*Wilsonia citrina*)), but their roadside abundance was not significantly lower than either off-road estimate.

Thirty-three species were present on fewer than 10 sites. Total numbers of these rare or incidental species were also highest on the roadside points. Roadside points detected 25 of these 33 rare species, 21 of 33 were detected on 200-m points and 17 of 33 were detected on 400-m points.

Thus, the major difference between roadside and off-road counts was the increased abundance of some species that are generally associated with forest edges, such as Indigo Buntings, and species associated with the grassy strip adjacent to the road such as Chipping Sparrows and robins. This increased count of edge species resulted in more species and more individuals detected from roadside points than off-road points. However, no species that are considered area-sensitive (Robbins and others 1989:25) were counted in significantly lower numbers from roads than from 200 m or 400 m off the road.

Increased abundance along the road could also result from increased visibility along roads (Hutto, in this volume). While sighting distances would be required to evaluate this possibility, we feel this is not a major explanation of our results, simply because most of our detections were by sound and we would expect visibility to enhance detection of many species, not just those associated with edges.

Roadside samples with large counts of edge species, or even small counts of other species, do not necessarily pose a problem for temporal population monitoring, provided an adequate sample of sites and counts of each species can be obtained. Where the same route is covered year after year, data can provide an index to population trends, if we assume that counts are related to population size and that population parameters are not influenced by the road.

Roadside and Off-Road Assessment of Avian Community

Although point counts have no adjustments for different detectabilities among species, land managers are likely to use point counts to assess the distribution of species in an area, and to provide rough estimates of the avian community on the property they manage. The high counts of edge species from roadsides will require some interpretation in describing the avian community from road counts. For example, roadside counts suggest Indigo Buntings are the most widely distributed species, occurring on 74 percent of the sites (*table 2*). However, off-road, they are ninth in abundance, occurring on 36 percent of the sites. Their distribution and dominance in the avian community is exaggerated in the roadside sample. There is some suggestion that the distribution of the Veery (*Catharus fuscescens*) is underestimated from the roadside sample. However, with these exceptions, the roadside sample actually provided a fairly similar assessment of species occurrence. Twelve of the 15 most common species found in the 400-m sample were among the 15 most common roadside species (*table 2*). And the same set of species occurred in 200-m and 400-m samples as the nine most common species on the roadside. Managers must realize that a few edge

Table 2--*Fifteen species most frequently encountered in 81 point counts conducted 0 m, 200 m, and 400 m from the roadside, and the percentage of the 81 counts in which they occurred*

Frequent species at 0 m	Percent	200 m	Percent	400 m	Percent
Indigo Bunting	74	Eastern Wood-Pewee	66	Eastern Wood-Pewee	64
Scarlet Tanager	66	Scarlet Tanager	64	Scarlet Tanager	56
Eastern Wood-Pewee	64	Rufous-sided Towhee	58	Red-eyed Vireo	53
Red-eyed Vireo	59	Wood Thrush	56	Rufous-sided Towhee	53
Wood Thrush	57	Red-eyed Vireo	54	Ovenbird	51
Rufous-sided Towhee	54	Ovenbird	49	Wood Thrush	44
Ovenbird	48	American Redstart	42	Veery	42
American Redstart	44	Veery	42	American Redstart	40
Veery	28	Indigo Bunting	36	Indigo Bunting	36
Chipping Sparrow	28	Solitary Vireo	26	American Goldfinch	22
Brown-headed Cowbird	27	White-breasted Nuthatch	26	Brown-headed Cowbird	22
Common Raven	27	Yellow-billed Cuckoo	21	Rose-breasted Grosbeak	22
Tufted Titmouse	27	Common Raven	18	Acadian Flycatcher	21
American Goldfinch	25	Brown-headed Cowbird	17	Solitary Vireo	21
American Crow	23	Acadian Flycatcher	17	Tufted Titmouse	20

species will be widely distributed along roads but not as prevalent throughout large forested areas of the Park, while the occurrence of most species will be similar from roadside and off-road samples.

Three- Versus l0-Minute Counts

The mean number of species detected on a point count increased from 5.7 to 8.8 in counts of 3 and 10 minutes (n = 282 counts); thus approximately 65 percent of the species are detected within the first 3 minutes. Species varied in the likelihood of being detected in the first 3 minutes (*table 3*). Most species were detected in the first 3 minutes on 50 percent or more of the counts. Those most likely to be detected in the first 3 minutes were abundant, vocal species with small territories such as the Rufous-sided Towhee (*Pipilo erythropthalmus*), Wood Thrush, and Veery. Six species were missed in the first 3 minutes on more than 50 percent of the counts (*table 3*). These include less common or less vocal species with larger territories such as the Blue Jay (*Cyanocitta cristata*) and Brown-headed Cowbird (*Molothrus ater*). We expect to count more species with longer counts (Scott and Ramsey 1981), but it is important to recognize that length of count will influence the detection of some species more than others. Rarer and more cryptic species are less apt to be detected in shorter counts, and some differences appear even between 3- and 10-minute counts. Species with very low detectability may require special survey methods. As an example, we note that raptors were among those species detected on fewer than 10 sites. Raptors are known to have relatively low detection rates in eastern deciduous forests and they require special survey methods (Geissler and Fuller 1986, Mosher and others 1990).

Conclusions

These results suggest that biologists conducting roadside counts of birds are able to detect species that would be counted from points 200 m or 400 m from the road in the same habitat type. However, a greater number of species and greater abundance of many edge species will also be counted at the roadside. Most of these edge species had significantly lower abundance 200 m away from the road, suggesting they did not use forested areas very far from the forest edge. These differences should not impair our ability to monitor populations over time, but greater abundance of edge species at roadsides could influence assessments of the species composition of the avian community. Our results revealed that a greater number of species are detected if the count lasts 10 minutes rather than a shorter period. However, there were no apparent differences in the time required to detect edge species or area-sensitive species. Therefore, we suggest that the duration of the counts be based on efficiency (Verner 1988), number of sample points and, of course, objective. If the objective is to learn about the occurrence of all species on sample sites in a study area, more time should be spent at the site to increase the likelihood of seeing or hearing species with low probabilities of detection. If objectives emphasize the use of counts to monitor population trends of more common species, then sample size and the potential of counting individuals more than once become more important considerations (Verner 1988).

This study was conducted in the middle of a very large block of forest where area-sensitive species were abundant and the roadside edge was one of the few forest openings in the area (Robbins and others 1989). In this setting, where for-

Table 3--*Proportion of counts where a species was detected in the last 7 minutes (missed in first 3 minutes), for species detected on at least 20 point counts*

Species	Number of 10 minute counts where species was detected	Counts where species was detected in last seven minutes	
		Number	Percent
Blue Jay	25	17	68
Brown-headed Cowbird	61	37	61
American Goldfinch	51	29	57
Yellow-billed Cuckoo	53	29	55
Great Crested Flycatcher	40	21	53
Rose-breasted Grosbeak[a]	42	22	52
Downy Woodpecker	32	16	50
Gray Catbird	29	14	48
Carolina Chickadee	27	13	48
White-breasted Nuthatch[a]	78	37	47
Pileated Woodpecker[a]	32	15	47
Chestnut-sided Warbler	29	13	45
Cerulean Warbler[a]	33	14	42
Hooded Warbler[a]	36	15	42
Tufted Titmouse[a]	58	24	41
Common Raven	54	22	41
Solitary Vireo	66	24	36
American Crow[a]	43	13	30
Dark-eyed Junco	38	11	29
Scarlet Tanager[a]	176	50	28
Ovenbird[a]	143	40	28
Acadian Flycatcher[a]	54	15	28
Red-eyed Vireo[a]	161	41	25
American Redstart[a]	129	32	25
Indigo Bunting	127	31	24
Eastern Wood-Pewee	181	43	24
Veery[a]	114	26	23
Wood Thrush[a]	149	33	22
Chipping Sparrow	31	6	19
Rufous-sided Towhee	146	28	19

[a] Considered to be area-sensitive (Robbins and others 1989)

est habitat is abundant, 10-m to 35-m openings in the forest were not avoided by area-sensitive birds, and the openings are sufficient to attract several edge species. In this situation, point counts from roadsides were as useful for detecting many forest dwelling birds as were counts 200 m and 400 m from the road. The generality of these results is being investigated at five other forested study areas where habitat types are more patchy than in Shenandoah National Park.

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Point Counts of Birds: What Are We Estimating?[1]

Douglas H. Johnson[2]

Abstract: Point counts of birds are made for many reasons, including estimating local densities, determining population trends, assessing habitat preferences, and exploiting the activities of recreational birdwatchers. Problems arise unless there is a clear understanding of what point counts mean in terms of actual populations of birds. Criteria for conducting point counts depend strongly on the purposes to which they will be put. This paper provides a simple mathematical conceptualization of point counts and illustrates graphically some of the influences on them.

Point counts are used to sample bird populations for estimating densities in local areas, determining trends in populations over regional areas, assessing habitat preferences and other scientific and population monitoring purposes. Difficulty in analyzing point counts of birds arises from confusion about-or lack of-definitions. Rarely is a clear statement made about what is being estimated and often the objectives of conducting a point count are unclear or conflicting. Burnham (1981) harshly criticized the use of measures such as point counts because they lacked a clear connection to biological parameters such as population densities. This paper is intended to provoke thinking about what parameter of interest is estimated by point counts. It also provides an elementary precursor to the important and more mathematical contribution by Barker and Sauer, in this volume. It gives in straightforward terms one perspective of what point counts are attempting to accomplish. Mathematical models of point countsare introduced, not to complicate the life of the ornithologist, but to provide a concrete and explicit formulation of the assumptions involved and to guide further work.

A point count, or circular-plot survey, involves a series of points or stations at which birds are counted. Observers spend a prescribed time (usually 3 to 20 minutes, with longer times occasionally suggested for areas with more complex vegetation structure or where travel times between stations is a serious limitation) at each station, looking and listening for birds. Stations are to be separated by sufficient distance to preclude sighting the same bird at more than one station. Observers may restrict attention to birds within a prescribed distance of the station (fixed-distance circular plots) or record birds regardless of the distance (unlimited-distance circular plots). Although sighting distance might be recorded and used to develop estimates of density, typical point counts do not use information on sighting distance (Reynolds and others 1980). See International Bird Census Committee (IBCC) (1977) and Blondel and others (1981) for further details of the method, which is akin to the *Indice Ponctuel d'Abondance* (IPA) method. The North American Breeding Bird Survey (BBS) represents a cluster of 50 point counts (Droege 1990).

Models

Consider a population of a species of bird, distributed over its breeding range during its breeding season. We assume for simplicity that birds are territorial and sexually dimorphic and that the population can be enumerated by counting territorial males; say there are N of them during the breeding season of a particular year. The real world is more complicated than that, but we make these simplifying assumptions to avoid clouding the main issues. Interest might be in estimating N, but more typically we want to compare population size for 2 or more years and especially to determine if there is a consistent trend, either upward or downward. Another goal might be to identify habitat associations of the birds (Ralph and others, in this volume); this objective requires a fundamentally different approach (Pendleton, in this volume).

The distribution of territories can be considered as the outcome of a stochastic point process operating over the breeding range. That is, the locations of territories are viewed as random events in space. The intensity of the process (i.e., the density of territories) varies spatially and reflects the number of birds in the population, the size of the breeding range, and the quality and attractiveness of habitats at various locations within the breeding range. *Figure 1* (left) illustrates a greatly simplified situation, with only $N = 50$ territories. Notice that territories are more dense in the upper (northern) part of the breeding range, presumably reflecting higher-quality habitat there. The lower part of the breeding range has unoccupied areas.

Assume now that the distribution of territories is fixed-the birds have established their territories for the season-and that the area is far too large for complete enumeration by, for example, territory mapping. We select one or more sample study areas from within the breeding range. One such study area is shown schematically in *figure 1* (top right). A study area probably contains some territories in their entirety, parts of other territories, and voids where no territories cover. One measure of bird abundance for a study area is the total number of birds whose territories are at least partly included in the study area; this is four for the example in *figure 1*. A more useful measure is the total number of fractions of territories in the area; for the example in *figure 1,* that value is about 2.75 (one each from complete territories, 0.5 from the fraction of the territory at the upper left, and 0.25 from the part of the territory at the upper right). The usefulness of such numbers stems from the fact that they can give estimates of density of territories, and a random sample

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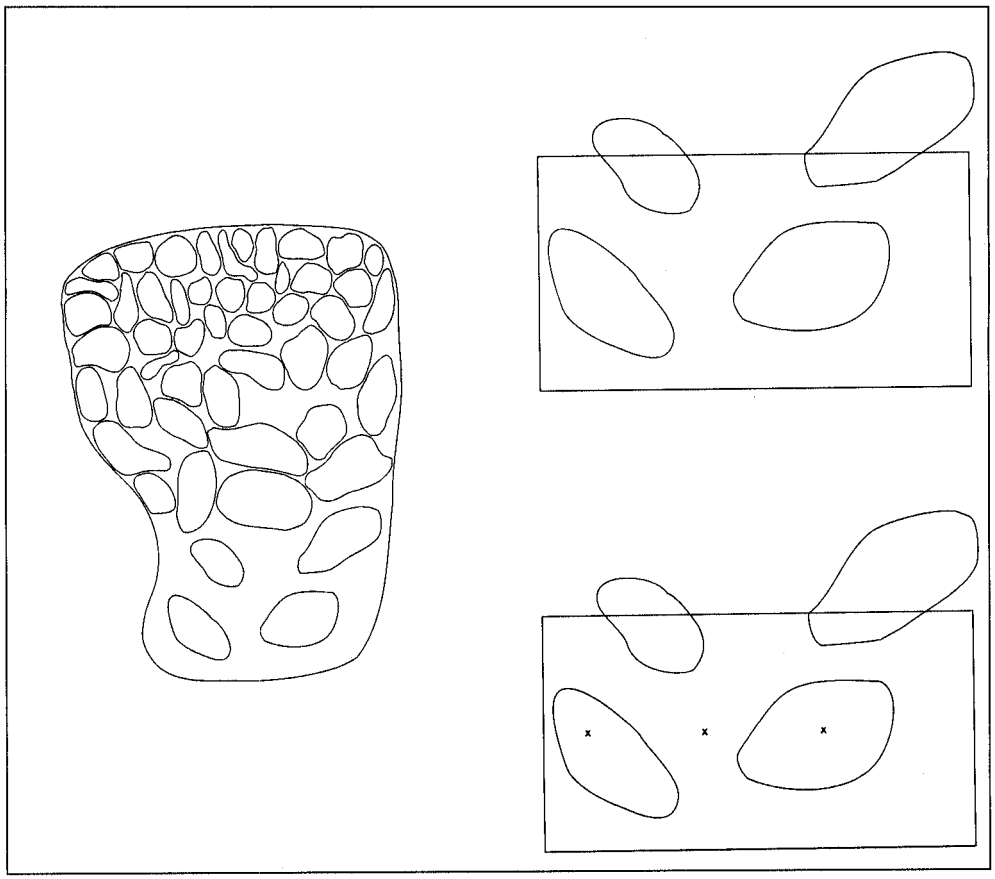

Figure 1--Left: Simplified example of a breeding range of a bird, partially filled with territories. Top right: Simplified example of a rectangular study area containing portions of four territories. Bottom right: The same study area in which three stations for point counts (located at the x's) have been established.

of study areas produces values with expectation N/A. Therefore, the total population size N can be estimated if A, the size of the study area, is known. Territory mapping is the principal method used to obtain such estimates of density, but I am not aware of its application to study areas randomly selected from a large breeding range. For example, North American Breeding Bird Censuses (Engstrom 1988) and the British Common Birds Census (Marchant and others 1990) involve sites that were not randomly chosen. For waterfowl, counts based on observations of "indicated pairs" are used to that end (Martin and others 1979).

Suppose a series of point counts, instead of territorial mappings, are made in the study area (*fig. 1*, bottom right). In the example, three stations are included. At each station, the number of males seen is tallied. Depending on the distance between stations, the size and configuration of territories, the behavior of the birds, and the skills of the observer, the same bird may be counted on more than one station. Such double counting is to be avoided, if possible. Probably more birds are missed than counted twice.

Denote the true count of territories in a study area by X and the observed count by Y. What relation does Y have with X? We consider three reasonable possibilities, among many.

An Additive Model

The most straightforward approach is to suppose that Y and X are linearly related by

$$Y = (1\text{-}b)X + \varepsilon, \qquad (1)$$

where, on average, the observed count is a fraction (1-b) of the true count, b is the bias rate, and ε represents the sampling error. That means that, if the survey were repeated numerous times in the same area under identical conditions (which is possible only conceptually, because conditions never stay the same), the averages would be related by

$$\overline{Y} = (1\text{-}b)X \qquad (2)$$

and the ε values would be the departures from count to count in that relation. If $b = 0$, the count is unbiased and we have the equivalent of a complete census, except for the sampling error. Most often some birds are missed, so that $b > 0$, often substantially so. Also, the sampling error depends on X; if no birds are in the area ($X = 0$), repeated counts will turn up similar numbers (usually $Y = 0$) so that the variation from count

to count will be small; if the population is very large, variability from count to count will be greater.

Under this additive model, the true error, the difference between observed and actual population sizes, is

$$\begin{aligned}\text{True error} &= Y - X = (1-b)X + \varepsilon - X \\ &= -bX + \varepsilon,\end{aligned} \tag{3}$$

essentially the bias plus sampling error for that specific count.

A Multiplicative Model

Because a true population of zero generally leads to an observed value of zero, it may be more reasonable to assume a relation of the form:

$$Y = (1-a)X\varepsilon, \tag{4}$$

in which a represents the bias and the error term affects the observed count multiplicatively. Here $X = 0$ implies $Y = 0$, but not the converse. That is, if no birds are present, the observer probably will count none, but a count of zero does not necessarily mean that the species is absent.

The true error under this model is

$$\begin{aligned}\text{True error} &= Y - X = (1-a)X\varepsilon - X \\ &= [(1-a)\varepsilon - 1]X,\end{aligned} \tag{5}$$

which now involves the product of the bias term $(1-a)$ and the sampling error (ε). This formulation is mathematically more difficult to handle than the additive model. It can be reduced to a linear additive form by taking logarithms of both sides, but zero counts render that remedy ineffective.

An Index Model

Often it is hoped only that point counts correlate strongly with the actual population. Then bias does not matter, as long as it is relatively constant. An appropriate model for this situation is

$$Y = CX, \tag{6}$$

where now C is not a fixed parameter, as were b and a in the models described earlier, but a random variable. More will be said about its variability shortly. We call C the detection probability, as used by Barker and Sauer (in this volume) in their counterpart to this model. It is the probability that a specific bird will be detected on a particular point count. Other index models are plausible (Caughley 1977:15).

The key point, brought out also by Barker and Sauer (in this volume), is that the variation in Y incorporates variation in both C and X. Specifically,

$$\text{Var}(Y) = C^2\text{Var}(X) + X^2\text{Var}(C) + \text{Var}(X)\text{Var}(C), \tag{7}$$

approximately, if C and X are independent. (If they are not independent---a very real possibility---the situation is complicated even further [Goodman 1950]).

When using point counts to compare areas or years, the comparison involves the C values as well as the populations. Let the two areas or years be indexed by subscripts 1 and *2*. Then

$$Y_1 - Y_2 = C_1X_1 - C_2X_2. \tag{8}$$

If detection probabilities are the same for both areas or both years, $C_1 = C_2 = C$, say, then $Y_1 - Y_2 = C(X_1 - X_2)$ and the observed difference faithfully reflects the actual difference. If detection probabilities are not the same, then

$$Y_1 - Y_2 = C_1(X_1 - X_2) + (C_1 - C_2)X_2, \tag{9}$$

or equivalently

$$Y_1 - Y_2 = C_2(X_1 - X_2) + (C_1 - C_2)X_1. \tag{10}$$

(Note that either of these reduces to $C(X_1 - X_2)$ when $C_1 = C_2 = C$.) This simply states that an observed difference in point counts reflects not only the true difference in the bird counts $(X_1 - X_2)$ but also the difference in detection probabilities $(C_1 - C_2)$. Barker and Sauer (1992) elaborate on how unequal detection probabilities can lead one to conclude that bird populations differ even when they do not. Because detection probabilities are presumed to vary so much from one habitat to another, point count data are rarely used to compare bird densities by habitat. If detection probabilities vary markedly from one occasion to another, the comparison of point counts over time can be equally hazardous.

For an effective index, we need C to be independent of X and Var(C) to be small. We assume the first condition, although it too can fail in practice; detectability has been reported both to increase and to decrease with increases in population density (Verner 1985). What can be done about Var(C)? One approach is not to worry about it and to assume its effects can be neglected, especially in large samples. Barker and Sauer (in this volume) showed the follies of this Pollyanna approach (*sensu* Johnson 1981); estimators of population change (trend) remain biased even for very large samples if detection probabilities are not identical.

The customary approach is to specify acceptable conditions for conducting point counts (Ralph and others 1993). Suppose p variables $z_1, z_2, \ldots, z_p$ are thought to influence detection probabilities. These include variables such as date, time of day, weather conditions, etc. With this approach we specify suitability ranges within which surveys can be conducted:

$$z_i^L \le z_i \le z_i^U, \text{ for } i = 1, 2, \ldots, p. \tag{11}$$

The survey is to be conducted only if each z value is between a lower limit z^L and an upper limit z^U. For example, in the North American Breeding Bird Survey, the time must be between one-half hour before sunrise and about 1030.

By taking this approach, it is hoped to minimize Var(C). Two drawbacks are (1) even within acceptable ranges, the variation of z_i probably will induce variation in C; and (2) increasing the width of acceptable ranges exacerbates the difficulty, but decreasing the width may result in conditions too stringent in practice, so that the survey does not get performed. A further drawback arises if observers actually conduct the survey when one or more conditions are not met.

On a side note, often conditions are prescribed to maximize the counts of birds recorded. This is equivalent to maximizing the detection probability C. There is no assurance that conditions that maximize C also minimize Var(C), so that criterion should be evaluated. Specifically, the "dawn chorus" provides a high value of C but is of such short duration that its results can be used only in comparison with other counts also made at dawn (Ralph and others 1993). A more complex but promising method is to derive "adjusted" detection probabilities. If we knew and could estimate how detection probabilities were affected by the variables z_1, z_2, ..., z_P, and if we could measure those variables, we could adjust the observed counts accordingly (Dawson 1981). This practice is widely done in other fields. For example, unemployment rates are adjusted to accommodate seasonal patterns and to give a picture of long-term trends not confused by normal month-to-month fluctuations. In our application, numerous variables that may influence detection probabilities of birds have been identified; see Diehl (1981) and other papers in Ralph and Scott (1981) for a review. Little work has been done to quantify the relations, and that will be a challenging-or hopeless (Burnham 1981)--task.

What Influences Detection Probabilities?

Recall that the detection probability (C) is the probability that a specific bird, indexed by j, will be detected on a particular point count. (This formulation does not allow the observer to double-count a bird. More generally, the detectability could be prescribed as the expected number of times a bird is detected and counted as separate individuals.) Detection probabilities vary in response to numerous variables, such as the observer's visual acuity, hearing ability, and experience; length of time spent at a station; season of year; time of day; wind, temperature, and other weather conditions; habitat features; and the bird's reproductive status and behavior.

Consider graphically the detection probability as a function of certain variables. At any instant the birds in a study area are located at specific points (*fig. 2*, top). When viewed over a period of time, the birds follow certain paths through their territories and possibly outside them *(fig. 2*, bottom). The term *utilization distribution* has appropriately been used to characterize the probability of using specified areas of a territory (Jennrich and Turner 1969).

Now let us invoke an observer, with a certain set of abilities to see, hear, and identify the bird. At any instant, she will detect the bird if she is within the *detection zone* for that bird (*fig. 3*, left). Treating detection zones as circles would be convenient, but overly simplistic; for example, the view of the bird might be blocked from one direction. Suppose our observer stays at a station for several minutes. She will detect the bird if at any time during her stay she falls within any detection zone generated by the bird during that time (*fig. 3*, right). The bird would be double counted if its movements were such that the observer thought two sightings or hearings represented different birds. The count of birds at a station is the number of birds present on the study area whose detection zones contain the station during the time the observer is recording.

Mathematically, the observed count at a station is

$$Y = \sum_j \Pr\{\text{detect bird } j \mid \text{bird } j \text{ present}\} \times \Pr\{\text{bird } j \text{ present}\}, \tag{12}$$

where the summation is over all birds in the population and a bird is defined to be present if it is on the study area. If all birds on the study area could be detected, then

$$\Pr\{\text{detect bird } j \mid \text{bird } j \text{ present}\} = 1 \tag{13}$$

and

$$Y = \sum_j \Pr\{\text{bird } j \text{ present}\}. \tag{14}$$

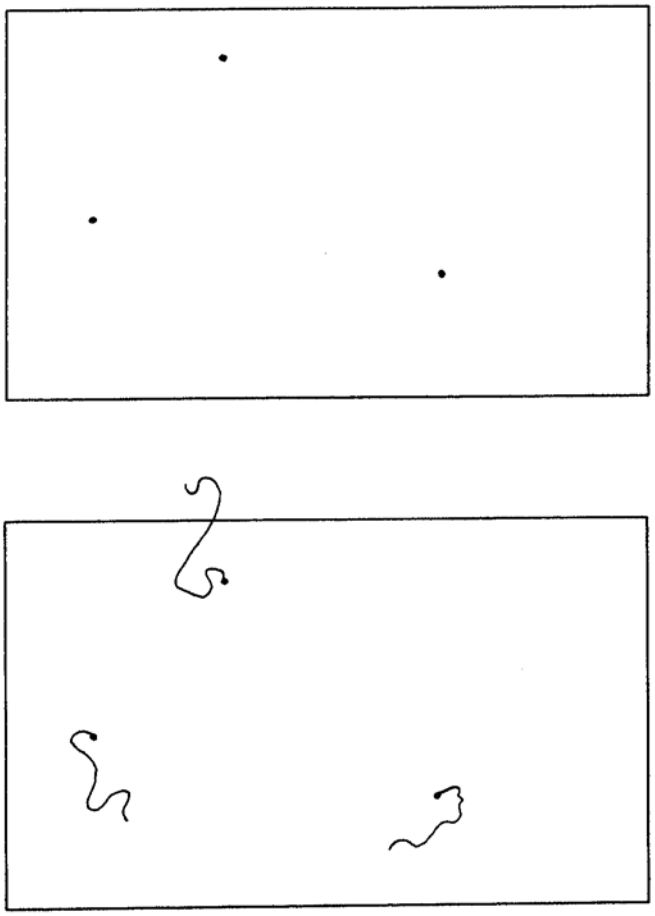

Figure 2--Top: The location of birds within the study area at one particular instant. Bottom: Hypothetical paths of birds in the study area taken during a period of time.

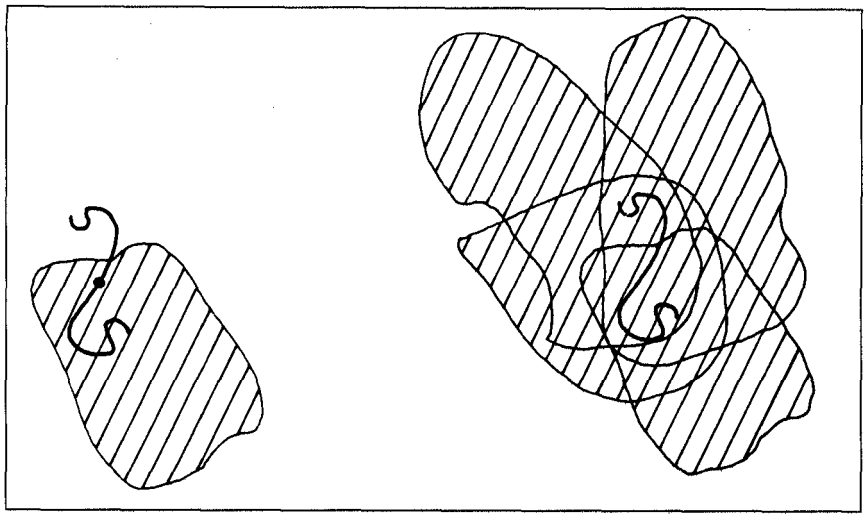

Figure 3--Left: The area in which a bird can be detected by the observer at a particular instant is called the detection zone. Right: The cumulative detection zone for a bird by an observer during the period of counting.

If we define the proportion of the territory of bird j that lies within the study area to be r_j (similar to what we did in association with *figure 1*) and assume that the bird spends time in the study area proportional to r_j, then Pr{bird j present} = r_j at any instant. But as the count period is extended, the number of birds present sometime during the count period increases, because of territories that partially overlap the study area (Granholm 1983, Scott and Ramsey 1981). Thus, lengthy counting periods tend to inflate the component of Y involving the presence of a bird. Another danger in using the total number of birds seen as a criterion to optimize is that that value may reflect not only an increase in delectability but also an increase in the count of birds not associated with the study area.

I illustrate a few of the numerous variables that influence the detection probability. A highly skilled observer, with better eyesight, hearing, and experience, has a much larger detection zone (*fig. 4*, left) than a less-skilled observer (*fig. 4*, center); Ramsey and Scott (1981) found that differences in hearing abilities could affect the area sampled by an order of magnitude. Increasing the counting period enhances the detection zone (*fig. 4*) but, as was mentioned, also increases the chance of counting nonstudy-area birds (Scott and Ramsey 1981). Granholm (1983) found that

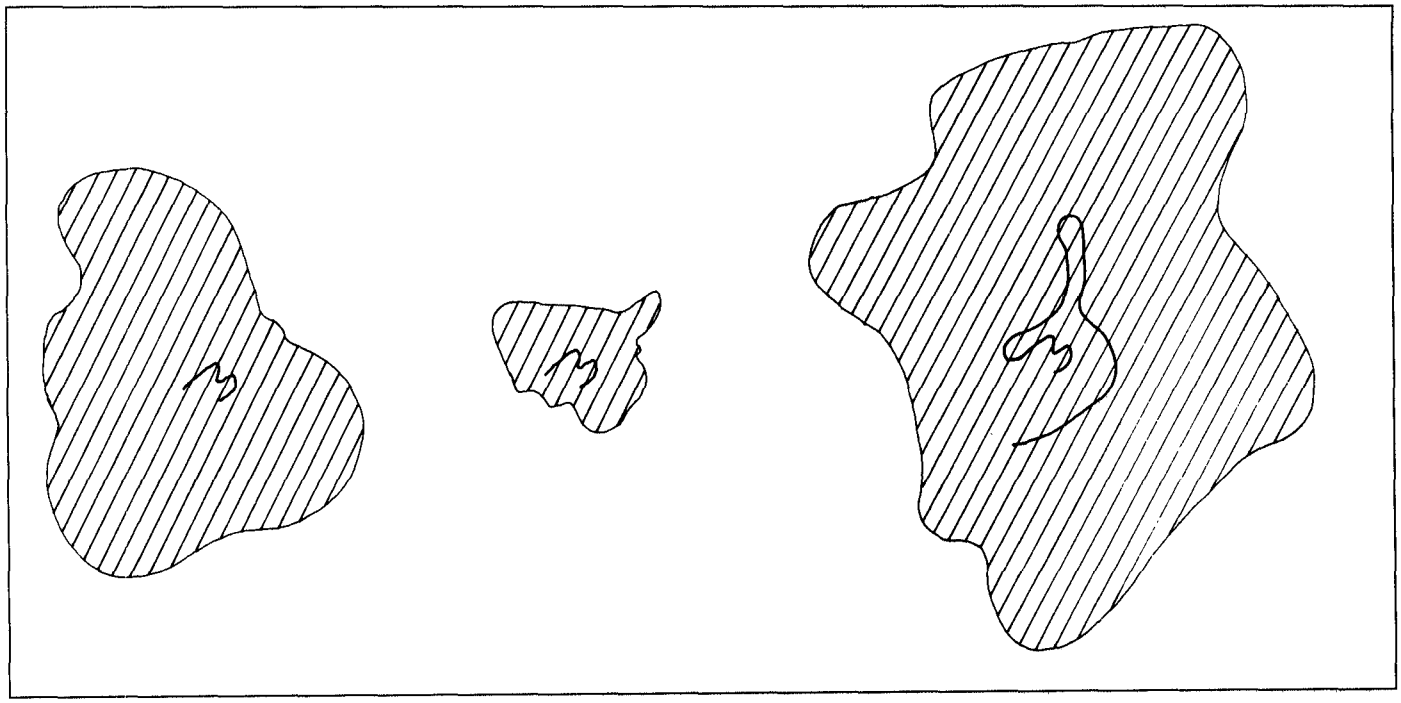

Figure 4--Cumulative detection zone of the same bird for a highly skilled observer (left) and a less-skilled observed (center). Right: Cumulative detection zone of bird increases with longer duration of counting period.

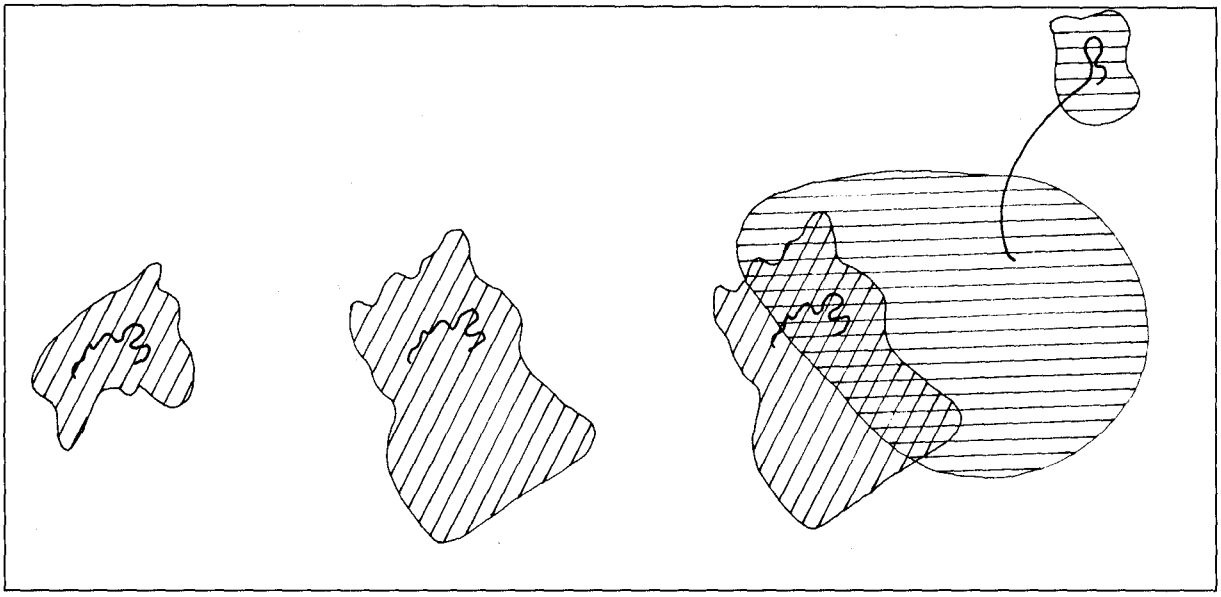

Figure 5--Cumulative detection zones can be increased from the normal (left) by using playbacks of calls or other attractors (center), but such devices may also induce birds from beyond the study area to move into it (right).

density estimates for three common and conspicuous bird species were 22 percent to 56 percent higher for 10-minute point counts than for 5-minute counts. As a logistical issue, longer counting periods also reduce the number of point counts that can be made in a fixed time period.

Similarly, the use of calls can increase the detectability of birds in an area and is especially useful for certain nocturnal or secretive species (Johnson and others 1981; *fig. 5*). Playbacks and the like can also induce birds to move into the study area, however. The tradeoffs with respect to objectives have to be assessed carefully because such devices may not only markedly increase the detection probability, C, but may also increase the variability in detection probabilities, Var(C), and thereby reduce the value of the count as an index.

If stations are too close together, the same birds can be counted at both (*fig. 6*). Unfortunately, what is too close depends on several things, including the openness of the habitat, the size of the bird's home range and its behavior, and the duration of the count.

The influence of roads on surveys in forested habitat is of considerable interest, with ease of access a potential trade-off with bias in the counts (Hutto, and Keller and Fuller in this volume). The issue is whether roads increase the detectability of birds in the habitat (Ralph and others, in this volume; *fig. 7*, center) or increase the actual number of birds using the habitat (Keller and Fuller, in this volume; *fig. 7*, right).

To conclude, a point-count survey should be designed under a clear statement of objectives, whether they be estimating population size, assessing trends in populations, determining habitat preferences, or providing recreation. A survey designed for one objective (or not designed at all) is of limited suitability for another. Unlike many quantitative applications in ecology, point counts of birds are not directly estimating a clearly defined population parameter. Of the three

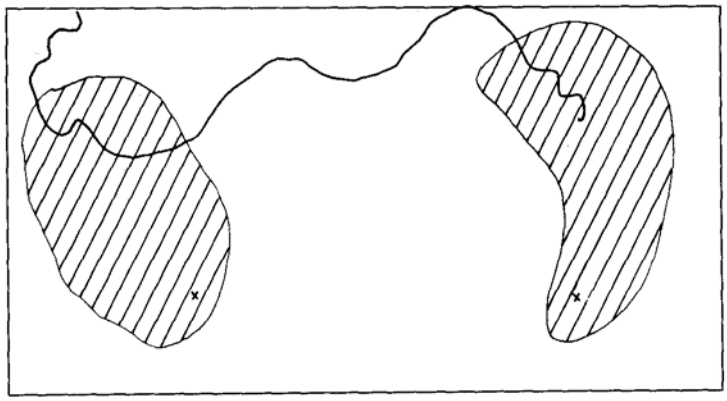

Figure 6--if stations are too close together, relative to the movement patterns of a bird, the bird may be double counted. The x's indicate stations at which the bird, whose path is shown, is counted.

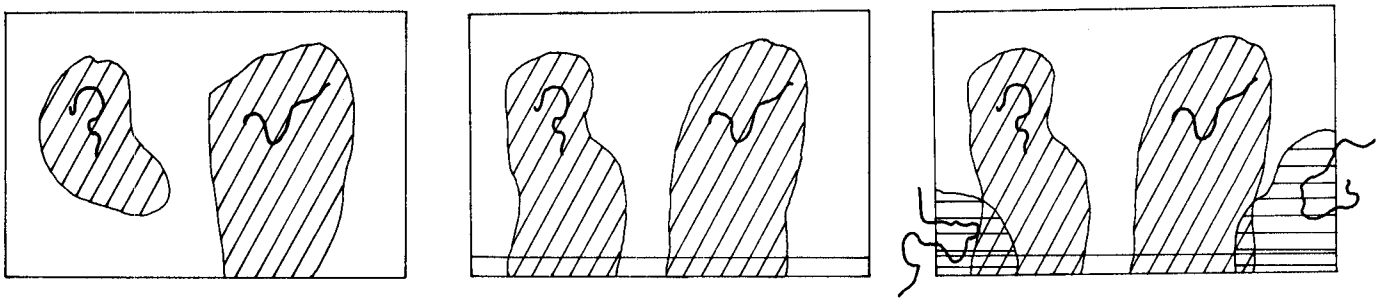

Figure 7--Compared with an area lacking roads (left), a road, indicated at the bottom of the area, may increase the count either by increasing the cumulative detection zones of birds (center) or by increasing the actual number of birds present (right), or both.

models proposed for point counts, the additive and multiplicative models include unknown biases. The index model, the most reasonable of the lot, involves the product of bird density (the parameter of interest) and detectability. We need to better understand the role of the detection probabilities if we are to draw inferences from the counts about bird populations.

In some ways the problems inherent in point counts of birds are mitigated by large sample sizes, but not always. Theoretical and simulation studies are needed to determine which shortcomings are most critical, and field studies are needed to evaluate the extent of those departures from the ideal.

Acknowledgments

I am grateful to Rolf R. Koford, John R. Sauer, and Terry L. Shaffer for comments on the manuscript, and to Diane L. Larson, Michael D. Schwartz, and John M. Steiner for preparing figures.

Statistical Aspects of Point Count Sampling[1]

Richard J. Barker and John R. Sauer[2]

Abstract: The dominant feature of point counts is that they do not census birds, but instead provide incomplete counts of individuals present within a survey plot. Considering a simple model for point count sampling, we demonstrate that use of these incomplete counts can bias estimators and testing procedures, leading to inappropriate conclusions. A large portion of the variability in. point counts is caused by the incomplete counting, and this within-count variation can be confounded with ecologically meaningful variation. We recommend caution in the analysis of estimates obtained from point counts. Using; our model, we also consider optimal allocation of sampling effort. The critical step in the optimization process is in determining the goals of the study and methods that will be used to meet these goals. By explicitly defining the constraints on sampling and by estimating the relationship between precision and bias of estimators and time spent counting, we can predict the optimal time at a point for each of several monitoring goals. In general, time spent at a point will differ depending on the goals of the study.

Most observational studies of birds have a goal of characterizing the numbers or distribution of birds through time or space using observations of the number of birds counted at randomly selected points, or clusters of points. Most biologists analyze these data using standard sampling estimation procedures (Cochran 1977) and assume that the counts can be used in place of exact measurements of bird abundance at the points. Unfortunately, most point counts miss over 50 percent of the individual birds at any point (Sauer and others, 1994a). Not only are the data incomplete counts, or indices of bird abundance, but usually we cannot estimate the proportion of birds counted, or detection probabilities, associated with each sample of counts. Burnham (1981) stated that without estimating detection probabilities, the use of counts as indices of abundance is scientifically unsound and unreliable. He also suggested that estimation of detection probabilities could be achieved relatively easily using detection distance data; unfortunately this view is probably overly optimistic for the majority of bird species that large-scale monitoring programs are designed to cover. Ironically, in these programs samples are collected in many habitats by many observers, and detection probabilities are unlikely to be comparable among points.

Therefore, it is critical that we address the question of how unmodeled detection probabilities affect inference based on point counts, and how sampling at points should be conducted to minimize possible inefficiencies and biases associated with :incomplete counts. In this paper we develop a model for point count sampling and consider how incomplete counting affects some of the common estimators of abundance and population trend. We then describe optimal allocation of sampling effort in point counts under our model.

Model

In this section, we develop a model for how animals are sampled at points. All statistical analyses require an underlying model, and we use the model to assess the effects of incomplete counts on commonly used estimation procedures. The model reflects a view of how an underlying population of individuals at a point is counted. Development of the model requires some discussion of the mathematical formalism, which should be of interest to quantitative ecologists.

Let c_i denote a count at the ith sampling location (point) from a population of N_i animals. Among points assume that animals are independent and identically distributed with mean μ and variance σ^2. To model the incomplete counting process we assume the c_i are binomial random variables with parameters N_i and detection probability p, thus

$$\mathbf{E}[c \mid N,p] = Np, \quad (1)$$

$$\mathbf{E}[c] = \mu p, \quad (2)$$

$$Var(c \mid N, p) = Np(1-p), \quad (3)$$

and

$$Var(c) = \mu p(1-p) + p^2 \sigma^2. \quad (4)$$

The **E** notation represents mathematical expectation.

Under this model, double counting is not allowed, and p is constrained between 0 and 1. Alternatively, one could model the counts conditional on N as Poisson random variables with parameter pN which would allow p to exceed 1, as may occur in some cases (Bart and Schoultz 1984). The Poisson model may also be advantageous in more complex models, such as models for the unconditional distribution of bird counts in space or time, as certain mixtures of the Poisson distribution can lead to other well known distributions such as the negative-binomial or the Neyman type A. As our intention is to discuss the sampling process, we consider only the binomial model, which is conceptually easy to understand in the point count context.

There are two basic ways to conceptualize what we refer to as incomplete counting. In the first case, as represented by unlimited distance point counts, all animals noted by the observer at a point are recorded. The region sampled at the ith point can then be described as that area lying within a circle of some unknown radius about the observer, the boundary of which marks the point at which detection probability can effectively be considered as zero. The number of animals associated with this point is then the collection of birds that are "located" within this circle, and c_i is the count obtained from this population. The second case, represented by limited

[1] An abbreviated version of this paper was presented at the Workshop on Monitoring Bird Population Trends by Point Counts, November 6-7, 1991, Beltsville, Maryland.

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distance sampling, is described in a similar manner, except at the time of the count only those animals present within some fixed radius of the observer are recorded. The detection probability, as described above, is now the product of the probability that any one of the N_i birds is located within the fixed distance of the observer at the time of the count, and the probability that it is detected by the observer given that it is present within the fixed radius. This latter probability is usually assumed to be 1.

Estimators

In this section, we use the model to evaluate the possible effects of incomplete counting on estimators of various population parameters. Data from point counts are used to estimate: (1) mean relative abundance and its variance; (2) differences between relative abundances for populations in different habitats or regions; (3) population trends; and (4) species richness. Point count data are often reasonable surrogates for total population sizes for all of these population parameters, but we demonstrate that the potential exists for analyses based upon point counts to not accurately reflect the real population.

Estimation of Total Counts

The mean and variance of the counts are given by expressions (2) and (4) above. Because *p* appears in both formulae, as detection probabilities decrease, both the average count and the variance of the counts decrease. Thus counts from populations with inherently low detection probabilities tend to also have low absolute variability. An implication of this, which we explore in a later section, is that using variance as a measure of count quality is not a good idea. Considering the coefficient of variation of the counts (CV_c), however, from (2) and (4) it can be shown that

$$CV_c^2 = \frac{1-p}{\mu p} + CV_N^2, \qquad (5)$$

which increases without bound as p tends to zero. Thus, not counting all the animals that are present increases the relative variability of the counts. If one is interested in modeling demographic processes, the information of interest is contained within the variance component described by the term CV_N^2 in expression (5). Clearly, however, if detection probabilities are not estimated, this information is confounded with the additional term associated with p. It is important to be aware of the presence of this additional component when interpreting index data. For example, variance associated with p can dominate the total variance, particularly for counts with low detection probabilities. Differences in variances over time or regions based on point counts therefore may reflect differences in the variability of counts, not real population differences in variance.

Ratio Estimator of Population Change

If it is assumed that detection probabilities remain constant through time, it is possible to obtain reasonable estimates of population change between 2 years using the ratio estimator

$$\hat{\beta} \approx \frac{\sum_{i=1}^{n} c_{i,t+1}}{\sum_{i=1}^{n} c_{i,t}} \qquad (6)$$

where *t* indexes year. Barker, Link, and Sauer (personal communication) used the model described in the first section to derive analytical expressions for bias and variance of the estimator (6). They showed that if $p_{t+1} = p_t$, then

$$Bias\left(\hat{\beta}\right) \approx \frac{\beta}{n\mu}\frac{\{1-p\}}{p}, \qquad (7)$$

and

$$Var\left(\hat{\beta}\right) \approx \frac{\beta(1+\beta)}{\mu}\frac{\{1-p\}}{p} + \sigma_\beta^2\left\{1+\frac{\sigma^2}{\mu^2}\right\}, \qquad (8)$$

where β denotes the ratio μ_{t+1}/μ_t, σ_β^2 denotes the variance of N_{t+1}/N_t among points, and σ^2 denotes the variance of the number of animals among points in the first year. It is evident from expression (7) that without complete counts the ratio estimator (6) is biased, with the extent of bias determined by the detection probability (*p*) and the number of points sampled (*n*). In the case that p_{t+1} is exactly equal to p_t, the bias tends to zero for large samples of points. However, if this condition is violated, even if the p_t and p_{t+1} are random variables with the same expected values, the expression (7) contains another term, and the estimator is no longer unbiased for large sample sizes. Thus it is critically important to consider the assumption of constant detection probabilities over time when using incomplete counts to estimate population changes. Numerous studies have demonstrated that observers and environmental conditions affect the number of birds counted (Ralph and Scott 1981); thus it is likely that in practice an assumption of constant detection probabilities through time is unreasonable. Therefore, bias in estimation of population change from point counts will always exist, but can be minimized by large sample sizes if p does not change over time. Use of statistical methods such as the base-year method that estimate trends as products of these ratio estimators should be avoided (Barker, Link, and Sauer, personal communication).

Comparison of Average Counts by Habitat or Regions

If it can be assumed that detection probabilities are identical between study areas that have been sampled using point counts, then it is possible to use the count data to test for differences in bird abundance between those areas. Under our model, power of a two-sided *z*-test for a difference in

means between two sets of counts with identical detection probabilities and equal sampling effort is given by:

$$Power = 1 - \Phi\left[\frac{\{z_{\alpha/2}\sigma_0 - pk\mu_i\}}{\sigma_1}\right] + \Phi\left[\frac{\{-z_{\alpha/2}\sigma_0 - pk\mu_i\}}{\sigma_1}\right], \quad (9)$$

where $\Phi(z)$ denotes the standard normal cumulative density function evaluated at z, σ_o denotes the standard deviation of the difference in means under the null hypothesis (H_0: $\mu_i = \mu_j$), σ_1 denotes the standard deviation of the difference in means under the alternative hypothesis (H_1: $\mu_i \neq \mu_j$), and where $\mu_j = (1\text{-}k)\mu_i$. The standard deviation of the difference in mean counts under the null and alternative hypotheses can easily be computed using expression (4). To demonstrate the effect of detection probabilities on power we generated power curves for a population with $\mu_1 = 20$ birds, $\sigma_1^2 = \sigma_2^2 = 20$, and for p =: 1, 0.75, 0.5, and 0.25 (*fig. 1*). The incomplete nature of the counting process leads to a reduction in power of the hypothesis tests, as shown by the decline in steepness of the curves as the p becomes smaller. More seri equal detection probabilities between areas would have. Such a failure leads to a shift in the curve away from the origin leading to both increased power and increased Type I error rates (*fig. 2*). Even small changes in detection probabilities can invalidate the statistical tests. Thus, a change in detection probabilities between treatments can never be separated from a real population difference, and the null hypothesis gets rejected at a greater rate even when no difference in population means exists.

Allocation of Sampling Effort

Several components of the design of point count studies remain controversial. One primary source of disagreement is the optimal length of time spent sampling at points. In our opinion, consistency in design is desirable for monitoring programs, and one consequence of this workshop is a set of standards for the design of point count studies. However, selection of point count duration should be viewed as a statistical problem, for which one uses available information and a model to predict a sampling procedure with optimal properties. In this section, we discuss a method of optimizing point count duration and review how different goals for a survey can lead to different point count durations.

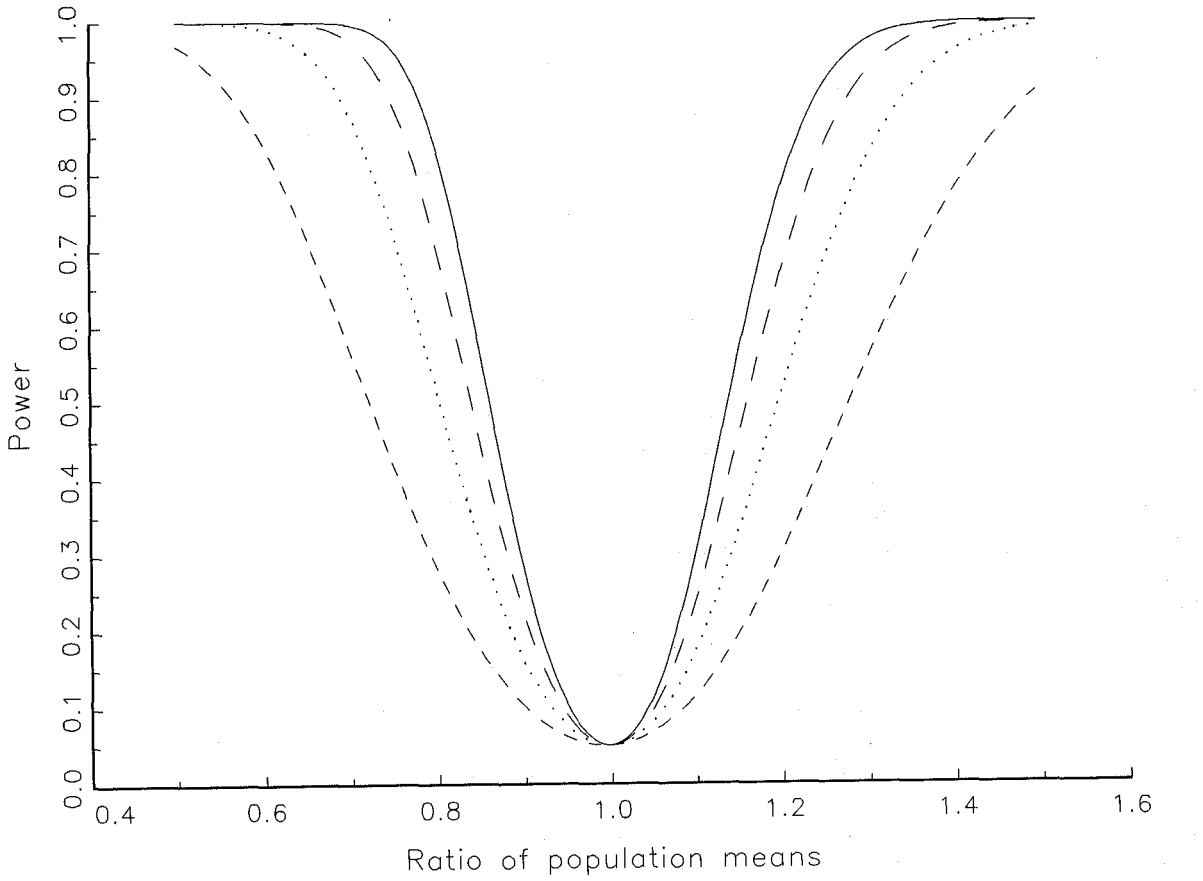

Figure 1--Power of a 2-sided *z*-test for a difference in means of two populations plotted as a function of the ratio of population means (1-*k*) and detection probability (p = 1: __; p = 0.75:_ _ _ ; p = 0.5: ...; p = 0.25: - - -). Detection probabilities are the same in the two populations and 20 point counts are made from each population. The mean and variance of the number of birds present at each point are the same within groups, and in the first group of counts there are an average of 20 birds per site present (μ_1). At the second group of sites there are an average of (1-*k*)μ_2 birds present per site.

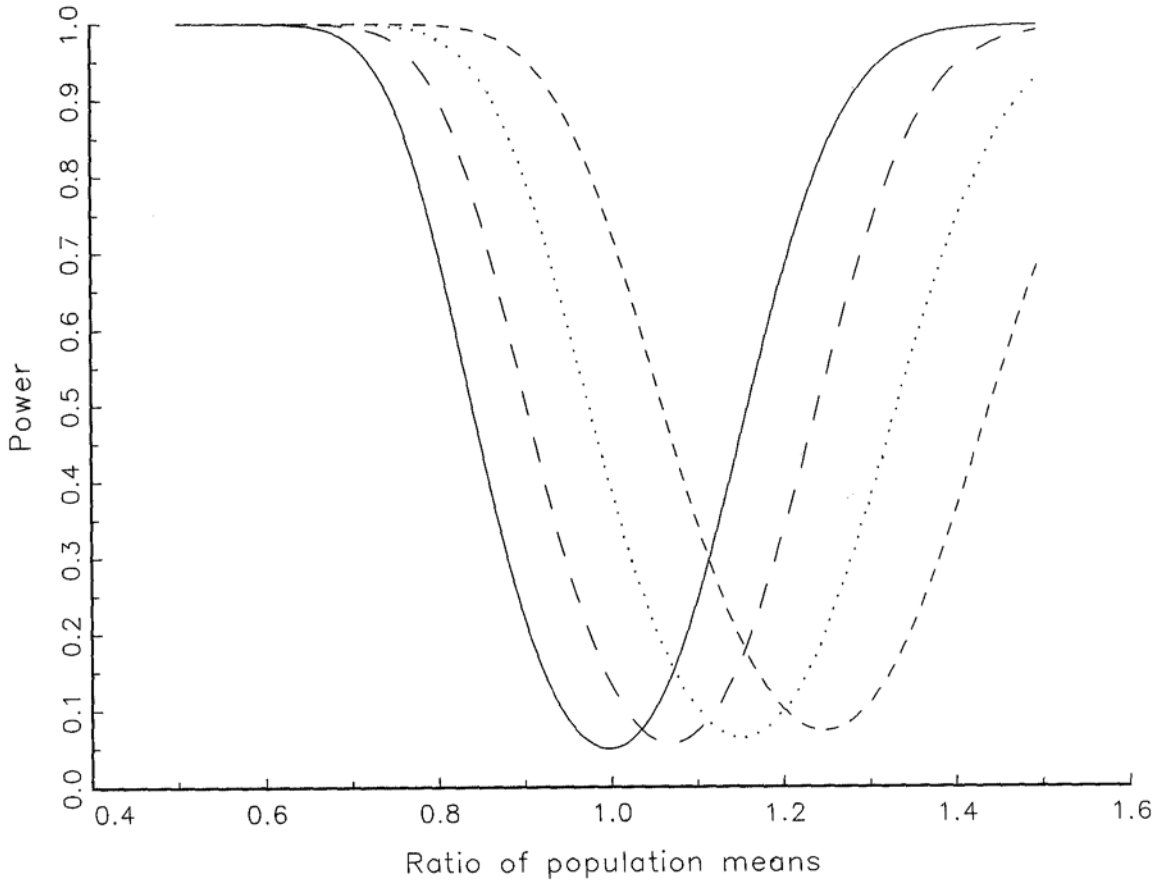

Figure 2--Power of a 2-sided *z*-test for a difference in means of two populations plotted as a function of the ratio of population means (1-*k*). Detection probability in the first population (p_1) = 0.75, but is different in the second population (p_2 = 0.75:___; p_2 = 0.70:_ _ _; p_2 = 0.5: ….; p_2 = 0.25: ----). Twenty point counts are made from each population. The mean and variance of the number of birds present at each point are the same within groups, and in the first group of counts there are an average of 20 birds per site present (μ_1). At the second group of sites there are an average of $(1-k)\mu_2$ birds present per site.

Clear Statements of Goals Are Necessary for Optimization

The first step in any optimization is to specify the appropriate estimators (or testing procedures) for the goals of the study, because optimal allocation of effort depends on the procedures used. For example, a study that is designed to test for differences in counts among habitats will be optimized differently from a survey designed for analysis of population trends. Of course, in practice, no study would begin without first identifying goals and evaluating if these goals can be met with the proposed study design. Once an estimator is specified, we can use its attributes to evaluate alternative study designs. For example, if we are interested in estimating population trend, we would want to design the study to minimize the mean squared error of the trend estimate.

Once the estimator or testing procedure has been selected, the next step is to obtain an expression that describes performance of the estimation procedure and is also a function of the time spent counting at a point. For example, it may be possible to express the relationship between detection probability and time spent surveying at a point; thus, for a fixed sampling time, the appropriate detection probability can be obtained. Many investigators have empirically described the relationship between point count duration and proportion of total birds detected (Buskirk and MacDonald, in this volume), although it can also be estimated by using more sophisticated procedures (Dawson and others, in this volume). Finally we need to specify time and other constraints placed on sampling.

Modelling Detection Probabilities as a Function of Count Duration

Detection probabilities play an important role in allocating point count sampling effort. Typically the experimenter is faced with the problem of trying to decide how best to allocate number of points and time spent sampling at a given point. Because the proportion of animals detected increases with time spent sampling, bias and relative variance at a point tends to decrease as count duration increases. Conversely, estimator precision tends to decrease as duration increases because fewer points can be sampled, so between-point components of the total variance increase. To optimally allocate sampling effort, the experimenter needs a model describing these relationships and a criterion for survey performance that can be used to judge the process of trading off time spent at points and the number of points sampled.

To describe the process by which the proportion of birds counted increases with time (denoted as the function $p = f(T_s)$), we assume that this proportion increases from zero to one as the cumulative distribution function of the random variable, time to first detection. One way to model these times until first detection is as independent and identically distributed exponential random variables with mean r. In this case

$$f(t) = 1 - e^{-rT_s} \qquad (10)$$

A drawback of this model is that it assumes that detection times are identically distributed. In practice, the parameter r may vary between individuals. For example, in the model described above, it is likely that in the case of unlimited distance methods, birds farther from the observer are counted with lower probability. In the case of fixed distance methods, it seems likely that the probability that one of the N_i birds associated with the sampling point occurs within the fixed radius at the time of the count decreases with distance from the observer.

A more flexible model is the Weibull model, in which the probability that the time to first detection is less than t is given by

$$f(t) = 1 - e^{-(ta)^b} \qquad (11)$$

This model reduces to the exponential model when the "shape" parameter $b = 1$.

Given estimates of the parameters, the percentage of animals sighted in the sampling period T_s can be estimated by

$$\hat{f}(T_s) = 1 - e^{-\hat{r}T_s}, \qquad (12)$$

under the exponential model, or by

$$\hat{f}(T_s) = 1 - e^{-(T_s\hat{a})^b}, \qquad (13)$$

under the Weibull model. In both cases maximum likelihood parameter estimates can be easily obtained.

Optimization Procedure

Using the components described above, we can use standard statistical procedures to estimate a count length that will provide efficient sampling in the context of the goals of the study. We will provide a brief example of this optimization procedure. For a more extensive description of the method and the issues involved in the optimization, see Barker and others (1993).

Consider a survey in which sampling effort is constrained by the time available for sampling. We assume total time surveying can be described by

$$T = (n\text{-}1)T_t + nT_s . \qquad (14)$$

where T is the total survey time, n is the number of points sampled, T_t is the travel time between points, and T_s is the sampling time spent at each point. We consider three possible goals of the study: estimation of (1) average count; (2) trend; or (3) z-test of difference between two study areas. Performance of these estimators is assessed either by minimizing mean square error (bias^2 + variance), or by maximizing test power (z-test for population change). Although not associated with a specific hypothesis, many investigators use total birds counted as a criterion for optimization.

Optimal allocation of sampling effort can now proceed using the constraint function (14), an estimate of the function $f(T_s)$ (obtained, say, from pilot data), and an appropriate measure of estimator performance (mean square error, test power, or total count). To obtain solutions we optimize the functions describing mean square error (minimize), test power (maximize), or total expected count (maximize) with respect to n or T_s . These are all functions of both n and T_s, so we use the constraint function to express the additional variable in terms of the variable to be optimized. Note that, as in other sample size allocation procedures, pilot estimates of population sizes and variances must also be used in the procedure.

Mathematical details of the optimization process are provided by Barker and others (1993), and they provide an example of optimization for a hypothetical bird population and several estimation procedures.

Numerical Example

We present a numerical example of the procedure for a bird population with an average of 20 birds present per site (μ), variance of the number of birds among sites of 40, 180 minutes of time available for sampling, travelling time of 10 units between sites, and an exponential parameter of 0.23 (*table 1*). This latter parameter corresponds to the parameter estimate that Barker and others (1993) obtained for the Hawaiian Thrush (*Myadestes obscurus*) from a published data set (Scott and Ramsey 1981). For this hypothetical population, we estimated allocation of sampling effort that corresponds to optimization criteria of: (1) the minimum mean square error of the count; (2) the maximum expected total count; (3) the maximum power of a 2-sided z-test for a difference in means of 10 percent; and (4) the minimum mean square error of the ratio estimator of population change (*table 1*). Allocations of point count lengths differ considerably among these criteria. Interestingly, maximum expected count does not coincide with maximum power of the z-test. The explanation lies in the fact that the maximum expected count depends only on the mean number of birds present and the detection probability, whereas test power depends on the variance of the number of birds among sites, as well as the number present, and the detection probability.

Discussion

From a statistical point of view, the dominant feature of point counts is that they do not completely census the population of animals that are associated with each sampling point. Instead, an incomplete count is obtained with the fraction of the population observed at each point unknown and varying. We have considered this sampling characteristic using a binomial sampling model and have demonstrated that it can bias estimates of number of animals present and trends. It also can be a substantial component of the variance of the counts, which is confounded with ecologically meaningful variation. These attributes of point count data suggest that estimates of population parameters based on them should be treated cautiously.

We recognize, however, that point counts are often the only source of data we have for most bird species. Because of their limitations, we believe that point counts are of best use in early-warning monitoring systems, but that population changes estimated from the count data should be used as a basis for further, more specific research. Attempts to use count data in sophisticated modeling procedures often lead to inappropriate results. Elsewhere, we have considered the effects of incomplete counts on modeling of density dependence, and we have shown that existing methods of detecting density dependence from incomplete count data are rendered worthless unless detection probabilities are close to 1, because of greatly elevated type 1 error rates (Barker and Sauer 1991).

If the survey is being used to describe trends for many species, "optimality" of sampling effort is an ill-defined concept because the allocation of sampling effort that leads to optimal performance of estimators or testing procedures is species specific. Thus, how should one allocate effort in such a multi-species program? This process itself must involve trading efficiency among competing species. One approach may be to pick key species from the assemblage associated with the study area and optimize effort with respect to the hardest species to sample. This will lead to a tendency to spend more time sampling at each point.

Table 1--*Optimal sampling allocation of number of sites and time spent sampling at each site (T_s) for four optimization criteria. These results apply to a hypothetical study with mean number of animals present at each point of 20, variance of the number of animals among points of 40, total sampling time available of 180 minutes of time, 10 minutes of time required for travel between points, and the function relating detection probability at each site (p) to the time spent sampling at each site (T_s) given by $p = 1 - e^{-rTs}$ where r = 0.23. MSE = Mean Square Error*

Optimization criteria	Number of sites	T_s	p
Count MSE	5.24	26.26	0.99
Total count	11.31	6.80	0.79
Power	13.00	4.62	0.66
Ratio	13.06	4.55	0.66

If too little time is spent at each point, bias may dominate estimator performance.

In a single species study, optimization can proceed using the methods we have outlined above. We stress that the critical step in the process is in determining the goals of the study and the analytical means by which this goal is to be met. In the absence of such goals and methods, the notion of optimality is without meaning. If the goal is to estimate some population parameter (e.g., annual growth rate), we suggest that mean square error is an appropriate measure of estimator performance. If the goal is to test a specific hypothesis (e.g., comparing mean count between areas), we suggest that test power is an appropriate performance criterion. Because different tests are different functions of various population parameters, optimal performance in terms of test power is also specific to testing procedures.

We have not attempted to address issues related to estimation of species richness from point counts. Obviously, the observed species richness from a point count is a biased estimate of actual species richness in the same manner that counts are biased estimates of number of animals present. However, because species are the variable of interest, mark-recapture procedures can often be used to estimate species richness.

Effects of Sampling Strategy, Detection Probability, and Independence of Counts on the Use of Point Counts[1]

Grey W. Pendleton[2]

Abstract: Many factors affect the use of point counts for monitoring bird populations, including sampling strategies, variation in detection rates, and independence of sample points. The most commonly used sampling plans are stratified sampling, cluster sampling, and systematic sampling. Each of these might be most useful for different objectives or field situations. Variation in detection probabilities and lack of independence among sample points can bias estimates and measures of precision. All of these factors should be considered when using point count methods.

Sampling strategies, variable detection probabilities, and independence among counts are aspects of point count methodology often overlooked but require emphasis when planning point count projects or analyzing point count data. At least as much planning should be focused on sampling schemes and potential sources of bias as on survey logistics.

The first consideration in planning a project with point counts is to explicitly state the objective. The three major objectives of point counts are to: (1) monitor trends, (2) assess habitat relationships, and (3) map bird distributions. Different sampling strategies best address each of these objectives; it might be impossible to design a single sampling plan that will provide data to do all three effectively. The effects of variable detection rates (e.g., birds are more easily detected at some time or place than at other times or places) and spatial correlation (counts at points close together are more similar than counts far apart even if in the same habitat) also differ among these objectives.

Sampling Strategies

Two aspects of sampling, the sample universe or frame and the sampling scheme, affect selection of the points to be sampled. The sample universe determines the area where samples may be located; this is also the area to which estimates or conclusions apply. The sampling scheme determines how the sample points will be chosen within the sample universe. Selection of the sample universe and the sampling scheme varies depending on the objective of the survey.

The sample universe for monitoring trends or mapping should be all areas where a species of interest is found within the overall study area. Studies assessing habitat relationships often sample exclusively in habitat blocks large enough to reduce the effect of neighboring habitats; mosaics of small habitat patches and edges are often avoided. Other studies might focus on bird abundance only in specific habitat types.

These examples illustrate the importance of selecting an appropriate sampling universe for the desired objective and the difficulty in trying to achieve combinations of objectives. Sampling only in specific habitats or avoiding habitat mosaics results in estimates and conclusions that apply only to the habitats or even habitat blocks of the size actually sampled. This sample would meet the objective of some habitat studies where only habitat-specific estimates are required. However, if the unsampled area is at all sizable, maps of bird abundance produced from these data could be misleading (e.g., when a species is abundant in an unsampled habitat). Also, if a species of interest occurs in the unsampled areas, overall trend estimates will be biased if the species' trend in the unsampled habitat is different from the trend in the sampled area. Habitat- or sample-specific estimates of trend could be produced, but these would be difficult to interpret.

Once the sample universe has been determined, a sampling scheme appropriate for the study objective can be selected. Simple random, stratified, cluster, systematic, or purposeful sampling are each appropriate in some studies. Completely random sampling is rarely used in point count studies for both theoretical and logistical reasons, but obtaining unbiased estimates requires some form of randomization. Purposeful sampling rarely is appropriate, but is sometimes used in some mapping studies to ensure that samples include transitions between areas with differing bird abundance.

The three most commonly used sampling schemes are stratified, cluster, and systematic (with a random start).

A stratified sample is one in which the sample universe is divided into groups of sample units (strata) that have more homogeneous bird abundance than the sample universe as a whole; for example, habitat types are often used as strata. Sample points are then randomly located within strata. Stratified samples reduce the variance of estimates when counts within strata are more similar than counts between strata. Strata need not have an equal number of samples, but weighted estimates might be needed for some unequal sample allocations (Cochran 1977). Stratum weights need to be known or estimated to obtain appropriate estimates and variances.

A cluster sample is one in which larger, primary sampling units are chosen (usually at random), then samples (i.e., point counts) are allocated within the primary sampling units (Cochran 1977). This sampling strategy is most useful when travel time between sample points is long and, therefore, simple random sampling is inefficient. However, under commonly encountered situations, the variance of an estimate based on a cluster sample is substantially larger than one based

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on a simple random sample. Effective use of cluster sampling can reduce travel time, allowing an increased sample size that overcomes the increased variance. Unlike stratified sampling, cluster sampling works best when the within-cluster variation is large and the between-cluster variation is small. Stratified or cluster sampling requires more complex estimators of means and variances than simple random sampling (Cochran 1977). Both stratified and cluster sampling could be used for all objectives of point count projects.

Systematic samples are those where a random starting point is selected and subsequent samples are located at uniform intervals. This results in samples uniformly distributed over the area of interest (uniformly spaced samples that cover only a subset of the area of interest would not be expected to give reliable results). With systematic samples, no unbiased estimates of variance are possible (see Independence of Counts below) (Sukatme and others 1984). However, under some conditions, estimates from systematic samples will be more precise than comparable random samples (Kingsley and Smith 1981, Sukatme and others 1984). Systematic samples perform poorly when populations have periodic fluctuations or clumped distributions. But, with careful planning of spacing between sample points, systematic samples can be useful because larger samples can be obtained because of the relative ease of locating sample points in the field. Mapping bird population distribution, which often does not require independent points or variance estimates, is best accomplished with uniform spacing of sample points, possibly with higher density strata in areas of particular interest.

Choice of sample universe and sampling scheme are important factors in designing a study using point counts. Equally important, once the universe and scheme are chosen, the appropriate estimation procedures should be used (i.e., based on stratified or cluster sampling).

Variation in Detection Probabilities

Detection probability is the probability of recording a bird's presence if the bird is at the point when the count is made. It has long been recognized as a. problem in wildlife surveys, including point counts (Lancia and others, 1994). Its potential effects should be seriously considered (Barker and Sauer 1992b). Two strategies have been used to reduce the effects of variable detection probabilities. The first is standardization of survey methods and the conditions when the survey is conducted, and the second is estimation of the detection probability, which is used to adjust the counts to get a population estimate (Lancia and others 1994). Standardized methods eliminate the effects of variable detection probabilities if they result in a constant fraction of the population in the count area being counted (e.g., exactly 57 percent of the animals are seen in all counts). This is not the same as having a constant detection probability (e.g., each animal has a 45 percent chance of being recorded on any given survey). The distinction between counting a constant fraction and having a constant detection probability is important because the second adds an additional source of variability (Barker and Sauer 1992a, 1992b). This additional variability occurs because, even though the detection probability is constant, the actual proportion detected is not exactly the same each time, in the same way that tossing a coin does not always result in exactly 50 percent heads and 50 percent tails.

Standardization of methods is encouraged, but there are weaknesses in data from standardized counts. It is unrealistic to think that all factors affecting detection probabilities can be controlled. One hopes that remaining variation in detection probabilities, after controlling as many factors as is feasible, is small relative to actual differences in abundance. However, because detection rates are not estimated, this cannot be evaluated.

The second approach estimates detection rates and adjusts counts for them (Lancia and others, 1994). These methods, including capture-recapture and variable circular plots, provide better information but are much more expensive than procedures that rely on standardized counts. For extensive surveys, these methods are usually not practical because of logistical restraints.

Both geographically and temporally variable detection probabilities can affect all uses of point count data. Estimation of population trends is more sensitive to detection probabilities changing over time (both within and among years). Also, interactions between geographically variable detection probabilities and actual population changes could mimic temporally changing detection rates. Analysis of habitat relationships and maps of bird distribution are sensitive to geographic changes in detection rates. If detection rates are unequal, an abundance map might show areas of high and low abundance that are actually areas of high and low detectability. But, combining data from different time periods (e.g., data from some habitat types in the spring and other habitat types in the summer) when there is a temporal trend in detection rates could bias resulting conclusions. For example, if detection rates were lower in the summer, a conclusion might be reached that a species was more abundant in the habitat sampled in the spring, when actually the species was equally abundant in both habitats.

Many factors affect detection probabilities, including differences among observers, annual variation in phenology, and weather. One major source of variation in detection probabilities with particular importance to many point count studies is differences in detectability among habitats. For example, clearcuts would likely have much different detection rates than neighboring forests. However, most uses of point counts involve some combination of data from different habitats. Mapping bird distributions with data from several habitats with habitat-specific detection probabilities will cause distortion of the distribution maps (Sauer and others, in these Proceedings). Bird habitat associations derived from point counts can also be biased by habitat-specific detections. Rather than ranking habitats by bird abundance, they would be ranked by the product of abundance and detectability, which could produce an entirely different pattern. Route-regression type trend estimators (Geissler and Sauer 1990) combine trends from individual routes that are often in more than one habitat. Trends of individual routes are weighted on the basis

of the size of the counts from that route, which could also be distorted by habitat-specific variation of detection rates.

Independence of Counts

Independence among point counts is one factor often considered when proposing standardized point count methodology. However, there are two types of independence between counts that are important-conditional and unconditional independence. The number of birds counted at a point can be considered to be a function of the actual number of birds at a count location plus random error [$y_i = f(x_i) + e_i$, where y_i is the observed count, x_i is the actual number of birds, and e_i is the random variation].Conditional independence relates to whether a count being above or below the average value for that point is affected by whether neighboring points are above or below their averages [$\text{cov}\{e_i, e_j | f(x_i), f(x_j)\}$]. This is a small-scale type of dependence that would likely include factors such as counting the same birds at successive points or having the calling rate of birds at a point affected by calling birds at a previously counted point. This is the type of dependence that the frequently suggested spacing between point counts (e.g., 100 m, 250 m, 500 m) is intended to reduce, although no empirical data are available to support selection of an appropriate distance.

The second type of independence, unconditional independence, is less often considered and relates to whether points close together have actual abundances more similar than points farther apart [$\text{cov}\{f(x_i) f(x_j)\}$]. Unconditional dependence is probably related to the size of the area of interest, but would likely occur over larger geographic scales than are important for conditional dependence. For example, a sample point having a Scarlet Tanager (*Piranga olivacea*) might reveal nothing about the probability of a second point 5 miles away having a Scarlet Tanager if the area of interest is an eastern National Park. If the area of interest is the continental United States, however, then the tanager at the first point might provide substantial information about the second point's probability of also having a Scarlet Tanager.

If locations of point counts are randomly selected and measurement error is small relative to sampling variation, point counts will be independent regardless of any underlying spatial relationships (de Gruijter and ter Braak 1990). This is a large advantage for some form of random sampling over nonrandom sampling strategies. If random sampling is not used and points are close enough together so that there is unconditional dependence, variance estimates will be too small and power associated with statistical tests is artificially inflated (Sukatme and others 1984, Whysong and Miller 1987). Spatial dependence could affect statistical comparisons of abundance between areas or habitats and significance tests associated with trends. The distance between points to achieve unconditional independence would have to be estimated separately for each area of interest using methods such as variograms (Isaaks and Srivastava 1989). Many mapping procedures are unaffected by spatial dependence and some actually use this information. Some geostatistical methods (i.e., variograms) are useful for detecting spatial dependence and estimating the distance needed between sample points to obtain independence.

Conclusion

All of these factors, choice of sample universe and sampling scheme, variable detection probabilities, and independence among counts, can have substantial effects on estimates and conclusions based on point count data. Different objectives require different choices of sampling procedure and are affected differently by these factors. Adjustments cannot be made for most biases introduced by these factors when analyzing point count data. Point counts, however, are the only practical way to obtain data for many species. These problems and factors should be carefully considered when planning a project that uses point counts. Efforts should be made to investigate and reduce aspects of sampling that lead to biased estimates.

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Point Count Modifications and Breeding Bird Abundances in Central Appalachian Forests[1]

J. Edward Gates[2]

Abstract: The effects of point count duration and radius on detection of breeding birds were compared by recording all birds seen or heard within two consecutive 5-minute intervals and for fixed-radius (within 30 m) or unlimited radius counts. Counts were conducted on Green Ridge State Forest (GRSF) and Savage River State Forest (SRSF) in western Maryland. More than 70 percent of all detections during fixed- and unlimited-radius counts occurred within the first 5 minutes. There was little overall gain in species richness from counting an additional 5 minutes. With fixed-radius counts, eight species at GRSF and two at SRSF showed significant differences in detections between the first and second 5 minutes. Using unlimited-radius counts, the resultant larger sample had a higher number of bird species showing significant differences between the first and second 5 minutes, 23 at GRSF and 12 at SRSF. Still, minimal changes in overall rank of species abundance resulted from counting an additional 5 minutes. About 80 percent of all bird detections and several new species were recorded >30 m from the counting point. Twenty-seven species at each of the two State Forests had significantly different detections within the two distance intervals. Compared with fixed-radius counts, detections >30-m distance often brought the rank order of species abundance up or down depending on whether the species had proportionally higher detections in the first or second distance interval. A time-distance interaction occurred with unlimited-radius counts, with more bird species >30-m distance tallied more often in the second 5-minute interval, indicating a possible increase in detection error with increasing distance and time. Observers may be recording more audible, nearby individuals first and only later noting less audible, more distant individuals. Fixed-radius counts done for 5 minutes should provide reasonable indices to species richness and abundance in a particular habitat, whereas unlimited-radius counts would provide a more complete list of species present in a local region.

Point counts (PC) have been conducted at different time intervals, often from 2 to 20 minutes (Robbins 1981, Scott and Ramsey 1981, Verner and Ritter 1986). Longer counts are less sensitive to species-specific differences in song intensity or changes in song or call rates throughout the morning hours (Robbins 1981). Longer counts soon become inefficient, however, as few new species are added with time and potentially fewer counts are possible. Additionally, because of bird movements, there is the chance of multiple-counting or of recording new birds that move into counting range from outside the area (Granholm 1983). Shorter time durations at more sites could also lead to increased statistical power in hypothesis tests. On the other hand, too short a time interval results in a smaller sample of the bird assemblage with potentially many birds being missed, particularly if the singing intensity is low. This factor is of greater importance later in the morning when the frequency of singing is lower (Robbins 1981, Verner and Ritter 1986).

Additionally, a fixed-radius or unlimited-radius count is often selected over a variable-radius count. Unlimited-radius counts are reported to be an efficient means for measuring species richness and for accumulating total counts of birds (Verner 1985, Verner and Ritter 1985). The same can be said for fixed-radius counts, and because the counting area is known, this method may provide a better index of abundance. With fixed-radius counts, observers inexperienced with estimating distances have to learn only one distance. However, selection of an optimum radius can be difficult. Although delectability of many species does drop considerably after distances of 20-30 m, there are species-specific differences in detectability with distance (Gutzwiller 1991, Hayward and others 1991, Hutto and Mosconi 1981). Some species are more easily detected nearby while others are more so at a distance. Some bird species may also move toward or away from an observer, or remain hidden if near an observer. Observers may also record more audible or nearby individuals first and only later focus on less audible or more distant individuals. Radii used in previous studies also have been quite variable, often ranging to >100 in (Edwards and others 1981, Hutto and others 1986, Morrison and others 1987, Verner and Larson 1989). Additional methodological problems and biases have been covered elsewhere (Ralph and Scott 1981, Verner 1985, Verner and Ritter 1985). My objectives were to evaluate the effects of count duration and distance from counting point on observer detection of breeding bird species on State Forests in western Maryland.

Study Area and Methods

Study Area

Two western Maryland State Forests, Green Ridge and Savage River, located in the central Appalachian Mountains were selected for study. The 15,699-ha Green Ridge State Forest (GRSF) is located in eastern Allegany County, while the 21,613-ha Savage River State Forest (SRSF) is located approximately 35 km west of Green Ridge State Forest (GRSF) in northeastern Garrett County. Both forest landscapes consist of a patchwork of different anthropogenic features, forest types (primarily oak-hickory), and successional stages, often isolated by private inholdings and both natural and human-made corridors. Since the mid-1970's, managers at both State Forests have conducted inventories (Continuous Forest Inventory (CFI)) to collect data on forest growth, volume, and other conditions. Each State Forest was stratified by type and stand-size class through a combination of field typing and aerial photograph interpretation and was gridded using a 609.6-m interval grid. Grid intersections representing the center of a 0.08-ha forest habitat (CFI) plot were then selected at random and permanently marked in the field. A sample of

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these permanent points, i.e., 91.0 percent of the 210 GRSF-CFI plots and 77.6 percent of the 277 SRSF-CFI plots, was used for a count survey of breeding birds on the State Forests.

Observer Selection and Training

Prior to selection as an observer, individuals were initially screened for experience and competence in the identification of birds by sight and sound. Tapes of bird songs of species present on the study areas were made available to each observer for study upon arrival. Further checks on their aural identification skills were frequently made in the field during flagging of points prior to beginning counts. Furthermore, for the first few days of counts, as a further check and confidence-building exercise, pairs of observers often went to the same point. At the end of such a count the pair of observers would then compare results for consistency. Data forms also were checked weekly to detect any problems or unusual species identifications by observers.

The observers were also trained in estimating whether or not a certain detection was ≤30 m or >30 m from the counting point. This distance was often flagged at a point using a rangefinder or pacing. A rangefinder or pacing also was used to check the distance to borderline detections. Nevertheless, because most detections were aural, placing a detection ≤30 m or >30 m from the point was often based on observer experience.

Point Counts

Point counts were done in 1990 at GRSF and 1991 at SRSF, beginning in May and ending in July. A minimum of four counts per point were scheduled during the breeding season; i.e., all points would be counted in one counting cycle prior to beginning the second, third, or fourth cycle. To reduce the effects of observer bias, each of four observers attempted to visit each point only once during the breeding season. To minimize any temporal bias, the four visits were equally distributed throughout the morning count period as well as over the breeding season. Point counts began at sunrise and generally ended 4.5-5 hours later. No counts were conducted during a steady hard rain, in thick fog, or when wind speeds were >20 km/hour.

Generally, two to four observers conducted counts on each day of the week. Under best of conditions, one observer could usually complete 6 counts (maximum of 12) each morning. Travel time between counts was approximately 35 to 40 minutes. Counts began when the observer reached a point. Birds were tallied if they were detected during the counts or were present at the point but stopped vocalizing or flushed without returning on perceiving the observer; e.g., Ruffed Grouse (*Bonasa umbellus*). Spring migrants detected during their regular migration period., but not during the breeding season, were considered transients and were not included in data analysis. We tallied, but did not analyze, birds flying over the plots (fly-overs) that were unlikely to be using the plots. Point counts were conducted for a total of 10 minutes at each point. To evaluate the effects of a shorter-time duration, the 10-minute count was divided into two consecutive 5-minute intervals. Birds counted during the first 5 minutes were not included in the second 5-minute count. The two intervals were combined for a 10-minute count. Observers also recorded birds as either within the 30-m radius or outside it. Birds moving into or out of a distance interval were counted only within the interval where first detected. Point count results within the two distance intervals, 0-30 m and >30 m, were added for unlimited-radius counts.

Statistical Analysis

To compare whether a species was more likely to be detected during the first or second 5 minutes of a 10-minute count or ≤30 m or >30 m of the counting point, species detections in each category were tested for significance with continuity adjusted Chi-square (χ^2) analysis (Siegel and Castellan 1988). The total number of detections or sample size can markedly influence the species richness (number of species) of an assemblage. Therefore, rarefraction was used to estimate species richness based on a standard number of detections (James and Rathbun 1981, Ludwig and Reynolds 1988). In order to compare 5- and 10-minute, and fixed- and unlimited-radius counts, I used a sample of n = 1314, i.e., the total detections for 5-minute, fixed-radius counts at SRSF, which is the smallest number of detections of the different count categories.

Results

Count Duration

Using fixed-radius counts and the overall proportion of bird detections during the first and second 5 minutes of a 10-minute count as a bench mark, the number of species on the State Forests having proportionally higher detections than the bench mark in the first 5 minutes was almost equal, 44.6 percent at SRSF to 50.0 percent at GRSF, to those having higher detections during the latter 5 minutes (*tables 1* and *2*). During the first 5 minutes, 70.5 percent (SRSF) and 75.6 percent (GRSF) of all bird detections were tallied. There was only a two species gain at GRSF (3.7 percent), and a four species gain at SRSF (6.6 percent) from the extra effort of counting 5 additional minutes. Based on rarefraction estimation, most of this increase can be explained by the larger sample resulting from counting longer. A gain of one species (1.6 percent at SRSF and 1.9 percent at GRSF) still occurred with the longer count after the number of detections was standardized. Few species, eight at GRSF and two at SRSF, had detectability patterns different than expected between the first and second 5 minutes. However, these species showed the same consistent patterns even when using different count radii (fixed or unlimited) at a State Forest or when using the same count methodology at different State Forests (*tables 1-4*). Furthermore, counting the extra 5 minutes for a 10-minute count had no major observable effect on the rank order of species abundance when compared with 5-minute counts (*tables 1* and *2*).

Using unlimited-radius counts and the overall proportion of bird detections during the first and second 5 minutes of a 10-minute count as a bench mark, the percentage of species with proportionally greater detections than the bench mark in the first versus the second 5 minutes was less than that with fixed-radius counts (*tables 3* and *4*). Only 34.7 percent (GRSF)

Table 1--*Total number of detections, relative abundance (percent), and rank order of bird species abundance by count duration on Green Ridge State Forest (GRSF) based on 191 fixed-radius counts done four times during the 1990 breeding season. Italicized values are significantly ($P < 0.05$) different between time intervals; all others not italicized are insignificant. Sample sizes ≤21 were too small for analysis and were eliminated from the table*

Species[a]	0-5 minutes			> 5-10 minutes			0-10 minutes		
	n	Pct	Rank	*n*	Pct	Rank	*n*	Pct	Rank
Detections greatest in 0-5 minutes									
Cedar Waxwing[b]	***25***	1.68	20	***1***	0.21	22	26	1.32	19
Ovenbird[b]	***116***	7.80	2	***17***	3.54	7	133	6.76	2
Hooded Warbler	27	1.81	19	4	0.83	19	31	1.58	17
American Redstart	47	3.16	12	7	1.46	16	54	2.74	13
Acadian Flycatcher[b]	***62***	4.17	8	***10***	2.08	14	72	3.66	10
Red-eyed Vireo[b,c]	***155***	10.42	1	***34***	7.08	1	189	9.60	1
Northern Cardinal	21	1.41	21	5	1.04	18	26	1.32	19
Rufus-sided Towhee	83	5.58	5	21	4.38	6	104	5.28	6
Indigo Bunting	53	3.56	10	14	2.92	10	67	3.40	11
Pine Warbler	37	2.49	15	10	2.08	14	47	2.39	15
Blue-gray Gnatcatcher	85	5.71	4	25	5.21	4	110	5.59	5
Wood Thrush	78	5.24	7	23	4.79	5	101	5.13	7
Great Crested Flycatcher	33	2.22	17	10	2.08	14	43	2.18	16
Detections greatest in 5-10 minutes									
Eastern Wood-Pewee	44	2.96	13	15	3.13	9	59	3.00	12
Worm-eating Warbler	87	5.85	3	33	6.88	2	120	6.10	3
White-breasted Nuthatch	31	2.08	18	12	2.50	12	43	2.18	16
Hairy Woodpecker	20	1.34	22	8	1.67	15	28	1.42	18
Scarlet Tanager	81	5.44	6	34	7.08	1	115	5.84	4
Black-capped Chickadee	38	2.55	14	16	3.33	8	54	2.74	13
Chipping Sparrow	34	2.28	16	15	3.13	9	49	2.49	14
Brown Creeper	20	1.34	22	11	2.29	13	31	1.58	17
Tufted Titmouse	***49***	3.29	11	***27***	5.63	3	76	3.86	9
Brown-headed Cowbird[b]	***59***	3.97	9	***34***	7.08	1	93	4.73	8
Blue Jay	15	1.01	24	10	2.08	14	25	1.27	20
Red-bellied Woodpecker[b]	***13***	0.87	26	***12***	2.50	12	25	1.27	20
American Goldfinch[b]	***12***	0.81	27	***13***	2.71	11	25	1.27	20
Total detections	1488	100.00		480	100.02		1968	100.04	
Total species	54						56		
$E\ (S_{1314})$[d]	53						54		

[a] Species are listed by decreasing proportion of detections within the first 5-min interval. The division of species between the two time intervals was determined by comparison of the proportion of detections of each species with the proportion of all species detections within each interval.

[b] Species showing the same significant difference with fixed- and unlimited-radius PCs at GRSF.

[c] Species showing the same significant difference with fixed-radius PCs at GRSF and Savage River State Forest.

[d] Rarefraction estimate of number of bird species based on $n = 1314$ individuals.

to 38.1 percent (SRSF) of the total number of bird species had proportionally greater detections during the first 5 minutes, 6.5 percent (SRSF) to 15.3 percent (GRSF) less than that observed with fixed-radius counts. Over 60 percent (61.9 percent SRSF to 65.3 percent GRSF) of the bird species had proportionally more detections than the bench mark in the second 5 minutes. There were 71.7 percent (SRSF) to 75.0 percent (GRSF) of overall bird detections tallied during the first 5 minutes, similar to fixed-radius counts. There were 10 more species (13.5 percent) observed, however, during the additional 5 minutes of counting at SRSF and no increase in numbers of species at GRSF. Rarefraction estimation indicated that this result was also greatly influenced by the larger sample, with only one species at GRSF and two species at SRSF (1.7 percent GRSF to 3.1 percent SRSF) added for the extra effort of counting after number of detections was standardized. Compared with fixed-radius counts, a larger number of species showed significant differences in detectabilities between the 0 to 5-minute and >5 to 10-minute categories, 23 at GRSF and 12 at SRSF, possibly related to larger samples. Again, these species exhibited consistent detectability patterns between fixed- and unlimited-radius counts at a State Forest and between State Forests when using the same count methodology (*tables 1-4*). In spite of the greater number of significant differences, I observed no major changes in rank order of species abundance resulting from counting an additional 5 minutes (*tables 3* and *4*).

Count Radius

The inclusion of birds detected >30 m from the counting point had a great influence on all parameters (*tables 5* and *6*). Using 10-minute counts and the overall proportion of

Table 2--*Total number of detections, relative abundance (percent), and rank order of bird species abundance by count duration on Savage River State Forest (SRSF) based on 215 fixed-radius counts done four times during the 1991 breeding season. Italicized values are significantly (P <0.05) different between time intervals, all others not italicized are* insignificant. *Sample sizes ≤17 were too small for analysis and were eliminated from the table*

Species[a]	0-5 minutes			> 5-10 minutes			0-10 minutes		
	n	Pct	Rank	*n*	Pct	Rank	*n*	Pct	Rank
Detections greatest in 0-5 minutes									
Chipping Sparrow	***21***	1.60	16	***2***	0.36	20	23	1.23	21
Golden-crowned Kinglet	19	1.45	18	2	0.36	20	21	1.13	22
Veery	35	2.66	12	8	1.45	14	43	2.31	13
Eastern Wood-Pewee	41	3.12	10	10	1.82	13	51	2.74	9
Red-eyed Vireo[b,c]	***221***	16.82	1	***62***	11.27	1	283	15.18	1
Scarlet Tanager	70	5.33	4	21	3.82	6	91	4.88	4
Acadian Flycatcher	74	5.63	3	26	4.73	3	100	5.36	3
Ovenbird	113	8.60	2	41	7.45	2	154	8.26	2
Hooded warbler	48	3.65	7	19	3.45	7	67	3.59	6
Black-throated Green Warbler	20	1.52	17	8	1.45	14	28	1.50	18
Black-capped Chickadee	17	1.29	20	7	1.27	15	24	1.29	20
Black-throated Blue Warbler	55	4.19	5	23	4.18	5	78	4.18	5
Detections greatest in 5-10 minutes									
White-breasted Nuthatch	18	1.37	19	8	1.45	14	26	1.39	19
Indigo Bunting	39	2.97	11	18	3.27	8	57	3.06	8
Black-and-white Warbler	42	3.20	9	21	3.82	6	63	3.38	7
Rufous-sided Towhee	52	3.96	6	26	4.73	3	78	4.18	5
Wood Thrush	32	2.44	13	16	2.91	9	48	2.58	11
Gray Catbird	25	1.90	15	13	2.36	12	38	2.04	14
Chestnut-sided Warbler	28	2.13	14	15	2.73	10	43	2.31	13
Canada Warbler	13	0.99	22	7	1.27	15	20	1.07	23
American Redstart	43	3.27	8	24	4.36	4	67	3.59	6
Brown-headed Cowbird	16	1.22	21	10	1.82	13	26	1.39	19
Common Yellowthroat	28	2.13	14	19	3.45	7	47	2.52	12
Solitary Vireo	28	2.13	14	21	3.82	6	49	2.63	10
Cedar Waxwing	18	1.37	19	14	2.55	11	32	1.72	16
Rose-breasted Grosbeak	19	1.45	18	15	2.73	10	34	1.82	15
Magnolia Warbler	17	1.29	20	14	2.55	11	31	1.66	17
Total detections	1314	99.98		550	99.97		1864	99.93	
Total species	61						65		
$E(S_{1314})$[d]	61						62		

[a] Species are listed by decreasing proportion of detections within the first 5-minute interval. The division of species between the two time intervals was determined by comparison of the proportion of detections of each species with the proportion of all species detections within each interval.

[b] Species showing the same significant difference with fixed- and unlimited-radius point counts at SRSF.

[c] Species showing the same significant difference with fixed-radius point counts at Green Ridge State Forest and SRSF.

[d] Rarefraction estimate of number of bird species based on n = 1314 individuals.

Table 3--*Total number of detections, relative abundance (percent), and rank order of bird species abundance by count duration on Green Ridge State Forest (GRSF) based on 191 unlimited-radius counts done four times during the 1990 breeding season. Italicized values are significantly (P < 0.05) different between time intervals; all others not italicized are insignificant. Sample sizes ≤20 were too small for analysis and were eliminated from the table*

Species[a]	0-5 minutes			>5-10 minutes			0-10 minutes		
	n	Pct	Rank	*n*	Pct	Rank	*n*	Pct	Rank
Detections greatest in 0-5 minutes									
Cedar Waxwing[b]	***50***	0.66	30	***3***	0.12	40	53	0.52	35
Yellow-breasted Chat	***46***	0.61	32	***6***	0.24	38	52	0.51	36
Rose-breasted Grosbeak	18	0.24	43	3	0.12	40	21	0.21	46
Field Sparrow	47	0.62	31	8	0.32	36	55	0.54	34
Wood Thrush	***628***	8.27	3	***123***	4.86	5	751	7.42	3
Ovenbird[b,c]	***661***	8.71	2	***132***	5.22	2	793	7.84	2
Red-eyed Vireo[b,c]	***690***	9.09	1	***142***	5.61	1	832	8.22	1
Solitary Vireo	24	0.32	42	5	0.20	39	29	0.29	43
Rufous-sided Towhee	***340***	4.48	7	***78***	3.08	13	418	4.13	8
Eastern Wood-Pewee[c]	***390***	5.14	5	***93***	3.68	10	483	4.77	5
Scarlet Tanager	***531***	7.00	4	***128***	5.06	3	659	6.51	4
Acadian Flycatcher[b]	***232***	3.06	11	***56***	2.21	17	288	2.85	11
Prairie Warbler	76	1.00	27	19	0.75	29	95	0.94	28
Brown Creeper	78	1.03	26	24	0.95	27	102	1.01	27
Common Yellowthroat	28	0.37	39	9	0.36	35	37	0.37	41
Indigo Bunting	238	3.14	10	78	3.08	13	316	3.12	10
Detections greatest in 5-10 minutes									
Blue-gray Gnatcatcher	168	2.21	14	56	2.21	17	224	2.21	16
American Crow	314	4.14	8	112	4.43	6	426	4.21	7
Tufted Titmouse	349	4.60	6	127	5.02	4	476	4.70	6
Hooded Warbler	83	1.09	25	30	1.19	24	113	1.12	25
Pine Warbler	130	1.71	20	47	1.86	19	177	1.75	21
Chipping Sparrow	202	2.66	12	74	2.93	14	276	2.73	12
Mourning Dove	78	1.03	26	29	1.15	25	107	1.06	26
Northern Cardinal	116	1.53	21	44	1.74	20	160	1.58	22
American Redstart	91	1.20	24	35	1.38	22	126	1.25	24
Louisiana Waterthrush	31	0.41	37	12	0.47	32	43	0.42	38
Worm-eating Warbler	281	3.70	9	110	4.35	7	391	3.86	9
Eastern Phoebe	25	0.33	41	10	0.40	34	35	0.35	42
Gray Catbird	30	0.40	38	12	0.47	32	42	0.42	39
Wild Turkey	27	0.36	40	11	0.43	33	38	0.38	40
Carolina Wren	71	0.94	28	31	1.23	23	102	1.01	27
Great Crested Flycatcher[c]	***191***	2.52	13	***84***	3.32	11	275	2.72	13
Yellow-throated Vireo	34	0.45	36	15	0.59	30	49	0.48	37
Black-capped Chickadee	***100***	1.32	23	*48*	1.90	18	148	1.46	23
Blue Jay	***146***	1.92	17	***71***	2.81	15	217	2.14	17
Pileated Woodpecker	***138***	1.82	18	*68*	2.69	16	206	2.04	19
American Robin	42	0.55	34	22	0.87	28	64	0.63	32
Cerulian Warbler	15	0.20	45	8	0.32	36	23	0.23	45
White-breasted Nuthatch[c]	***131***	1.73	19	***79***	3.12	12	210	2.08	18
Yellow-billed Cuckoo[c]	***152***	2.00	16	***97***	3.84	9	249	2.46	15
Brown-headed Cowbird[b,c]	***162***	2.13	15	***105***	4.15	8	267	2.64	14
Northern Flicker	***52***	0.69	29	***35***	1.38	22	87	0.86	29
Red-bellied Woodpecker[b]	***104***	1.37	22	***74***	2.93	14	178	1.76	20
Hairy Woodpecker[c]	***42***	0.55	34	***31***	1.23	23	73	0.72	31
American Goldfinch[b]	***35***	0.46	35	***27***	1.07	26	62	0.61	33
Downy Woodpecker	***43***	0.57	33	***36***	1.42	21	79	0.78	30
Black-billed Cuckoo	***15***	0.20	45	***13***	0.51	31	28	0.28	44
Northern Oriole	***10***	0.13	46	***11***	0.43	33	21	0.21	46
Total detections	7591	100.06		2529	100.02		10120	100.04	
Total species	72						72		
$E(S_{1314})$[d]	59						60		

[a] Species are listed by decreasing proportion of detections within the first 5-minute interval. The division of species between the two time intervals was determined by comparison of the proportion of detections of each species with the proportion of all species detections within each interval.

[b] Species showing the same significant difference with fixed- and unlimited-radius point counts at GRSF.

[c] Species showing the same significant difference with unlimited-radius point counts at GRSF and Savage River State Forest (SRSF).

[d] Rarefraction estimate of number of bird species based on $n = 1314$ individuals.

Table 4--*Total number of detections, relative abundance (percent), and rank order of bird species abundance by count duration on Savage River State Forest (SRSF) based on 215 unlimited-radius counts done four times during the 1991 breeding season. Italicized values are significantly (P < 0.05) different between time intervals; all others not italicized are insignificant. Sample sizes ≤18 were too small for analysis and were eliminated from the table*

Species[a]	0-5 minutes			>5-10 minutes			0-10 minutes		
	n	Pct	Rank	*n*	Pct	Rank	*n*	Pct	Rank
Detections greatest in 0-5 minutes									
Golden-crowned Kinglet	27	0.45	32	4	0.17	39	31	0.37	40
Least Flycatcher	25	0.41	34	5	0.21	38	30	0.35	41
Hermit Thrush	***74***	1.22	22	***16***	0.67	29	90	1.06	28
Red-eyed Vireo[b,c]	***843***	13.90	1	***222***	9.25	1	1065	12.58	1
Northern Parula	37	0.61	29	11	0.46	33	48	0.57	34
Eastern Wood-Pewee[c]	***340***	5.61	4	***103***	4.29	4	443	5.23	4
Yellow-throated Vireo	19	0.31	39	6	0.25	37	25	0.30	43
Ovenbird[c]	***492***	8.11	3	***156***	6.50	3	648	7.65	3
American Crow	***599***	9.88	2	***200***	8.34	2	799	9.44	2
Scarlet Tanager	299	4.93	5	100	4.17	5	399	4.71	5
Wood Thrush	221	3.64	7	78	3.25	8	299	3.53	8
Veery	181	2.98	10	65	2.71	11	246	2.91	11
Acadian Flycatcher	220	3.63	8	80	3.33	7	300	3.54	7
Louisiana Waterthrush	30	0.49	31	11	0.46	33	41	0.48	37
Hooded Warbler	166	2.74	12	62	2.58	13	228	2.69	12
Rufous-sided Towhee	237	3.91	6	90	3.75	6	327	3.86	6
Indigo Bunting	205	3.38	9	80	3.33	7	285	3.37	9
American Robin	33	0.54	30	13	0.54	31	46	0.54	35
Detections greatest in 5-10 minutes									
Canada Warbler	40	0.66	28	16	0.67	29	56	0.66	32
Carolina Wren	20	0.33	38	8	0.33	36	28	0.33	42
Chipping Sparrow	70	1.15	23	28	1.17	25	98	1.16	27
Black-throated Blue Warbler	180	2.97	11	73	3.04	10	253	2.99	10
Blue-gray Gnatcatcher	26	0.43	33	12	0.50	32	38	0.45	39
Common Yellowthroat	103	1.70	15	48	2.00	17	151	1.78	18
Tufted Titmouse	76	1.25	20	36	1.50	22	112	1.32	23
Black-and-white Warbler	114	1.88	14	55	2.29	14	169	2.00	15
Solitary Vireo	70	1.15	23	35	1.46	23	105	1.24	24
Rose-breasted Grosbeak	121	2.00	13	62	2.58	13	183	2.16	14
Blue Jay	101	1.67	16	53	2.21	15	154	1.82	17
Field Sparrow	40	0.66	28	21	0.88	27	61	0.72	31
Black-capped Chickadee	83	1.37	19	44	1.83	19	127	1.50	20
Chestnut-sided Warbler	76	1.25	20	41	1.71	20	117	1.38	22
Black-throated Green Warbler	92	1.52	18	50	2.08	16	142	1.68	19
Gray Catbird	65	1.07	24	36	1.50	11	101	1.19	26
Magnolia Warbler	45	0.74	27	25	1.04	26	70	0.83	30
Wild Turkey	18	0.30	40	10	0.42	34	28	0.33	42
White-breasted Nuthatch[c]	***75***	1.24	21	***45***	1.88	18	120	1.42	21
Northern Cardinal	24	0.40	35	15	0.63	30	39	0.46	38
Pileated Woodpecker	46	0.76	26	29	1.21	24	75	0.89	29
American Redstart	***100***	1.65	17	***64***	2.67	12	164	1.94	16
Cedar Waxwing	***62***	1.02	25	***40***	1.67	21	102	1.20	25
Brown-headed Cowbird[c]	***114***	1.88	14	***76***	3.17	9	190	2.24	13
Downy Woodpecker	30	0.49	31	21	0.88	27	51	0.60	33
Song Sparrow	11	0.18	43	8	0.33	36	19	0.22	45
Cerulian Warbler	17	0.28	41	13	0.54	31	30	0.35	41
Mourning Dove	17	0.28	41	13	0.54	31	30	0.35	41
Great Crested Flycatcher[c]	22	0.36	37	***17***	0.71	28	39	0.46	38
Northern Flicker	10	0.16	44	9	0.38	35	19	0.22	45
Hairy Woodpecker[c]	***23***	0.38	36	***21***	0.88	27	44	0.52	36
Yellow-billed Cuckoo[c]	***10***	0.16	44	***12***	0.50	32	22	0.26	44
Total detections	6065	100.03		2399	100.00		8464	99.92	
Total species	74						84		
$E(S_{1314})$[d]	64						66		

[a] Species are listed by decreasing proportion of detections within the first 5-min interval. The division of species between the two time intervals was by comparison of the proportion of detections of each species with the proportion of all species detections within each interval.

[b] Species showing the same significant difference with fixed- and unlimited-radius PCs at SRSF.

[c] Species showing the same significant difference with unlimited-radius PCs at Green Ridge State Forest and SRSF.

[d] Rarefraction estimate of number of bird species based on $n = 1314$ individuals.

Table 5--*Total number of detections, relative abundance (percent), and rank order of bird species abundance by plot radius on Green Ridge State Forest (GRSF) based on 191 10-minute counts done four times during the 1990 breeding season. Italicized values are significantly (P < 0.05) different between distance intervals; all others not italicized are insignificant. Sample sizes≤26 were too small for analysis and were eliminated from the table*

Species[a]	0-30 m			>30 m			Unlimited		
	n	Pct	Rank	*n*	Pct	Rank	*n*	Pct	Rank
Detections greatest in 0-30 m									
Blue-gray Gnatcatcher[b]	***110***	5.59	5	***114***	1.40	21	224	2.21	16
Cedar Waxwing	***26***	1.32	19	***27***	0.33	40	53	0.52	35
American Redstart[b]	***54***	2.74	13	***72***	0.88	28	126	1.25	24
American Goldfinch	***25***	1.27	20	***37***	0.45	36	62	0.61	33
Hairy Woodpecker	***28***	1.42	18	***45***	0.55	34	73	0.72	31
Black-capped Chickadee	***54***	2.74	13	***94***	1.15	23	148	1.46	23
Gray Catbird[b]	***15***	0.76	23	***27***	0.33	40	42	0.42	39
Brown-headed Cowbird[c]	***93***	4.73	8	***174***	2.13	16	267	2.64	14
Solitary Vireo	9	0.46	26	20	0.25	41	29	0.29	43
Worm-eating Warbler	***120***	6.10	3	***271***	3.32	9	391	3.86	9
Brown Creeper	***31***	1.58	17	***71***	0.87	29	102	1.01	27
Yellow-throated Vireo	14	0.71	24	35	0.43	37	49	0.48	37
Hooded Warbler	***31***	1.58	17	***82***	1.01	26	113	1.12	25
Pine Warbler	***47***	2.39	15	***130***	1.59	20	177	1.75	21
Acadian Flycatcher[b]	***72***	3.66	10	***216***	2.65	14	288	2.85	11
Rufous-sided Towhee	***104***	5.28	6	***314***	3.85	8	418	4.13	8
Red-eyed Vireo[b]	***189***	9.60	1	***643***	7.88	3	832	8.22	1
American Robin	14	0.71	24	50	0.61	32	64	0.63	32
Indigo Bunting	67	3.40	11	249	3.05	10	316	3.12	10
White-breasted Nuthatch	43	2.18	16	167	2.05	17	210	2.08	18
Detections greatest in >30 m									
Louisiana Waterthrush	8	0.41	27	35	0.43	37	43	0.42	38
Chipping Sparrow	49	2.49	14	227	2.78	13	276	2.73	12
Scarlet Tanager	115	5.84	4	544	6.67	4	659	6.51	4
Prairie Warbler	16	0.81	22	79	0.97	27	95	0.94	28
Ovenbird	133	6.76	2	660	8.09	1	793	7.84	2
Downy Woodpecker	13	0.66	25	66	0.81	30	79	0.78	30
Northern Cardinal	26	1.32	19	134	1.64	19	160	1.58	22
Common Yellowthroat	6	0.31	28	31	0.38	38	37	0.37	41
Tufted Chickadee	76	3.86	9	400	4.90	7	476	4.70	6
Great Crested Flycatcher	43	2.18	16	232	2.84	11	275	2.72	13
Red-bellied Woodpecker	25	1.27	20	153	1.88	18	178	1.76	20
Wood Thrush[b]	***101***	5.13	7	***650***	7.97	2	751	7.42	3
Carolina Wren	13	0.66	25	89	1.09	24	102	1.01	27
Eastern Wood-Pewee[b]	***59***	3.00	12	***424***	5.20	5	483	4.77	5
Blue Jay[b]	***25***	1.27	20	***192***	2.35	15	217	2.14	17
Yellow-breasted Chat	5	0.25	29	47	0.58	33	52	0.51	36
Yellow-billed Cuckoo	***19***	0.97	21	***230***	2.82	12	249	2.46	15
Pileated Woodpecker[b]	***14***	0.71	24	***192***	2.35	15	206	2.04	19
Field Sparrow[b]	***3***	0.15	31	***52***	0.64	31	55	0.54	34
Northern Flicker	***3***	0.15	31	***84***	1.03	25	87	0.86	29
American Crow[b]	***8***	0.41	27	***418***	5.12	6	426	4.21	7
Mourning Dove[b]	***1***	0.05	33	***106***	1.30	22	107	1.06	26
Black-billed Cuckoo	***0***			***28***	0.34	39	28	0.28	44
Eastern Phoebe	***0***			***35***	0.43	37	35	0.35	42
Wild Turkey[b]	***0***			***38***	0.47	35	38	0.38	40
Total detections	1968	100.04		8152	100.31		10120	100.04	
Total species	56						72		
$E(S_{1314})$[d]	54						60		

[a] Species are listed by decreasing proportion of detections within the 0-30 m distance interval. The division of species between the two distance intervals was determined by comparison of the proportion of detections of each species with the proportion of all species detections within each interval.

[b] Species showing the same significant differences with 10-minute point counts at GRSF and Savage River State Forest (SRSF).

[c] Species showing opposite significant differences with 10-minute point counts at GRSF and SRSF.

[d] Rarefraction estimate of number of bird species based on $n = 1314$ individuals.

Table 6--*Total number of detections, relative abundance (percent), and rank order of bird species abundance by plot radius on Savage River State Forest (SRSF) based on 215 10-minute counts done four times during the 1991 breeding season. Italicized values are significantly (P < 0.05) different between distance intervals; all others not italicized are insignificant. Sample sizes ≤23 were too small for analysis and were eliminated from the table.*

Species[a]	0-30 m			>30 m			Unlimited		
	n	Pct	Rank	*n*	Pct	Rank	*n*	Pct	Rank
Detections greatest in 0-30 m									
Golden-crowned Kinglet	***21***	1.13	22	***10***	0.15	45	31	0.37	40
Solitary Vireo	***49***	2.63	10	***56***	0.85	28	105	1.24	24
Blue-gray Gnatcatcher[b]	***17***	0.91	24	***21***	0.32	39	38	0.45	39
Magnolia Warbler	***31***	1.66	17	***39***	0.59	31	70	0.83	30
Yellow-throated Vireo	***11***	0.59	28	***14***	0.21	43	25	0.30	43
American Redstart[b]	***67***	3.59	6	***97***	1.47	20	164	1.94	16
Gray Catbird[b]	***38***	2.04	14	***63***	0.95	27	101	1.19	26
Black-and-white Warbler	***63***	3.38	7	***106***	1.61	17	169	2.00	15
Chestnut-sided Warbler	***43***	2.31	13	***74***	1.12	25	117	1.38	22
Louisiana Waterthrush	15	0.80	26	***26***	0.39	37	41	0.48	37
Canada Warbler	20	1.07	23	***36***	0.55	32	56	0.66	32
Hairy Woodpecker	15	0.80	26	29	0.44	35	44	0.52	36
Acadian Flycatcher[b]	***100***	5.36	3	***200***	3.03	10	300	3.54	7
Carolina Wren	9	0.48	30	19	0.29	40	28	0.33	42
Cedar Waxwing[b]	***32***	1.72	16	***70***	1.06	26	102	1.20	25
Common Yellowthroat	***47***	2.52	12	***104***	1.58	18	151	1.78	18
Black-throated Blue Warbler	***78***	4.18	5	***175***	2.65	11	253	2.99	10
Cerulian Warbler	9	0.48	30	21	0.32	39	30	0.35	41
Hooded Warbler[b]	***67***	3.59	6	***161***	2.44	13	228	2.68	12
Least Flycatcher	8	0.43	31	22	0.33	38	30	0.35	41
Red-eyed Vireo[b]	***283***	15.18	1	***782***	11.85	2	1065	12.58	1
Northern Cardinal	10	0.54	29	29	0.44	35	39	0.46	38
Rufous-sided Towhee	78	4.18	5	249	3.77	7	327	3.86	6
Ovenbird	154	8.26	2	494	7.48	3	648	7.65	3
Chipping Sparrow	23	1.23	21	75	1.14	24	98	1.16	27
Scarlet Tanager	91	4.88	4	308	4.67	5	399	4.71	5
Detections greatest in >30 m									
White-breasted Nuthatch	26	1.39	19	94	1.42	22	120	1.42	21
Downy Woodpecker	11	0.59	28	40	0.61	30	51	0.60	33
Great Crested Flycatcher	8	0.43	31	31	0.47	33	39	0.46	38
Indigo Bunting	57	3.06	8	228	3.45	8	285	3.37	9
Black-throated Green Warbler	28	1.50	18	114	1.73	16	142	1.68	19
Black-capped Chickadee	24	1.29	20	103	1.56	19	127	1.50	20
Northern Parula	9	0.48	30	39	0.59	31	48	0.57	34
Rose-breasted Grosbeak	34	1.82	15	149	2.26	14	183	2.16	14
Veery	43	2.31	13	203	3.08	9	246	2.91	11
Wood Thrush[b]	***48***	2.57	11	***251***	3.80	6	299	3.53	8
American Robin	7	0.38	32	39	0.59	31	46	0.54	35
Tufted Titmouse	16	0.86	25	96	1.45	21	112	1.32	23
Brown-headed Cowbird[c]	***26***	1.39	19	***164***	2.48	12	190	2.24	13
Hermit Thrush	***11***	0.59	28	***79***	1.20	23	90	1.06	28
Eastern Wood-Pewee[b]	***51***	2.74	9	***392***	5.94	4	443	5.23	4
Field Sparrow[b]	***6***	0.32	33	***55***	0.83	29	61	0.72	31
Blue Jay[b]	***12***	0.64	27	***142***	2.15	15	154	1.82	17
Pileated Woodpecker[b]	***5***	0.27	34	***70***	1.06	26	75	0.89	29
Wild Turkey[b]	***1***	0.05	38	***27***	0.41	36	28	0.33	42
American Crow[b]	***11***	0.59	28	***788***	11.94	1	799	9.44	2
Mourning Dove[b]	***0***			***30***	0.45	34	30	0.35	41
Total detections	1864	99.92		6600	99.99		8464	99.92	
Total species	65						84		
$E(S_{1314})$[d]	62						66		

[a] Species are listed by decreasing proportion of detections within the 0-30 m distance interval. The division of species between the two distance intervals was determined by comparison of the proportion of detections of each species with the proportion of all species detections within each interval.

[b] Species showing the same significant differences with 10-minute point counts at Green Ridge State Forest (GRSF) and SRSF.

[c] Species showing opposite significant differences with 10-minute point counts at GRSF and SRSF.

[d] Rarefraction estimate of number of bird species based on $n = 1314$ individuals.

detections of 0-30 m and >30 m from the sampling point as a bench mark, 42.9 percent of the species at SRSF to 45.8 percent of the species at GRSF had more detections than the bench mark ≤30 m of the counting point. However, 78.0 percent (SRSF) to 80.6 percent (GRSF) of all bird detections were tallied >30 m from the counting point. Sixteen new species at GRSF and 19 at SRSF (approximately 29 percent increase) were added to the species list by including birds >30 m away. Based on rarefraction, the increase dropped to four new species at SRSF to 6 new species at GRSF (6.5 percent SRSF and 11.1 percent GRSF), indicating a large contribution due to sample size but with some species recorded only outside the 30-m radius. Including detections >30 m in a count had a marked effect on rank order of species abundance. If the species was tallied more frequently at ≤30 m, inclusion of detections at >30 m often brought the species rank order of abundance down for unlimited-radius counts, whereas the rank order of species whose detections were greater at >30-m distance often increased in unlimited-radius counts over that within fixed-radius counts (*tables 5* and *6*). Species detected more frequently at ≤30 m from the counting point were often those whose songs or calls cannot be heard very well >30 m away (e.g., Blue-gray Gnatcatcher (*Pilioptila caerulea*)). Species detected more often at >30-m distance included many whose calls or songs carry great distances (e.g., Blue Jay (*Cyanocitta cristata*), American Crow (*Corvus brachyrhynchos*)) or are difficult to approach (e.g., Wild Turkey (*Meleagris gallopavo*)). Species having significant differences exhibited the same trends in detections regardless of State Forest, except for the Brown-headed Cowbird (*Molothrus ater*). At GRSF the cowbird was detected more frequently at ≤30 m from the counting point, whereas at SRSF it was detected more frequently at >30 m from the counting point. This factor might be related to differences between the two State Forests in distribution of preferred breeding habitat or concentrations of livestock on which this species depends for foraging (Verner and Ritter 1983).

Interactions Between Count Duration and Radius

I wanted to determine the association between number of species with detections either proportionally higher or lower than the distance bench mark in each distance interval and count duration. I investigated this question by analyzing those species having proportionally higher detections within 30 m and >30 m of the sampling point separately to minimize the effect of distance from the counting point on detectability. I first selected those species whose detections were proportionally higher ≤30 m from the counting point. I then determined the number that were proportionally higher or lower in the first or second 5 minutes, using the time bench marks. In the analysis, I assumed no difference in the number of nearby species within the two time intervals; therefore, half of the species should have proportionally higher detections in 0-5 minutes and the remainder >5-10 minutes. At GRSF, 33 bird species had proportionally higher detections ≤30 m from the counting point. Twelve (36.4 percent) were placed in the 0- to 5-minute interval, while 21 (63.6 percent) were in the >5- to 10-minute interval (χ^2 = 2.45, df = 1, P >0.05). At SRSF, 36 species had proportionally higher detections ≤30 m of the counting point. Of these, 15 (41.7 percent) had proportionally higher detections during the first 5 minutes, and 21 (58.3 percent) had proportionally higher detections during the latter 5 minutes (χ^2 = 1.00, df = 1, P >0.05). Within 30 m of the counting point, there was an apparent, but insignificant, trend for more species to have proportionally higher detections during the latter half of a 10-minute count.

However, when bird species with proportionally more detections >30-m distance were compared against the time interval, there were significant differences. At GRSF; 39 species had proportionally greater detections >30 m. Thirteen (33.3 percent) species had proportionally higher detections during the first 5 minutes, and 26 (66.7 percent) during the latter 5 minutes (χ^2 = 4.33, df = 1, P <0.05). At SRSF, 48 bird species had proportionally greater detections >30 m. Seventeen (35.4 percent) species had proportionally higher detections during the first 5 minutes, and 31 (64.6 percent) during the latter 5 minutes (χ^2 = 4.08, df = 1, P <0.05).

Discussion

Whether one uses fixed- or unlimited-radius counts, use of a shorter 5-minute count would seem most efficient for studies of forest birds in the central Appalachians. Little additional information was gained by counting for 10 minutes, because more than 70 percent of all detections occurred within the first 5 minutes. However, counts ≥5 minutes are reported to compensate better for diminished cue production later in the morning (Robbins 1981). Many of the species having higher detections than expected during the >5- to 10-minute interval (e.g., the Brown-headed Cowbird) generally had lower cue production than those with higher detections within the 0- to 5-minute interval. Anderson and Ohmart (1981) reported that 6 minutes was insufficient for censusing variable circular plots (120-m radius limit). They found that 7 and 8 minutes were apparently better because of a more thorough census, but the possibility existed that some of the later detections could actually be recounts. Using unlimited-radius counts, Verner and Ritter (1986) failed to show any significant decline in total counts during later hours with counts of 8 and 10 minutes. If the goal is to have as complete a species list as possible and rank order of species abundance is not a priority, the new species detected by longer counts might be worth the effort, particularly if travel time is considerable and repeat visits are not possible.

Major differences resulted from including birds detected at >30 m distance. The higher number of detections (approximately 80 percent) strongly influenced rank order of species abundance when compared with fixed-radius counts and resulted in 13 new species at SRSF to 18 new species at GRSF with 5-minute counts and 16 new species at GRSF to 19 new species at SRSF with 10-minute counts. Much of the increase is attributable to larger sample sizes. Compared with fixed-radius counts, bird species >30 m from the counting point had disproportionately higher detections in the latter 5 minutes of a 10-minute count. This result suggests that as area counted expands and count duration lengthens, counts of birds become more variable, possibly because observers

unintentionally recorded nearby birds first and only later focused on more distant birds. I have not seen any published data that would indicate a time-distance interaction in detectability among observers; however, intuitively such a result might be a natural outcome of the order in which cues are perceived or focused on by observers. There also may be more of a problem with multiple detections of the same distant individual or movement of birds into counting range with longer counts. It becomes increasingly difficult to monitor bird movements at great distances and over long time intervals. Additional errors also result because for certain particularly numerous species, pairs or trios of detections far from the observer will often be counted as a single one (R. W. Howe personal communication). This bias also contributed to the greater number of species showing differences in detections during the first versus the second 5 minutes of unlimited-radius counts. Nevertheless, detections >5 minutes did not seem to have a major effect on overall rank order of species abundance based on unlimited-radius counts.

Although there were species-specific differences in detectability with count duration and radius, fixed-radius counts conducted for 5 minutes would seem to offer a reasonable sample of most species and provide a rank order of species abundance that can be related to habitat. Unlimited-radius counts done for 5-10 minutes would provide a more complete sample of species in a local area. However, rank order of species abundance was markedly affected by counting birds >30-m from the sampling point. Furthermore, at greater distances and over longer time intervals, there would be a greater chance of multiple-counting the same bird. Additional work also needs to be done to understand the apparent observer bias in tallying nearby individuals first and more distant individuals later in the count. If this bias is further confirmed, unlimited-radius counts would be affected much more by count duration than fixed-radius counts, at least at the 30-m distance used in this study. Therefore, such counts should be long enough to sample distant individuals, but short enough to minimize multiple-recordings. In conclusion, it is important to recognize that no method is without certain inherent problems and biases, and that data obtained from using the method should be analyzed accordingly.

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Experimental Design Considerations for Establishing an Off-Road, Habitat-Specific Bird Monitoring Program Using Point-Counts[1]

JoAnn M. Hanowski and Gerald J. Niemi[2]

Abstract: We established bird monitoring programs in two regions of Minnesota: the Chippewa National Forest and the Superior National Forest. The experimental design defined forest cover types as strata in which samples of forest stands were randomly selected. Subsamples (3 point counts) were placed in each stand to maximize field effort and to assess within-stand and between-stand variation for a variety of bird parameters. Data gathered in 1991 were used to evaluate several assumptions that were made in the experimental design and showed that variance of most bird parameters among strata were similar. This data indicated that a proportional stratified sample by forest cover type was reasonable. We also found that two subsamples per stand would be optimum when a variety of strata types and bird variables were considered. Analyses based on 120 stands in the Chippewa National Forest and 150 stands in the Superior National Forest indicated that a two-tailed *t*-test could detect a 25 percent change in bird numbers for common species. For most other species, we could detect less than a 50 percent annual change. Monitoring programs within regions should be habitat specific so that changes in bird numbers can be related to: (1) habitat changes that have occurred in the region; (2) natural fluctuations in bird numbers; or (3) other factors.

We recently suggested guidelines for determining the number of samples and size of study areas required for monitoring bird populations using line-transects (Hanowski and others 1990). We present a similar statistical approach to suggest an experimental design for establishing bird monitoring programs using point counts. An experimental design for determining monitoring programs in a region will be influenced by the objectives and resources available for each region. We assumed that the primary objectives of a monitoring program would be to: (1) monitor relative abundance of common bird species to assess annual changes, (2) define avian habitat relationships, (3) determine how forest management activities influence breeding bird abundance and distribution, and (4) provide a product that a regional wildlife biologist could use to plan forest management activities to accommodate a variety of bird species, especially those with specific habitat needs or declining populations in a region.

Our objectives here are to: (1) describe in detail the methods that we used to establish a habitat-specific bird monitoring program in two regions of northern Minnesota, (2) present results of statistical aspects of the experimental design in terms of sample stratification and allocation of samples and subsamples, and (3) describe an observer training and testing program that will provide quality assurance in the data collection.

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Study Areas and Methods

We established bird monitoring programs in two areas in Minnesota. The Chippewa National Forest is located in the north central portion of the State, and the Superior National Forest in the northeastern region. Major habitat types are similar within each Forest with the exception that upland spruce-fir (*Picea* sp. and *Abies balsamea*) forests are more common in the Superior National Forest.

Experimental Design

We designed our monitoring program so that it would integrate with each National Forest's method of describing vegetation cover types. Each unit or stand within each Forest is described by a forest cover type and age class code. With this method, bird census data can be directly linked to both the Forest Service inventory of cover types, total area of each cover type, and locations within the Forest. We used groups of cover types as our strata for sampling (*fig. 1*).

Our sample unit in the design was a forest stand that was ≥ 40 acres, the minimum size needed for three subsamples (point count). We subsampled stands for several reasons. First, we wanted to obtain measures of both within and between stand variation. This information would allow us to determine the optimal allocation of samples based on effort (see below). Second, subsamples would allow us to sum numbers from counts within a stand for species and thus would provide a better estimate of mean individuals per unit area. Subsequently, this sum would allow us to better meet assumptions for statistical tests (e.g., normality and homogeneity of variance) and the overall power of our statistical tests would be improved with larger means (Hanowski and others 1990).

This sample design was tailored to meet specific objectives of an individual Forest. With this particular method, small stands and habitats that are not managed for timber are not represented in the sample. The basic sample design can be modified to address specific questions, however, on a regional basis. For example, we have subsequently initiated a similar monitoring program in the Chequamegon National Forest in Wisconsin and have included upland and lowland shrub habitats as well as small wildlife openings in the sample.

Sample Stratification

The number of samples within each Forest was determined *a priori* by calculating the number required to detect about a 20 percent annual change in a common birds species abundance (Hanowski and others 1990). The first step in the sample stratification procedure was to determine the number of strata to sample. For our study, we used two different approaches, each to accommodate criteria established by each

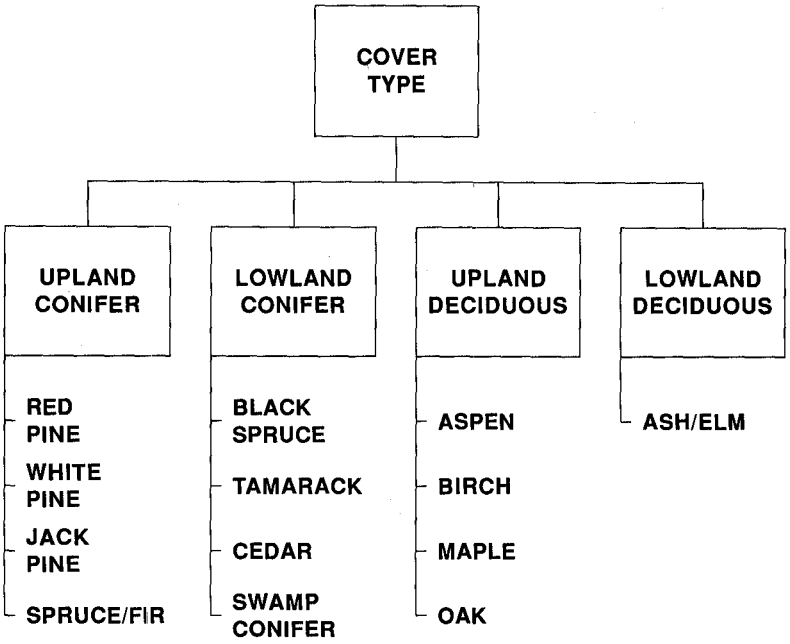

Figure 1--Four major strata (e.g., upland conifer) and cover types (e.g., red pine) sampled within the Chippewa and Superior National Forests in Minnesota.

Forest. We identified five habitat groups as strata in the Chippewa National Forest and four habitat groups or strata in the Superior National Forest. These included the types listed in *figure 1*, plus a regenerating type that included both upland deciduous and upland conifer types. Cover types selected represented areas where forest management activities are conducted. No lowland deciduous cover types were included in the Superior National Forest because no timber harvesting is done in these areas. Because the focus of the monitoring was forest birds, nonforested wetland habitats were excluded.

The next step was to determine; how many samples were required within each stratum. Because we had no estimate of the variance for point count data in Minnesota, we used data gathered previously in northern Wisconsin and Michigan. We found that the variances of several bird parameters in different habitat strata were similar (Hanowski and others 1990). Consequently, samples were allocated proportionally rather than optimally to strata.

We summed the number of acres and number of stands >40 acres and calculated the proportion of the total within each stratum. We could have stratified on the basis of total acres or by total number of stands. However, the proportion of samples that would be allocated to each stratum with either method was similar. We decided to use the number of stands in the Forest >40 acres to calculate the proportions of samples allocated within each stratum. This was done because the stand was considered the experimental unit for this study.

Another item that needs to be considered in the experimental design is the minimum number of samples required to provide biological information necessary for statistical analyses within each stratum. It was evident from the habitat breakdown in the Chippewa National Forest that there was a disproportionate amount of upland deciduous habitat in the Forest (approximately 45 percent). If we had stratified strictly on the proportion of habitat available, the majority of the samples would have been allocated to upland deciduous forest. The remaining habitats, however, would have been inadequately sampled. Therefore, we modified the stratification so that at least five samples were placed within each stratum.

Sample Unit and Selection

Forests are mapped in large management units (compartments). To select a stand, a compartment was first selected with a random number table, and stands within the compartment were chosen randomly. Because of travel time and, hence, cost to travel between stands and compartments, four or five stands were randomly selected within each compartment with the restriction that all could be sampled by one observer in one morning (between 0445 and 0930 c.d.t.). Stands selected within each compartment generally represented two or three different cover types. Other restrictions for stand selection were road access and physical barriers (e.g., large rivers and bodies of water could not be crossed). A total of 140 stands (420 subsamples) were selected within the Chippewa National Forest and 150 stands (450 subsamples) within the Superior National Forest. With this method, each stand is not randomly selected, and therefore the design is a cluster sample.

Bird Counts

All stands were located and count points were marked on compartment maps and aerial photos. Each stand was visited before counting to permanently mark locations and routes of travel between points. We conducted one bird count (10 minutes

in duration) at each point during the breeding season (Reynolds and others 1980). Point counts are excellent for determining relative abundances of singing passerines but are inadequate for raptors, waterfowl, and other wide-ranging species. In addition, because only one count is conducted in the breeding season (June to early July in northern Minnesota), relative densities of early nesting species are probably underestimated (e.g., most permanent residents including woodpeckers and chickadees).

Six trained (see observer training section below) observers conducted the censuses, which were done from 0.5 hours to 4 hours after sunrise. Censuses were conducted only during good weather (i.e., wind <15 mph and no precipitation). Types of stands censused (forest cover type) were stratified by time of morning. For example, we avoided sampling all upland pine stands early or late in the morning. Forest cover types censused also were stratified by observer; each observer sampled essentially the same number of stands in each stratum.

We recorded weather (cloud cover, temperature, and windspeed) and time of day the census was conducted. All birds heard or seen from the center point were recorded in a circle with estimates of their distance from the center point (up to 100 m).

Observer Training

Four of the six observers in this study had conducted point counts previously but had not been specifically trained in the identification of northern Minnesota breeding birds or with the methodology used in this study. Observers were hired in April and were given a list of species that they were required to identify by sight and sound. Tapes of bird songs were provided as a learning tool for all observers. All observers were required to pass an identification test of 75 bird songs made by Cornell Laboratory of Ornithology Library of Natural Sounds. A standard for the number of correct responses was established by giving the test to experienced observers (>4 years) in the field identification of Minnesota's forest birds by sound. This was done to identify songs on the tape that were not good representations of songs heard in northern Minnesota. Based on results of trained observers, we set the standard for passing at 85 percent correct responses. Songs on the tape were grouped by habitat (e.g., upland deciduous) to simulate field cues that would aid in song identification.

Observer field training was done in late May. Observers were first instructed on the methods for recording data on the field sheets. Observers then conducted simultaneous counts (4 mornings; 40 points) and were allowed to ask questions about unknown birds after each count. Count information was compiled for each observer and their data were compared to data gathered by the experienced observers. Species lists and number of individuals recorded on the count by each observer were compared. Deviations from the average number of individuals observed or species missed were noted on the field sheets and returned to each observer.

In addition to training and testing, all observers were required to have a hearing test to ensure that their hearing was within normal ranges for all frequencies (125 to 8000 hertz). Normal ranges were standards established by audiologists.

Statistical Considerations

We made two assumptions in the sample allocation for monitoring. First, we assumed the variance of counts measured within each stratum was equal (based on data from Michigan and Wisconsin). Therefore, we stratified our sample strictly on proportion of stands within each stratum in each Forest. We examined data collected in 1991 to determine whether this assumption was valid. For these analyses we computed standard deviations of estimates for several bird community, bird guild, and species in strata where they occurred within each Forest. We were interested in determining whether the standard deviation in any one stratum for any variable was a factor of 2 higher than the standard deviation in any other strata. If standard deviations are within a factor of 2, a strict proportional stratification can be employed in a study (Kish 1965).

The second assumption was that three subsamples/sample would be optimal in terms of effort. We tested whether this assumption was valid by computing the components of variance among stands (samples) and among counts (subsamples) (SAS 1988, PROC VARCOMP). We then computed the optimum number of subsamples by assigning a cost to collecting a sample and subsample in the formula:

$$n_2 = \sqrt{\left(\frac{C_1 S_2^2}{C_2 S_1^2}\right)}$$

where n_2 = optimum number of subsamples; C_1 = cost of samples; C_2 = cost of subsample; S_1 = variance of sample; and S_2 = variance of subsample. For our calculations we assigned C_1 = 1.0 and C_2 = 0.4 (Snedecor and Cochran 1967: 532). Cost of sample values were estimated on the basis of our experience in the first year of the census.

We calculated an optimum number of subsamples for the total number of individuals, long-distance Neotropical migrants, and Ovenbirds (*Seiurus aurocapillus*) for all strata within the Chippewa and Superior (each Forest separately). We combined all strata for these analyses because we wanted to provide an overall recommendation for the number of subsamples/sample for a regional monitoring program. We realize that each stratum may provide a unique optimum number. However, because strata are not always comparable among regions, an average value would be of more use overall. In addition, if a monitoring program is being set up, it would be unrealistic (primarily for statistical analyses considerations) to place different numbers of subsamples within samples. In presenting these results, we assume that a monitoring program that uses subsamples is more cost efficient and would increase the overall power of statistical tests (see Experimental Design above).

In addition to testing the assumptions that we made in establishing the experimental design, we calculated the power of statistical analyses using means and variances of data collected in 1991. We used the formula presented by Lehmann and D'Abrera (1975: 78) to calculate the power of a two-tailed *t*-test ($\alpha = 0.05$) for detecting annual differences in species abundances for two levels: a 25 percent and a 50 percent change in the mean per 40 acres. This was calculated for species that occurred in densities within each Forest of two to eight individuals per 40 acres and included about 90 percent of all species detected.

Density Calculations

Although point counts generally are used to assess "relative abundance" of birds, we calculated relative density values per unit area for each species. This information was used to determine baseline relative populations for species in a region. We calculated the number of territorial males in 40 acres by summing numbers of individuals for each species in three point counts within each stand. We determined the area of each sample (point count) on the basis of a radius of 100 m for most species. This was the distance that we used in our data collection. Although some birds could be heard beyond 100 m, we did not count them (Howe and others, in these Proceedings). We did this primarily because we did not want to count the same individual on adjacent points (our points were 250 m apart). We used a smaller radius for Cape May Warbler (*Dendroica tigrina*), Golden-crowned Kinglet (*Regulus satrapa*), and Bay-breasted 'Warbler (*Dendroica castenea*), because we were not confident that we could detect these species beyond 75 m. A relative density value for each bird in the forest can be calculated by multiplying the density value of a species within each habitat by the total amount of that habitat in the Forest.

The relative density calculations should be used with caution. They are not meant to be an absolute density value for the Forest. Rather, they should be viewed as base values with which future monitoring data can be compared to determine whether species populations are going up, down, or remaining the same. More importantly, as these data become coupled with forest change, they will allow an approximate measure of the effects of these changes.

Table 1--*Standard deviations for long-distance migrants and Ovenbirds within forest cover type and age class. Ovenbirds did not occur in lowland conifer types. Calculations were done on values from stands (e.g., sum of three subsamples/stand)*

Forest cover types	Age class	Long-distance migrants	Ovenbirds
Upland deciduous	Regenerating	1.4	0.8
	Pole size	1.7	0.9
	Saw size	2.3	0.9
Upland conifer	Regenerating	2.1	0.8
	Pole size	1.8	0.8
	Saw size	1.7	0.6
Lowland conifer	Regenerating	1.5	-
	Pole size	1.3	-
	Saw size	2.1	-

Results

Allocation of Samples to Strata

An estimate of the variance for bird species within different cover types is required to calculate the optimal allocation of samples to stand (equation 1). Standard deviations for numbers of long-distance migrants (mean of Chippewa and Superior National Forests) within nine cover types ranged from 1.3 to 2.3 (*table 1*). The range of standard deviations for numbers of Ovenbirds within six cover types ranged from 0.6 to 0.9 (*table 1*). We did not include standard deviations for the lowland conifer type for the Ovenbird, because it occurs in these types only occasionally.

Allocation of Subsamples to Samples

Components of variance between counts (subsamples) and between stands (samples) for three bird parameters were similar between the two Forests (*table 2*). The optimum number of counts per stand calculated for three bird parameters (total number of individuals, number of long-distance migrants, and number of Ovenbirds) indicated that between 1.5 and 2.0 counts per stand would optimize the effort involved in the sampling.

Table 2--*Between-stands (samples) and between-counts (subsamples) components of variance, and optimum number of counts per stand for three bird parameters in the Chippewa and Superior National Forests. See Methods section for details of equation used to calculate optimum number of counts per stand*

Bird parameter	Forest	Between stands	Between counts	Optimum number counts/stand
Total individuals	Chippewa	5.44	5.89	1.6
	Superior	5.38	4.75	1.5
Long-distance migrants	Chippewa	3.03	3.81	2.0
	Superior	2.49	2.95	2.0
Ovenbirds	Chippewa	0.51	0.48	1.5
	Superior	0.29	0.55	2.0

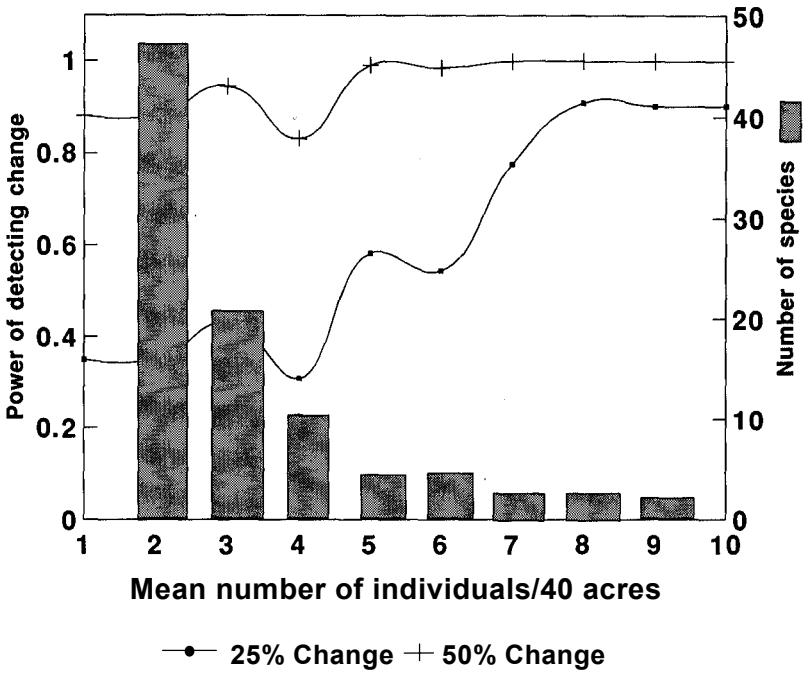

Figure 2--Power of a two-tailed *t*-test for detecting a 25 percent or 50 percent annual change in individual species that occurs within the Chippewa National Forest in densities from 2 to 10 per 40 acres. Number of species that occur at different densities is indicated on the Y2 axis.

Power of Statistical Analyses

Power analyses (two-tailed *t*-test) indicated that we would be able to detect a 25 percent annual change for those species that occurred with a relative density greater than seven individuals per 40 acres in the Chippewa National Forest (*fig. 2*). However, only two species, the Ovenbird and Red-eyed Vireo (*Vireo olivaceus*), occurred in the Forest at those densities (*fig. 2*). The power of detecting a 50 percent annual change, however, was greater than the standard (80 percent) used in most statistical tests for all species (*fig. 2*). This indicates that we would be able to detect a 50 percent or less annual change for many species that occur in the Forest. Results were slightly different for the Superior National Forest. In this region we should be able to detect a 25 percent annual change for six species that occur in densities greater than or equal to five pairs per 40 acres.

Observer Training

All new observers (four total) passed the song test on the first attempt (85 to 100 percent correct responses). Although we did not quantitatively examine results of the observer training sessions, three of the four observers recorded numbers of individuals and species that were similar to the experienced observers. One new observer at first tended to record fewer individuals than the other observers. This was brought to the attention of the observer and in later sessions the discrepancy was minimized. In addition, results of the hearing tests indicated that all observers had hearing within the normal ranges for all frequencies with one exception; one individual had a slightly lower threshold of detection at the highest frequency.

Discussion

Experimental Design

We have presented an approach for an experimental design that can be used to establish regional monitoring programs using point counts. It is critical that some aspects of the design be met in establishing a program, while others can be tailored to meet the objectives for the region. Number of strata sampled and allocation of samples to strata can be modified for each region. In our monitoring, we allocated 50 percent of our total sample to lowland and upland conifer in the Chippewa National Forest because the wildlife biologist wanted more information on bird indicator species that occur in conifer forests in the Chippewa. In the Superior National Forest, we concentrated the monitoring efforts in cover types that are managed for timber production. Some attention needs to be given to the variance within each stratum, although it is not a critical component of how allocation of samples to strata. Strata with higher variances will require relatively more samples (Kish 1965).

The number of subsamples within samples can also be modified to meet objectives and resources available within a region. Although we placed three subsamples within each sample, our *a posteriori* analyses indicated that about two subsamples would optimize the effort of field sampling. We stress that this is an approximate figure and would change depending upon the relative cost of collecting a sample and a subsample. It would also vary depending on the relative homogeneity (in terms of variance) of the stratum that is being sampled (*equation 1*).

There are at least two points that must be considered in all experimental designs. First is the manner of how samples

and subsamples are treated in data analyses. The sample unit for our design is a stand and, therefore, analyses of counts within stands are not valid (e.g., the pseudoreplication of Hurlbert 1984). Second, it is critical that at some level the sampling (stands in this design) be random or most statistical tests will be invalid. The assumption of independence of errors is the only one in most statistical methods for which violation is both serious and impossible to cure after the data have been collected (Green 1979).

Bird Habitat Relationships

A major objective of our monitoring program was to relate bird numbers to forest cover types. Such information is required for any monitoring program that intends to relate annual variation of bird numbers to change in forests on the breeding grounds and to management practices of the region. For example, in our monitoring program we can calculate annual change in bird abundance for each species on the basis of data collected at all points. This information can then be linked to forest inventory data to estimate the number of birds in the forest. Therefore, annual changes in bird abundance can be attributed independently to either changes in abundance (based on points) or to changes in the amount of suitable habitat in the forest.

Another advantage of selecting samples based on forest cover strata in a region is that the samples can be linked to a regional data base and to a geographic information system (if present). This link can be a powerful tool for analyzing spatial patterns of bird distribution, identifying source and sink habitats for individuals species, and for determining on a gross scale the relative number of birds in the region. These monitoring goals are best designed for each region, and some comparisons (e.g., density) are not entirely comparable across regions because of differences in habitats and bird census methods. However, with our proposed methods, the count data could be compared across regions if similar methods are used.

Power of Statistical Analyses

The power of statistical analyses for detecting annual differences in numbers for individual bird species with this design and sample size was quite good in comparison to values we calculated in Wisconsin and Michigan (Hanowski and others 1990). This was primarily due to the larger sample that was gathered in the present study. Detecting annual changes of 25 percent to 50 percent in bird numbers on a species level in a region is reasonable with this design using a sample of 120 to 150 stands in each region. The power was somewhat higher in the Superior National Forest because the sample size was larger for that region.

More specific monitoring programs may be needed for rare species with very specific habitat requirements (Verner 1985). We are exploring how this monitoring program works for all forest species in a region and what modifications need to be made to deal with species that are not adequately covered with this method.

Observer Training

The quality of data collected in any monitoring program can be improved if observers are trained and then tested in their ability to identify regional bird songs. It is also helpful if data-recording training sessions are used to familiarize new observers with methods and regional dialects. Hearing tests document the levels (decibels) at which individuals can detect a variety of frequencies. However, although observer training and testing are necessary, they do not eliminate observer variation from the sample. Observers differ in their estimate of singing birds especially when a judgment needs to be made regarding multiple cues from the same species at a point. Because some sources of observer bias cannot be controlled, we recommend that observers be distributed over the strata that are being sampled. For example, to ensure that observer variation is distributed evenly across strata all observers should sample relatively the same proportion of strata in the sample.

Mapping of Bird Distributions from Point Count Surveys[1]

John R. Sauer, Grey W. Pendleton, and Sandra Orsillo[2]

Abstract: Maps generated from bird survey data are used for a variety of scientific purposes, but little is known about their bias and precision. We review methods for preparing maps from point count data and appropriate sampling methods for maps based on point counts. Maps based on point counts can be affected by bias associated with incomplete counts, primarily due to changes in proportion counted as a function of observer or habitat differences. Large-scale surveys also generally suffer from regional and temporal variation in sampling intensity. A simulated surface is used to demonstrate sampling principles for maps.

Bird distributions are of great interest to both amateur birdwatchers and professional ornithologists. Range maps published in field guides and other sources provide a large-scale view of approximate range and relative abundance that have obvious uses for determining if species are likely to be seen in an area (Robbins and others 1986, Root 1988). They are also used to evaluate more subtle questions about ecological aspects of bird distributions (Repasky 1991). Because of the importance of assessing changes in bird ranges in association with global climate change and other large-scale environmental changes, existing range maps take on added importance as standards from which we can evaluate future changes in ranges. But range maps published in field guides generally contain many biases associated with the anecdotal nature of the observations.

Maps generated from extensive bird survey data sets such as the North American Breeding Bird Survey (BBS) (Droege 1990) and the Audubon Christmas Bird Count (CBC) (Butcher 1990) provide a reasonable source of systematically-collected information on bird distributions, and several recent publications have used these data to generate distribution maps (Robbins and others 1986, Root 1988, Sauer and Droege 1990). Because information from these surveys is now used in Geographic Information Systems (GIS) to address many management-oriented questions (e.g., analysis of the potential for bird-aircraft collisions or evaluation of bird species presence in existing patches of forest for county planning), it is of interest to evaluate the potential for error in these maps and review how sampling procedures can bias our maps of bird distribution.

Home-range estimation methods provide another example of spatial mapping procedures. In this case, the map must be formed on the basis of density of points because only presence data exist for each point. In bird surveys, these data can result from presence-absence counts, such as those obtained from miniroute stations or atlas blocks. These methods require uniform sampling density to avoid distortion in the map.

A fundamental problem with creating and assessing the efficiency of maps estimated from any sample data is that we do not have complete information on the number of birds at all points in the region (the actual surface of the map) for comparison with the estimated map surface. It is, therefore, difficult to assess error in the interpolated portion of the map. A much greater difficulty exists with maps generated using point count samples. For these data, we do not even have point estimates of the number of birds at any location on the real surface. The maps are based upon counts, which are related to the actual numbers of birds by an unknown probability of detection p (Barker and Sauer in this volume). In this paper, we review methods for developing contour maps of bird distributions from data collected at discrete points and discuss how sampling constraints associated with point counts can bias and create error in the maps. We develop a measure of bias and efficiency for maps and use simulation to show how different sampling strategies can change the efficiency of maps from point count data.

Procedures for Mapping

Early maps from BBS data were prepared by a skilled ornithologist using average counts at each survey location. Using his knowledge of bird distributions and bias in the coverage of the survey, the observer drew contours that used both the existing data and "expert opinion" for areas where survey data did not exist (D. Bystrak, personal communication). Examples of these maps appear in Robbins and others (1986).

Recently, use of statistical methods for smoothing data has become popular for bird survey mapping. Let $\mathbf{m}_i$ be the location of point i in two dimensions (e.g., $\mathbf{m}_i = \{X_i, Y_i\}$), and let $Z(\mathbf{m}_i)$ be the count at point i. These procedures take the counts at points at known locations $\mathbf{m}_i$ and estimate counts at all points that were not sampled in the region. In practice, many programs (e.g., SURFER [Golden Software 1987]) use a smoothing procedure to estimate the predicted counts for a uniform grid of points spaced over the area to be mapped. They then either plot out the counts at these grid points or use some algorithm to estimate a contour map based on the uniform grid points.

We illustrate this process using a square region, which we call point count land (PCL), with a simulated surface with height $Z' = a(X + Y)$, where X and Y are locations of the point in the X, Y plane and a is a scaling factor to make the maximum value of $Z' = 20$. The actual surface (which is not observed in real life) can be thought of as an actual bird distribution map (*fig. 1a*). The counts at randomly located sampling points are shown in *figure 1b*. The gridding process based on the Z values at the randomly selected points is shown in *figure 1c*, and the smoothed topographic map from the sample is shown in *figure 1d*. This simulated surface will be used later in the paper to demonstrate certain aspects of

[1] An abbreviated version of this paper was presented at the Workshop on Monitoring Bird Population Trends by Point Counts, November 6-7, 1991, Beltsville, Maryland.

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sampling for distribution maps. We use program SURFER (Golden Software 1987) to estimate maps from point data.

Mapping Methods

Several methods of estimating the values at the systematically-located grid nodes from data collected at random points are available. Most mapping methods were developed for geological applications, where they are used to estimate the shape of underground strata from a series of samples taken at specified locations (Isaaks and Srivastava 1989). An extensive literature has developed on smoothing methods such as kriging (Isaaks and Srivastava 1989), variants of

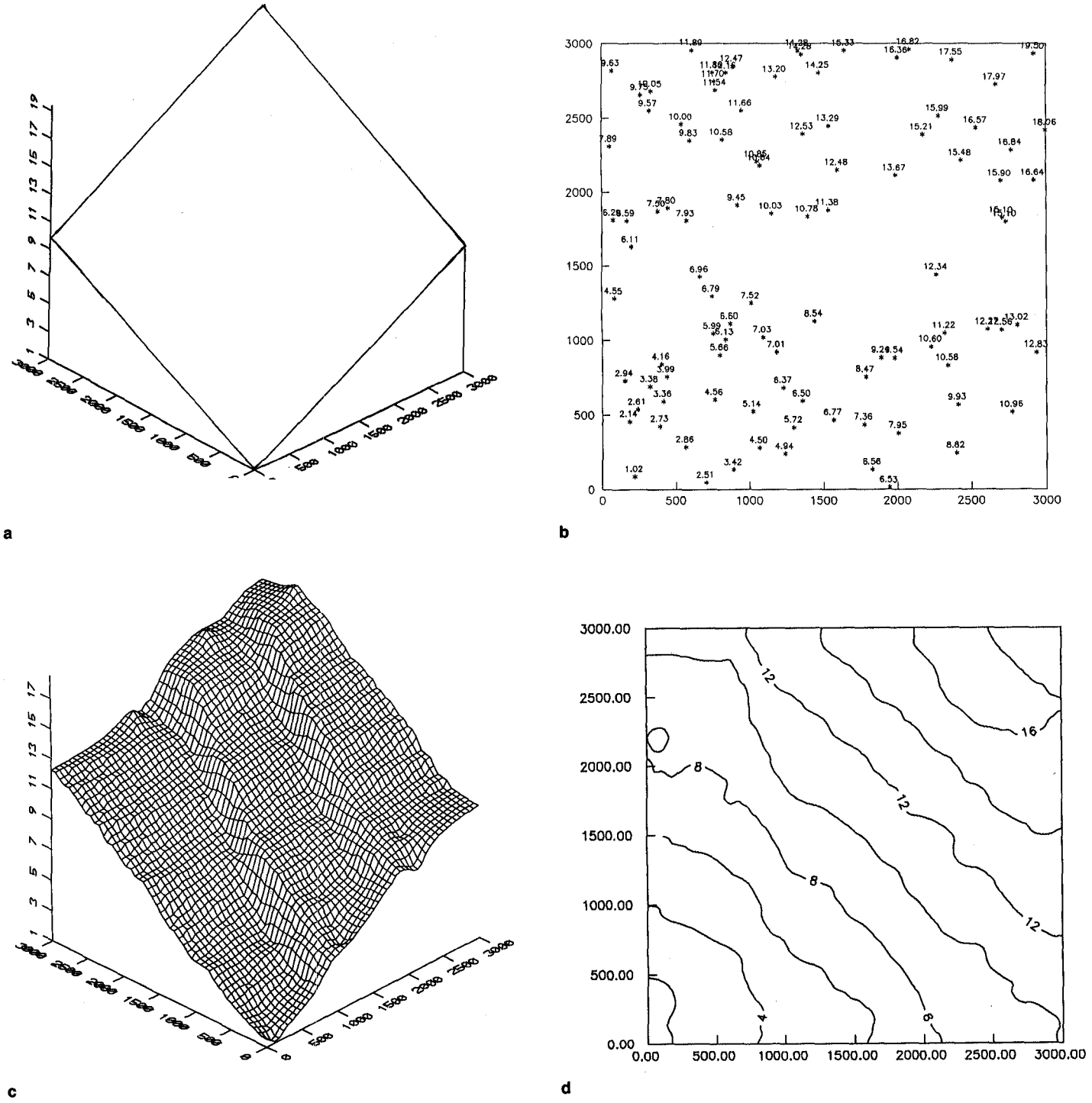


Figure 1--(a) A hypothetical surface that varies in height from 0 at the 0,0 point to 20 at the 3000,3000 point. (b) A sample of 100 randomly selected points, listed with counts. (c) A grid of counts estimated from the counts at the 100 randomly selected points. (d) A contour map based on the grid illustrated in *figure 1c*.

which have become quite popular. We briefly discuss two of these methods, inverse distancing and kriging.

Inverse Distancing

In this procedure, the count at a point at location $\mathbf{m}_i$ is estimated as a weighted average of points within a neighborhood of the point of interest, or

$$z(m_i)\frac{\sum_j \left(\frac{1}{h_j}\right) Z(m_j)}{\sum_j \left(\frac{1}{h_{i,j}}\right)}$$

In this average, the j is an index for all sample points which fall within a preselected neighborhood (or circle) of the location $\mathbf{m}_i$, and the weights are the Euclidean distances between $\boldsymbol{m}_i$ and $\mathbf{m}_j$ or $h_{i,j}$, defined as:

$$h_{i,j} = \sqrt{(x_j - x_i)^2 + (y_j - y_i)}^2$$

Often, a function of h such as h^2 is used as the weighting factor, and it is clear that the choice of both the size of the neighborhood and the choice of the function h can influence the estimated count $z(\boldsymbol{m}_i)$. We present an example of a bird relative abundance map produced from BBS data using inverse distancing (*fig. 2a*).

Kriging

Kriging is a well-known statistical procedure that fits a best linear unbiased estimator to sample data. A kriging estimate of $z(\boldsymbol{m}_i)$ is also a weighted linear combination of the existing sample data points, or

$$z(m_i) = \sum_j w_j Z(m_i)$$

The weights w_j. must sum to 1.0 and minimize the error variance. In practice, the weights are estimated from the covariance structure of known sample points. To do this, we must estimate the covariance among the sample points ($c_{j,k}$) and define a matrix **C:**

$$\begin{bmatrix} c_{11} & c_{12} & . & . & . & c_{1n} & 1 \\ c_{21} & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ c_{n1} & . & . & . & . & c_{nn} & 1 \\ 1 & 1 & . & . & . & 1 & 0 \end{bmatrix}$$

Also, the vectors $\mathbf{w}' = \{w_1, w_2, ..., w_n\mu\}$ and $\boldsymbol{D}' = \{c_{l,i}, c_{2,i}..., c_{n,i}, 1\}$ must be defined where i represents the point to be estimated. Note that the additional parameter μ is included as a mean term, which corresponds to the 1 and 0 values in the other matrices. The vector of weights $\mathbf{w}$ is estimated using Lagrange multipliers as $\mathbf{C}\ \mathbf{w} = \mathbf{D}$, hence $\mathbf{w} = \mathbf{C}^{-1}\mathbf{D}$, which is called the ordinary kriging system (Isaaks and Srivastava 1989).

In practice, the kriging system is often defined in terms of variograms, which are easier to estimate than covariances. A variogram is defined as:

$$2\gamma(m_i, m_j) = \mathrm{Var}(z(m_i) - z(m_j)).$$

$\gamma(\boldsymbol{m}_i,\boldsymbol{m}_j)$ is called the semivariogram. The variogram is similar to a covariance function, but is inverse (a large covariance implies a small variogram). Furthermore, simplifying assumptions about the underlying distribution of counts must be made to estimate components of C and D. A major assumption is that the value of the covariance (and variogram) between points depends only on the distance between the points (h). Consequently, we can plot the value of the variogram as a function of h (fig. 2b), and we can model this relationship using a variety of linear, exponential, Gaussian, logarithmic, or other functions. Using this model, we can estimate the value of the variogram for any value h, which means that we can construct C and D from knowledge of the model and the distances between points, A contour map based upon an estimated variogram is presented in figure 2c.

The estimation of the variogram is a critical component of spatial analyses and has received a great deal of attention in the geostatistical literature (Armstrong 1989). Variogram analyses assume a constant covariance structure, and if this does not exist, the kriging estimates will be inappropriate. One common departure from the required consistency occurs when the covariance structure differs depending on direction as well as distance.

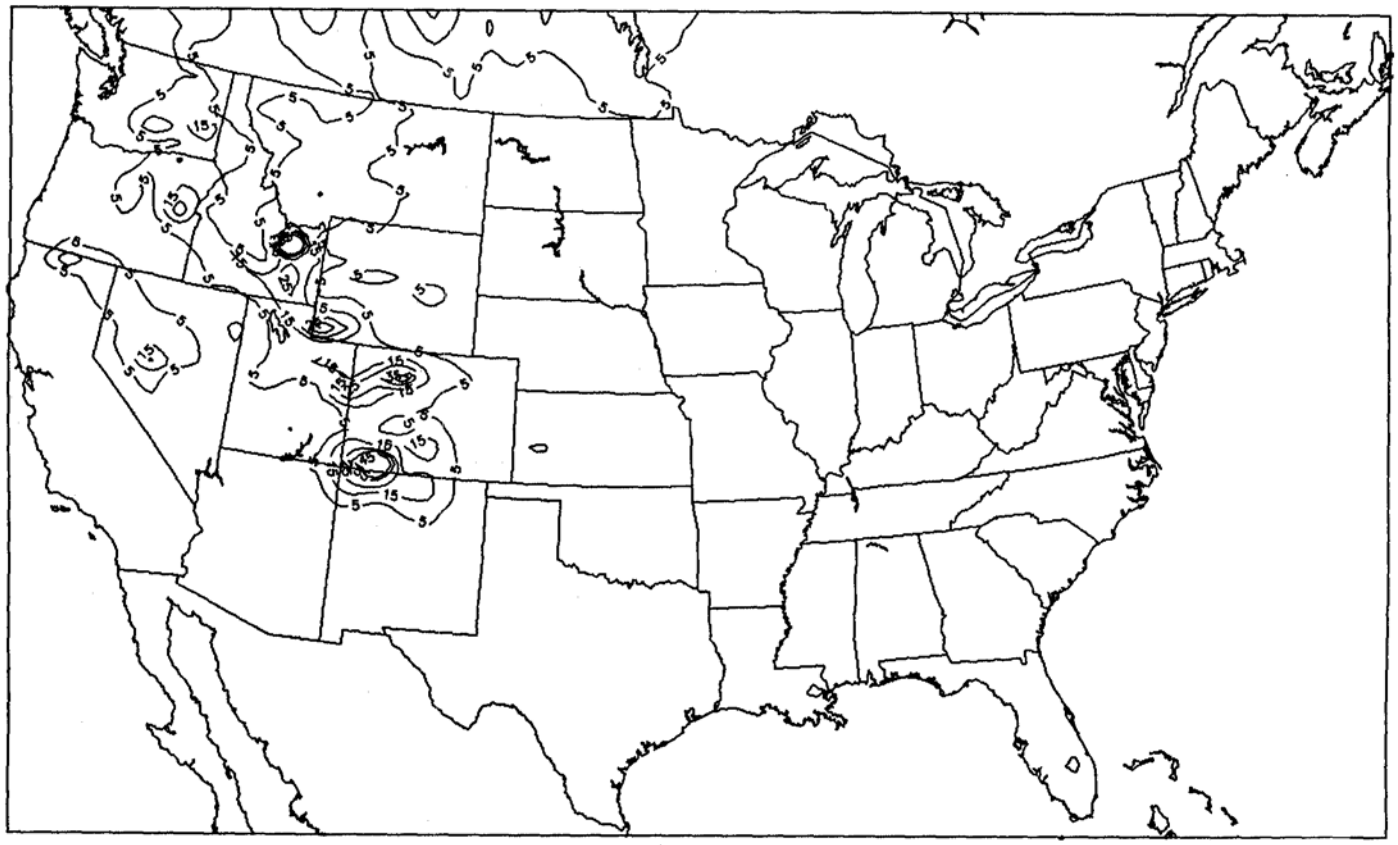
How Do We Evaluate the Quality of a Map?

There has been no research into the validity of applying kriging and other smoothing methods to bird survey data. When an automated procedure is used in mapping, there is a tendency to treat the analysis as a black box in which we vary the input parameters in an attempt to get a good picture. Unfortunately, to judge a "good picture," we use both other knowledge (often anecdotal) of what the map should look like and information from the data. Both of these sources are often flawed. All surveys are judged by how well they display people's "common knowledge" of populations. Is this an appropriate criterion? All maps are conditional on the existing data, but the information from the survey data contains many possible biases and errors, many of which are difficult to evaluate using the data.

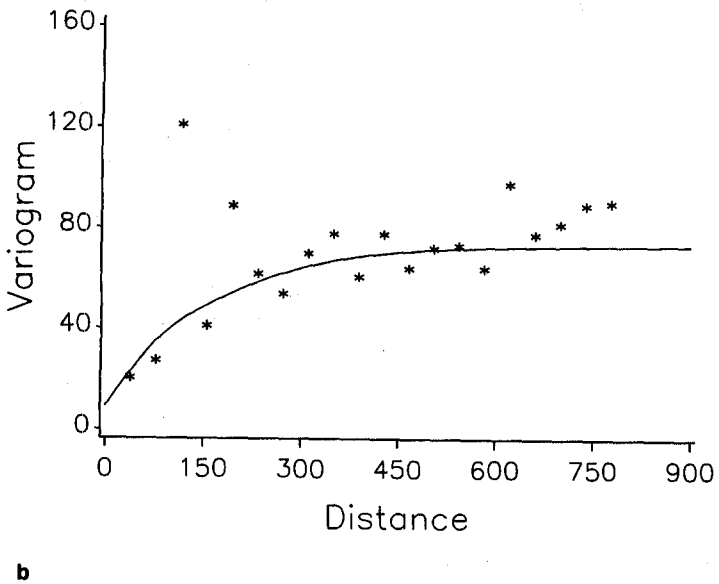
Two statistical attributes, bias and variance, can be used to evaluate how good a map is or, in fact, how good any survey is.

Bias

Bias is a measure of how different the expected value of an estimator is from the underlying (true) parameter value. In point counts, the parameter is population size, but the estimate is the count. In a map, bias is $\mathbf{E}(z(\boldsymbol{m}_i) - \mathbf{Z}(\boldsymbol{m}_i))$: the distance from a point on the expected surface developed from the counts to the "real" surface of the bird distribution.

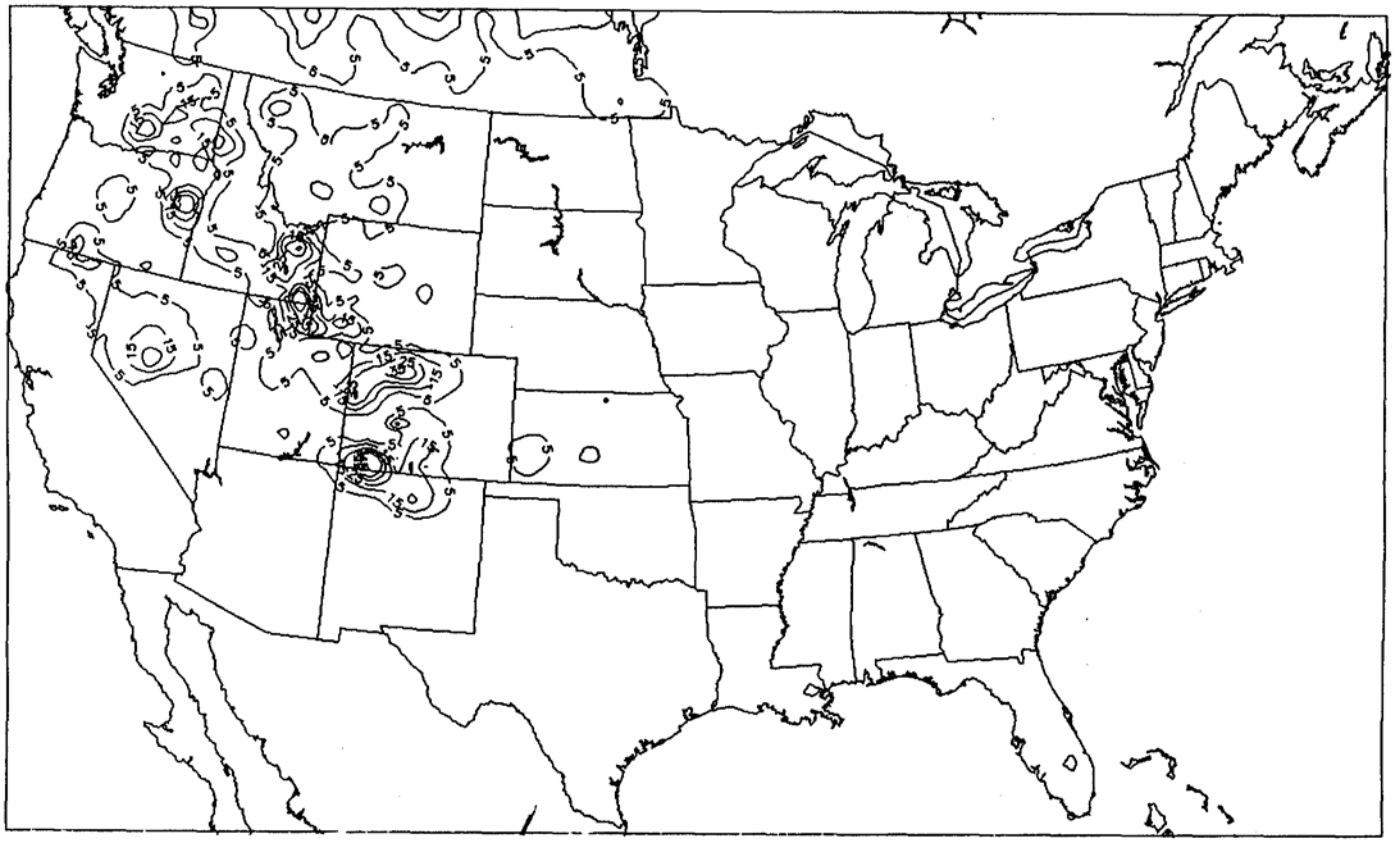


a



b

Figure 2--(a) BBS data on Black-billed Magpie (*Pica pica*), used as examples of mapping procedures. Data are averages of counts from the interval 1981 to 1990 from BBS routes. (a) A relative abundance map produced by using inverse distancing to estimate counts at nodes of a 100 x 100 grid over the map, and then contouring over the grid. (b) A sample variogram estimated for the Black-billed Magpie data. The smooth line represents a model fit to the variogram.



c

Figure 2 *(cont.)*--(c) A contour map developed from a kriging function using the sample variogram presented in *figure 2b*.

As with other analyses of point count data, the statistical properties of the proportion of birds sampled at a point (*p*, the ratio of the number of birds counted to the number of birds present at a point) are a major determinant of bias in mapping bird distributions. In our PCL example, this means that due to this *p* our point estimates of *Z*, that is *z*, are not unbiased. We can ***never*** observe the actual abundance of birds at any point with point count data. However, other attributes associated with sampling such as the roadside nature of counts and distortions due to topographic features can also bias smoothed maps of bird distributions.

Variance

Because we never measure the actual abundance of birds, the counts we derive from point counts are measured with error. A map made with point count data captures both error associated with incomplete counts and real variation in populations.

One reasonable measure of efficiency of a map is the mean square error, or MSE, which combines bias and variance as:

$$MSE = Bias^2 + variance.$$

How Can We Evaluate Bias and Precision in Maps?

We present two approaches to assessing possible difficulties with developing relative density maps from bird survey data.

First, we try to decipher some of these issues from existing data. Unfortunately, evaluation of bias in estimates from point count data is difficult because we infrequently know the real values. Validation of bird surveys generally involves comparison with alternative data sets that often contain similar bias in their estimates, and agreement or differences in estimates between surveys do not provide sufficient information to judge which is less biased. There are several examples, however, where we can reasonably assume that the estimates from comparative data are less biased (generally through collection using less biased methods), which can provide us with insights into bias associated with point count data.

Second, we can simulate maps and look at effects of our sampling methods on the mapping process. The advantage of this approach is that it allows us to evaluate the exact extent of bias for various sampling schemes. We, therefore, can avoid the conceptual problems that arise in comparing two surveys, each of which is of uncertain validity. Unfortunately, simulations are never completely representative of the vagaries of sampling and tend to provide idealized views of the world. We will use simulations to provide some insight into the effects of several sampling decisions on resulting maps.

Looking for Biases in Existing Data

There are many potential biases associated with large-scale surveys such as the BBS. Some of the biases are directly related to the vagaries of point counts, but others are a consequence of the constraints imposed by the necessity of collecting counts along roadsides using volunteers. The challenge in using large-scale survey data is in documenting the existence of potential biases and, if possible, modifying the analysis to accommodate them. In this section, we review some of the possible biases in surveys that could influence maps produced from survey data and, if possible, document their existence using survey data.

Point Count Biases

Point count methods are the only feasible way of monitoring birds on a large geographic scale. Unfortunately, by not explicitly modeling p at each site, changes in the count data among sites are confounded with factors that affect p. Therefore, changes in counts at points can be a function of changes in (1) observer efficiency, (2) regional or local habitat, and (3) population density.

Observer Efficiency

All observers count birds differently and differ in their ability to perceive birds. These differences are evident both from field studies (Bart and Schoultz 1984) and from analysis of survey data (Sauer and Bortner 1991, Sauer and others, 1994).

Regional or Local Habitat

It is also easy to document habitat effects on observability of birds. Birds are less observable in dense vegetation. An example of this occurs in the USDI Fish and Wildlife Service Mourning Dove (*Zenaida macroura*) call-count survey, in which data for birds seen are recorded separately from number of birds heard. As expected, distinct regional variation occurs in the relative size of these indices. In the Eastern United States, more birds are heard than seen, but in the Central and Western United States more birds are seen than heard. This suggests that the proportion of birds detected is changing for both variables. Furthermore, there is no reason to expect that variation in detectability between the two indices is consistent, so even their sum may not be a valid index of abundance. Unfortunately, with bird species composition and abundance and detection probabilities all varying among habitats and regions, associations among count data and habitats may not be accurate reflections of actual bird use of habitats.

Biases Associated with Population Density

It has been documented that a smaller proportion of birds are counted as the total number of birds at a stop increases (Bart and Schoultz 1984). This tends to lower p in regions with many birds. It has also been observed, however, that some bird species call more frequently at high population densities (Gates 1966). This increase in p with population size also would invalidate the index.

Other Survey Biases

In addition to the biases associated with the point counting technique discussed above, many other aspects of survey design can also bias maps from survey data. Any large-scale survey is constrained by logistical details such as availability of surveyors and ability to reach locations of sampling sites. These details include (1) variable sampling intensity, (2) temporal change, (3) roadside biases, and (4) appropriate analysis scale.

Regional Differences in Sampling Intensity

It is well known that all large-scale surveys for passerine birds contain extensive regional differences in sampling intensity. The BBS, for example, has a disproportionate number of routes in the Eastern United States and has few samples in northern and intermountain west regions. This bias is also obvious in surveys such as the Audubon Christmas Bird Count, and the Breeding Bird Censuses (Sauer and Droege 1990). This suggests that the validity of maps will differ depending on the region of interest. If maps are used to evaluate year-to-year changes in bird populations, these differences in precision will cause a perception of more predicted shifts in distributions and regional changes in counts in regions with lower sampling intensity.

Temporal Biases

Large-scale surveys tend to sample larger or smaller areas over time in response to changes in participation by volunteers. In particular, both the Audubon Christmas Bird Counts and the BBS have increased in range and participation over time, leading to both more consistent coverage of routes within regions and more routes established on the periphery of the survey. These changes in effort lead to extreme biases in trend estimators based upon regional average counts (Geissler and Noon 1981) and have led to the development of trend estimation procedures that model trends on consistently surveyed areas (Geissler and Sauer 1990). It is also evident that in the BBS, number of species and total counts tend to increase over time, suggesting increases in observer quality and participation (B.G. Peterjohn, personal communication). Maps based upon counts will display these biases.

Roadside Biases

It has been suggested that surveys such as the BBS, in which observers count birds along roadsides, provide a biased view of bird populations because many species are either attracted or repelled by roads (Droege 1990). Also, habitats that do not occur along roads are not sampled. It is clear that habitats are often missed along BBS routes and, therefore, marginal populations of birds near the edges of their ranges are not well sampled by the BBS. If habitats not sampled by surveys do contain population densities that differ from sampled habitats, maps can be distorted.

Bias and Scale of Analysis

The biases discussed above do not necessarily invalidate maps made from point count data. In fact, maps made from

BBS data appear to provide a reasonable view of regional abundances of many species (Robbins and others 1986). We believe that many large-scale geographic questions can be addressed using BBS data. We suggest consideration of the following guidelines, however, for analysis of maps from surveys:

(1) Extrapolations of counts between data points should be viewed with caution. Because p can differ between survey locations, differences in counts between routes may not accurately reflect changes in population size, and smoothed values may reflect sampling error rather than real regional variation.

(2) Regional variation in sampling intensity can create the appearance of greater variability in bird populations. Maps created from different time intervals may indicate more variation in bird populations in certain regions as a consequence of fewer samples or poor quality data.

(3) Phenomena that occur at scales smaller than the survey cannot be accurately modeled using survey data. Rare species or species sampled at the edge of their ranges will be poorly mapped. Because of the emphasis on marginal populations in evaluations of changes in ranges, edges of distributions receive special emphasis in biogeographic analysis. Unfortunately, sampling in many extensive surveys is coarse-grained, and the local patches of acceptable habitat in which marginal populations occur are often poorly sampled or missed completely. Edges of range as estimated from surveys are extremely variable, reflecting the poor sampling characteristics of low-density populations.

(4) Bird population "surfaces" are a composite of real populations and differences in sampling attributes of the population. By treating the discrete survey points as continuous functions and modeling a density surface for a species, all of the sampling problems discussed above are incorporated into the estimation. Trend analysis procedures that are structured to accommodate spatial variation in sampling intensity (through area weightings), changes in observers (through covariables), and missing data (by estimating changes over time at individual points) may provide a more reliable view of bird population changes within regions. Maps are conditional on counts, or mean counts, and methods to adjust for these biases do not exist.

Sampling for Maps

In designing any survey to estimate parameters of bird populations, choices must be made about the number of points to be sampled and the dispersion of points. Other papers in these Proceedings have examined allocation of the number of samples (e.g., Barker and Sauer, in this volume), but the dispersion of sampling locations becomes important for sampling for mapping. Geostatisticians have addressed the issue of allocating additional samples to minimize map error when pilot data have been used to define a preliminary kriging model (Barnes 1989). It is clear from this work that it is difficult to make generalizations about sampling for maps, as additional sample locations are dependent upon the model used for the pilot data.

A basic distinction exists between sampling for maps and sampling for other population attributes. When sampling for maps, a model is defined for the covariance structure of the surface, and additional samples (e.g., count locations) are selected to better define attributes of the model. Because the sampling is model-based, optimal sampling for models will introduce bias in the sample if it is used to estimate other attributes that are not model-based (such as population means), which are unbiased only if all locations have an equal chance of occurring in the sample. de Gruijter and ter Braak (1990) review this distinction between design-based and model-based sampling and suggest that design-based sampling is more likely to provide robust estimates of statistical attributes of the population. Because mapping of bird distribution is probably not the principal goal of most surveys, we suggest that model-based sampling procedures such as those suggested by Barnes (1989) not be used for allocation of additional samples in bird surveys. Steps can be taken to minimize error in mapping, however, that do not bias standard sampling.

How Can Point Count Surveys Be Designed to Provide Acceptable Information for Mapping Procedures?

In this section, we demonstrate some of the basic principles of sampling for maps. To give some insights into how sampling affects maps, we will use the simulated surface (PCL) presented in *figure 1*. The actual surface is a tilted plane that has height 0 at X,Y coordinates of (0,0) and has height $20(X + Y)/6000$ at point (X,Y). The constant 20 is the maximum height at the coordinates (3000,3000). To illustrate how sampling can affect maps, we conducted a simulation in which we (1) sampled from the surface by taking counts at (X,Y) locations under various conditions, (2) used mapping procedures to estimate a systematic grid and topographic map from the sampled counts, and (3) plotted the maps to provide a visual comparison of the consistency of the estimated maps.

Examples of Effects of Sampling Design on Map Error

Systematic versus Random Sampling

Random sampling is a traditional method of ensuring an unbiased sample. Systematic sampling ensures consistent coverage over a region that may not occur by chance in random sampling with small sample sizes. We illustrate this by simulating 900 sample points on PCL, using both a systematic grid and random points (*fig. 3*). Under these conditions, it is clear that a more consistent map is produced by systematic sampling. Exceptions to this are noted below.

Sample Points

The number of points sampled has an obvious effect on the estimation of any statistical attribute of a population. Comparison of the maps presented in *figure 3* with a map prepared with only 100 points (*fig. 1d*) illustrates the effects of decreased sample sizes on the efficiency of maps.

Detection Probabilities

Point counts do not provide unbiased estimates of the actual number of birds present at a point, because only a proportion of the birds are sampled. We evaluated the effects

of this by considering the counts at a point (Z') to be a binomial random variable, with parameters Z, the predicted height at point (X, Y), and p, the detection probability. To illustrate this, we set p at two levels: 0.8 and 0.5 (*fig. 4*). Compare these results with *figure 1d,* which has the same sampling intensity, but with $p = 1$. As expected, the surface becomes more biased (i.e., differs more from the true surface) and more variable as p gets smaller (*fig. 4*). Variation in detection probabilities over a surface can create serious biases in a map (*fig. 5*).

Replication

When $p < 1.0$, the counts are no longer measured without error at a point. In this case, there may be some advantage to replication at the point, as the mean of several counts is a "better" (i.e., more precise) estimate of Z' than is a single count. We demonstrate by averaging 20 independent "replicates" of Z' at each point (*fig. 6*) for comparison with *figure 4a*. Replication does not eliminate bias, in that the surface based on replicated counts never reaches the height of the real surface. In addition, if p varies within the area of interest, the observed surface is not only proportionately lower than the true surface, but is also distorted.

Sampling Must Occur at the Appropriate Scale for Detection of the Phenomena of Interest

In nature, no surface is smoothly increasing or declining as is modeled by our PCL surface. Instead, areas of large populations are intermixed with areas of small populations as a function of both biological and geographic features. Obviously, the more complex the distribution, the larger a sample is needed to describe it adequately. We demonstrate the effects of scale of measurement using PCL with an additional surface feature, a small area with much higher counts than the region around it (*fig. 7a*). Widely spaced sample points might not detect this feature (*fig. 7b*). One solution is to increase the sample size. If a systematic sample is used, and the spacing between sample points is less than the shortest axis of the area of interest, at least one sample point will be within the feature. Alternatively, if small features (*fig. 7a*) are known to exist, stratified sampling can be used and these small areas can be sampled with a higher density of sample points (*fig. 7c*).

Conclusions

Because of the incomplete nature of count data and deficiencies in the design of large-scale bird surveys, it is likely that maps from survey data contain significant biases. These biases should be considered in analyses of ecological attributes of the ranges of birds, and are most likely to be important at small geographic scales.

Maps are useful descriptions, and we believe that they should be produced from survey data. They have great potential for evaluation of large-scale changes in bird distributions over time. However, their deficiencies must always be made explicit. We suggest that maps of bird distributions be treated in the same way that Isaaks and Srivastava (1989:42) treat contour maps of geological data, "as helpful qualitative displays with questionable quantitative significance."

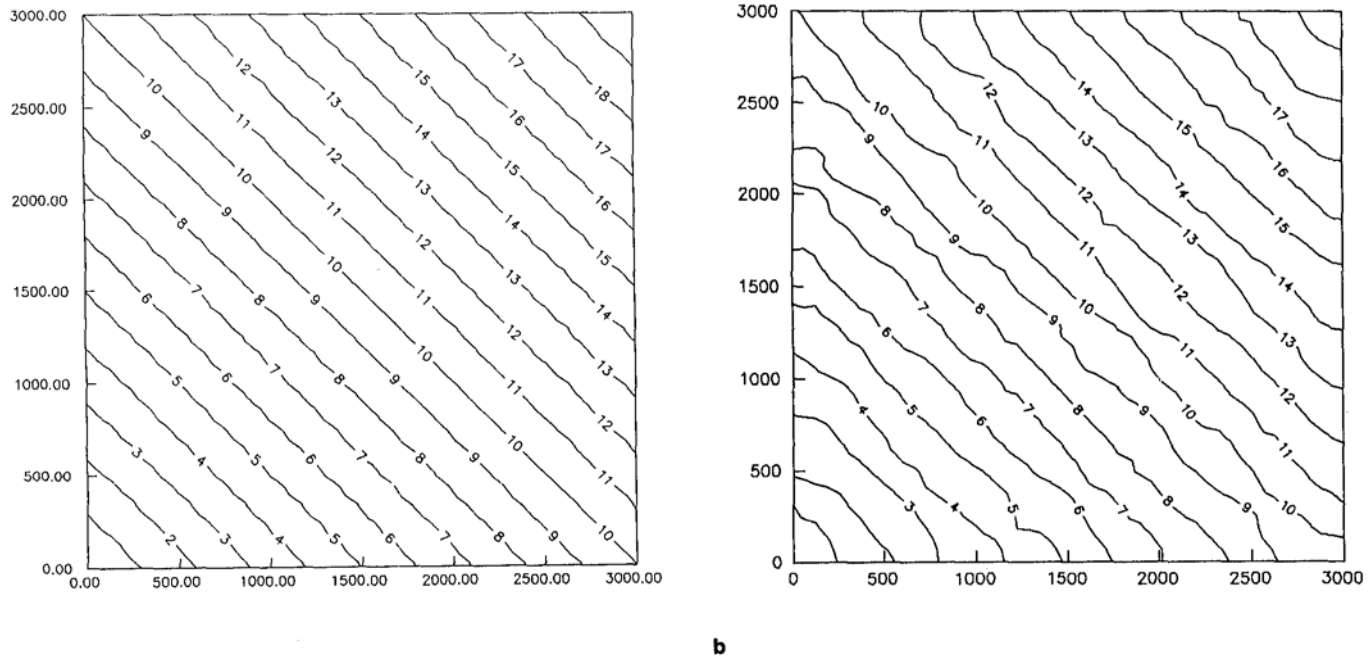
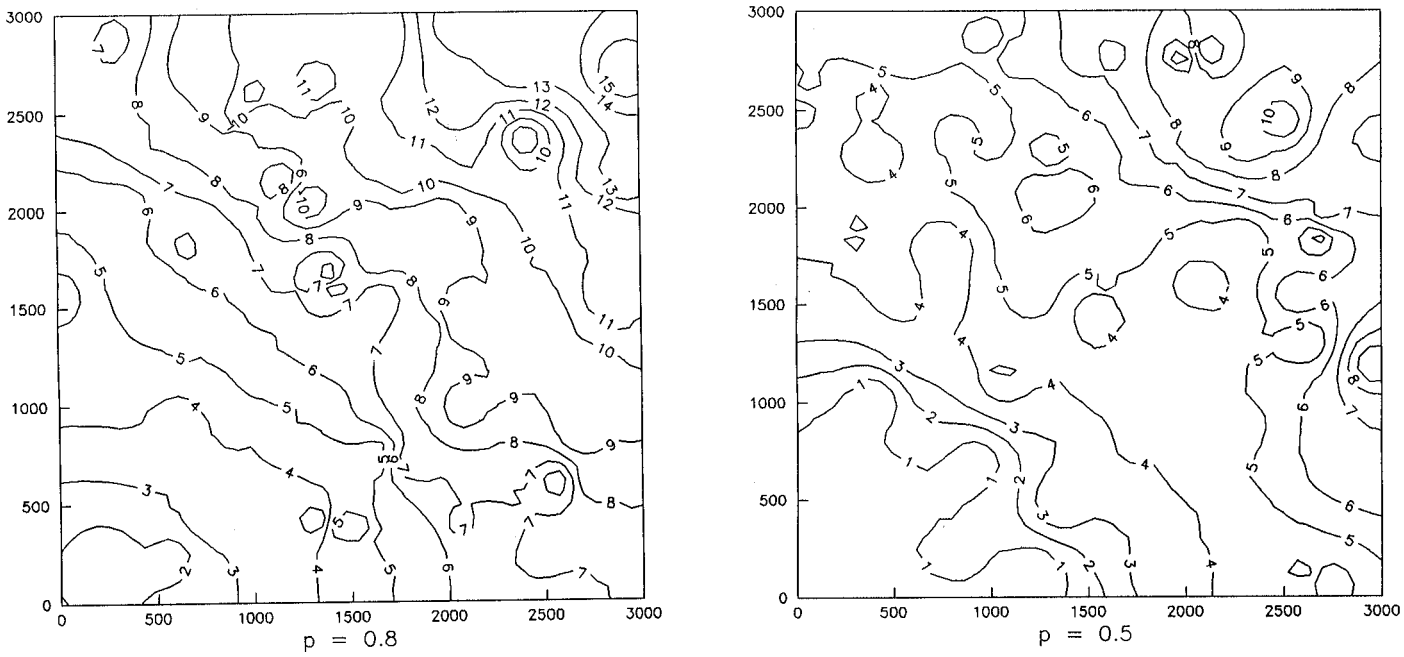


Figure 3--The effects of systematic versus random sampling on maps. (a) A sample contour map based on a systematic sample of 900 points. (b) A sample contour map based on a random sample of 900 points.



a **b**

Figure 4--The effects of varying detection probabilities on maps. Both maps were generated from the same 100 randomly located points, but differed in *p*. (a) *p* = 0.8. (b) *p* = 0.5. Compare the surface of these maps with *figure 1d*.

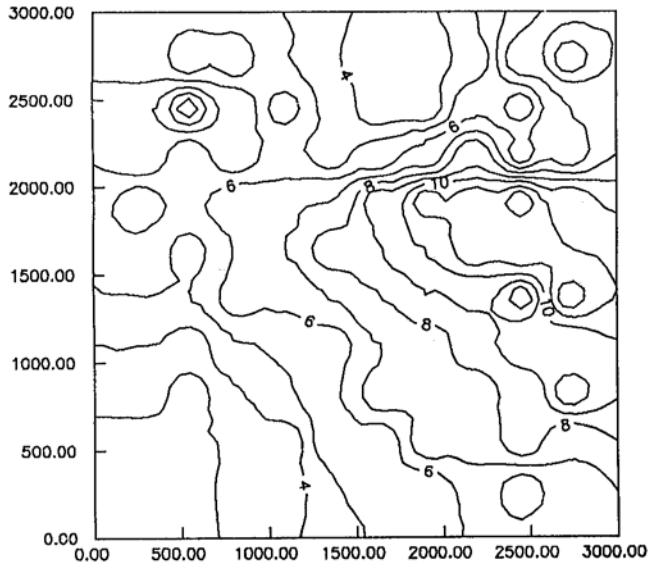


Figure 5--PCL with a systematic sample of 100 points, and *p* = 0.8 on the portion of the map below 2000 on the y-axis. Above 2000, *p* = 0.4.

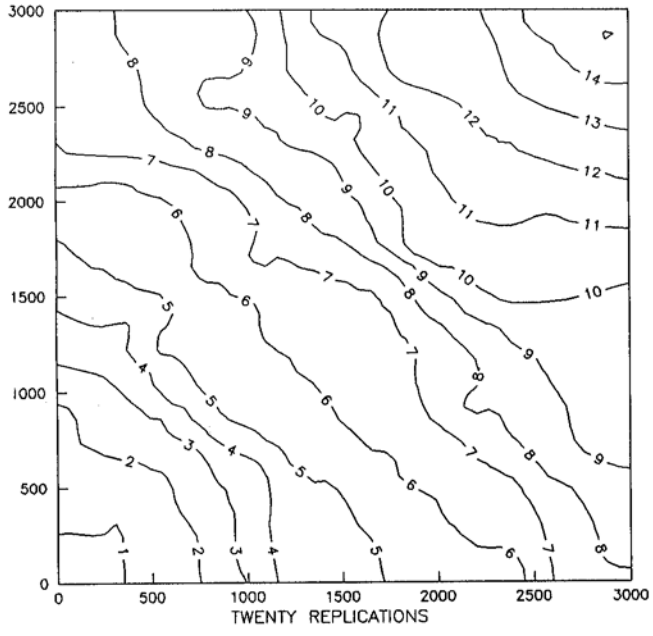


Figure 6--A map based upon similar conditions as in *figure 4a,* but the counts at each point are the average of 20 independent replicates.

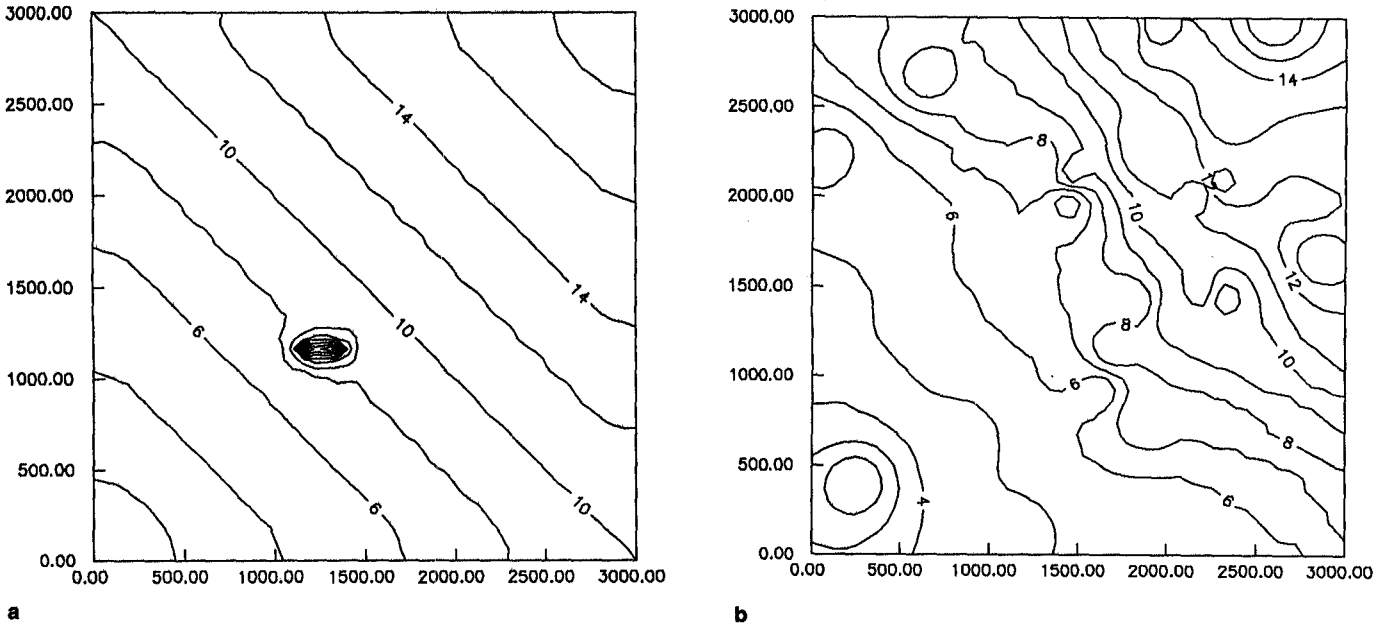


Figure 7--PCL with a raised region that is 3 times the height of the surface. (a) Detail of the surface, as shown by a 900-point systematic sample. (b) A surface produced by a low intensity sample (a 49-point sample), which misses the feature entirely. (c) An example of a stratified sample in which the surface, excluding the raised area, is sampled with 25 points uniformly located, but an additional sample of 20 points are uniformly located around the raised area.

Managing and Monitoring Birds Using Point Counts: Standards and Applications[1,3]

C. John Ralph, Sam Droege, and John R. Sauer[2]

The use of population size as a measure of health of a species has been a very common tool of ornithologists for many years (Lack 1954, 1966; Hutchinson 1978). Methods for surveying population size are detailed in Ralph and Scott (1981), the excellent compendium by Cooperrider and others (1986), and the manual by Koskimies and Vaisanen (1991). Many types of counting techniques are available to estimate relative abundance and population trends. Probably the most widely used are modifications of unlimited distance point counts (Blondel and others 1981), conducted at a series of counting stations. These often represent the best compromise between economy of collection effort and precision and accuracy of the estimates of population trends or population indexes (Verner 1985).

This document presents a set of suggested standards to provide consistency between studies for managers and researchers who would like to use point counts during the breeding season to track population trends or determine associations between birds and their habitats.

The following standards for point counts were developed during the workshop. Many of the biologists attending gave papers on point count methodology. The purpose of this process was to develop the components of point count methodology sufficient to: (1) provide trend data for monitoring population changes; and (2) predict population responses to habitat manipulations. Each of the papers given at the workshop addressed specific aspects of the methodology.

National, Regional, and Tropical Applications

The methodological standards identified in this document are designed to provide a sound starting point in the development of local or regional monitoring programs. They should also function as a means of standardizing the collection of data which will facilitate comparisons among projects. The standards identified should permit any manager to develop an appropriate monitoring or research program.

Data generated from these programs will have a number of valuable uses beyond local assessments. Population trends from National Parks and other protected areas will permit comparisons of species in wilderness areas with populations from areas under active management. Comparisons can also be made with the more widespread assessments from the Breeding Bird Survey or Christmas Bird Counts. Population trends from lands managed by government agencies will permit agency-specific evaluations of population health and status. Point count data that can be associated with habitat measures can be pooled across many programs to test hypotheses regarding bird-habitat relationships (e.g., Ruggiero and others 1991) and to validate existing bird-habitat models.

Comparisons of bird-habitat relationships across different regions require the use of standardized collection techniques. Managers who are using point counts to develop bird-habitat models should feel more constrained to use standardized techniques.

Point count methodology has applicability in seasons, climates, and circumstances beyond those we discuss. Point counts have been used in both the tropics and temperate areas to monitor wintering migrants (Hutto and others 1986; Blake 1992; Lynch in this volume). Point count methodology can be applied in Latin America, but may need modifications. For example, in hot weather and in the non-breeding season, detectability declines more rapidly during the course of the day. Playbacks of sound recordings may have to play a more important part. Investigations of the applicability of the monitoring techniques discussed here for use during the winter and in Latin America need to be launched as quickly as possible.

Many of the suggested standards presented in this document will undoubtedly require future modification as components of point count methodology are tested under new conditions and in new environments.

National Data Center

In light of the additional uses these data can have to researchers and managers, it would be useful to have copies of the data sent to an accessible central repository, either a national or several regional data centers.

A crucial element in implementing a national program would be the establishment of data center(s) to help maintain uniformity of methods, provide data tabulation, advice, interpretation, analysis, and act as a conduit for providing data to agencies and researchers for analysis.

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[1] This paper was not presented at the Workshop on Monitoring Bird Populations Point Counts but is a summary of the papers.

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[3] The people who contributed to these standards by comments are: James Baldwin, William Buskirk, Andr6 Cyr, Deanna K. Dawson, D. Fillman, J. Edward Gates, Gary A. Griffith, JoAnn M. Hanowski, Robert Howe, Richard L. Hutto, Douglas H. Johnson, Ed Johnson, Gerald J. Niemi, Grey W. Pendleton, Sandra Orsillo, Jesse L. Overcash, Daniel R. Petit, Lisa J. Petit, Bruce Peterjohn, Chandler S. Robbins, Jean-Pierre Savard, Dave Smith, Frank R. Thompson, Jerry Verner, and Dan Welsh.

Developing a Local Monitoring Program

In the development of a program, managers should bear in mind that merely chronicling the population trend of a species does little in itself to suggest management options. Population size is only a retrospective tool. It tells only after the fact that a species has enjoyed an increase or suffered a decline. In order to ponder causes of changes, the biologist must couple population size with data on the internal composition of a population---its demographics (Temple and Wiens 1989). For example, data on sex ratio, age distribution, survivorship, average weight, parasitism rates, and population movements can all give valuable cues to factors or events regulating a population. Many studies have used data such as these to describe the dynamics of various populations (e.g., Hutchinson 1978, DeSante and Geupel 1987). The most common method of measuring demographics is capturing birds with constant effort mist nets. A protocol for nest searching is also being used. Both methods are detailed in Ralph and others (1993). Indeed, the Monitoring Working Group of the Neotropical Migratory Bird Conservation Program suggests (Butcher 1992) that at least 25 percent of the monitoring effort in an area go towards demographic monitoring.

As part of a manager's goal-setting process, the purposes behind the development of a monitoring program must be stated explicitly. In developing a program we suggest that the following questions be addressed:

(1) What is the intent of the monitoring?
   a. Regional trends or habitat-specific monitoring?
   b. Evaluation of all species, a target group of species, or a single species?
   c. What is the expected relationship between the results of a population change and management actions?

(2) How is the monitoring to be accomplished?
   a. What will be the protocol used for point counts?
   b. How will the samples be allocated?
   c. When will the surveys be conducted?

(3) How do we judge if the monitoring is successful?
   a. What are the initial goals of precision?
   b. What analytical methods will be used to determine if goals are met?

Once the above questions are answered, then the biologist can implement the point counts using the following recommendations. Each recommendation is then followed by a justification prepared by the participants in the workshop.

Recommendations and Justifications

Establishing the Dispersion of Stations

*** 1. Census stations should be systematically located with a random starting point, either on roads or off roads.**

Location of stations where each point count is to be conducted is a crucial component of any monitoring program to avoid biased estimates of both trend and habitat associations (Pendleton, in this volume). If the goal is to estimate population trends for an entire management unit, then point counts should be spaced evenly throughout that unit. Completely random samples such as this ensure no bias, but may be impractical to locate and survey in the field. Under these conditions, stations placed systematically along the road system in an area, without regard to current habitat configurations, may be the best option (Bart and Robson, in this volume). Systematic samples with a random starting point are often used in field experiments (Cochran 1977). Because systematic sampling ensures coverage throughout a study area, and samples are often limited in monitoring programs, systematic samples may be preferable to random samples for many sampling objectives (Sauer and others, in press). These samples are generally accepted as equivalent to random samples when no pattern exists in the environment. However, if sample stations are not independent because of, for instance, a pattern in the habitats, estimates from systematic samples may be biased (Sukhatme and others 1984). Consequently, care must be taken to avoid placement of a systematic sample along known gradients in bird abundance, such as all stations being placed along a road that follows a riparian corridor.

Stratification of Census Stations

*** 2. Stratification of census stations by habitat should occur only if habitat-specific population estimates are required.**

If the goal is to estimate population trends for an entire management unit (e.g., Welsh, in this volume), then stratification by habitat may not be appropriate. Stratification is appropriate when the management unit can be divided into discernible habitats differing in distribution or abundance of birds (Howe and others, in this volume). Unfortunately, habitats can change quite rapidly in a managed area, and initial stratification by habitat may not be appropriate after such a change. If consistent habitats can be identified, careful consideration should be made of edges and other types not readily classified to avoid bias in a regional estimate (Freemark and Rogers, in this volume). Elimination of these edge habitats from the sample is acceptable only when, for example, the sampling is designed to provide estimates for differences between major habitats in the area, but not an overall characterization.

Bird-Habitat Modeling

*** 3. Placement of stations for bird-habitat modeling should avoid boundaries between habitat types, if possible.**

Investigation of the relationship between bird abundance and habitat requires some means of associating bird counts with habitat types. A random or systematic sampling of bird communities across the entire landscape will cause some stations to fall on or near the boundaries of habitat types. These data can be used to form post hoc associations with habitat and will reflect the variation in habitat conditions within a landscape and along the continuum of habitat. Under some circumstances, a better design would be to systematically place sampling stations within the interior of habitat types so as to sample only those well defined habitats.

If the station has two or more habitat types within the distance that birds are detected, the birds at each station can be allocated to the different habitat types. For instance, at a station with a field and forest juxtaposed, birds detected in the field can be separated from forest birds. However the edge between the habitat types, with its own mixture and often augmentation of bird populations, may confound the relationship between birds and habitat (Howe and others, in this volume). In cropland situations, however, Freemark and Rogers (in this volume) found no significant differences in bird numbers between edges and interior of fields.

The underlying question is: how can samples be allocated within a certain habitat type? The easiest way of ensuring that stations measure birds within a given habitat is to stratify habitats and place edges and other questionable areas into separate strata. Samples should never be allocated so that a portion of the region could not be sampled. However, locations of stations can be constrained to be a certain distance away from the boundaries. This distance would logically be the radius that birds could be normally detected from the station. For most species this is under 100 m (see "Distance between stations").

Road Versus Off-Road Counts

*** 4. Observers should attempt to carry out censuses primarily on tertiary roads, then secondary roads, avoiding wide, primary roads. Off-road censuses should be carried out in major habitats not covered by road systems. These off-road censuses should be done on trails, if possible.**

Laying out a systematic or randomly located point count system on the ground requires large amounts of time. Sampling stations must be located and their positions permanently marked. Once sampling begins, a substantial amount of time must be spent travelling between the stations to do the surveys. The longer it takes to get between sampling stations, the fewer stations an observer can census during a day or a season. It is essential that before decisions are made as to using roads or off-road counts, the investigator must decide what population is being sampled. However, once those decisions are made, some general guidelines can be suggested.

If a road system exists in the region where monitoring is planned, the option of setting up samples along roadsides should be strongly considered. Using roads, travel time can be reduced to as little as 1 minute to 2 minutes between sampling stations. Under optimal road conditions, up to 40 5-minute point counts can be conducted in one morning. In an off-road situation, the number of point counts one observer can conduct during a morning varies between 3 and 15 counts.

Using roads as a means of traveling between counting stations is logistically appealing. Unfortunately, roadside habitats usually do not sample all of the available habitats, and they can have habitat features unique to themselves. In these situations, a collection of both on- and off-road surveys can be created that best fits local conditions.

In most cases the presence of a road modifies the surrounding habitats (Hutto and others, Keller and Fuller, Rotenberry and Knick, in this volume). However, Hutto and others (in this volume) have shown that in the case of tertiary road systems (i.e., narrow dirt roads), birds are counted in approximately the same proportions both on roads and off. Keller and Fuller (in this volume) found that along secondary roads, through forested environments, edge species are more abundant at the road edge versus away from the road. However, they also found that obligate forest interior species were detected at nearly the same rates along roadsides as they were in interior stations. Ralph and others (unpublished data) found in Alaska and California an increase in individuals along roads, but determined it was likely to be partially due to increased observability of birds along the road path. Road counts may increase detection rates by enabling the observer to miss fewer silent, flying birds. Finally, Rotenberry and Knick (in this volume) found little differences between on- and off-road densities of shrubland birds. While many regions and habitat types have not been investigated, it seems reasonable to assume that measures of relative abundance taken from counts along roadsides will be different from those in interiors. This is not to say, however, that one is preferable to the other, merely that they will be different. This difference is less likely to be the case when secondary and tertiary roads are used. If the goal is to monitor population trends, using roadsides will greatly increase data collection efficiency, as long as there is *no* reason to believe that bird populations or habitats along roadsides are changing at a different rate than the rest of the landscape. An example would be when woodlands along roads are left as a buffer while the remainder of the landscape is cleared. In the case of monitoring populations in relationship to habitat, roadside counts would be appropriate as long as the investigator also monitored the concomitant vegetation changes, as would also occur in off-road counts.

Number of Sampling Stations

*** 5. The number of samples necessary to meet the program objectives should be derived from the statistical evaluation of pilot data.**

Once the appropriate sampling framework has been established, the number of sampling stations needs to be determined. Because of the long-term nature of most monitoring programs, an evaluation of the number of samples necessary to meet the defined goals will help the manager assess the feasibility of meeting the stated goals before funding commitments are made.

Among the factors influencing sample size are:

(1) The sampling methods.-In point counts, the average number of birds per station and the variance of individual counts are determined in part by how the counts are conducted. Time of sampling at a point and replication of counts both affect the allocation of samples. Barker and Sauer (in this volume) review some of the tradeoffs. Once the decisions

are made regarding how to sample (using the guidelines here), the number of samples can be determined.

(2) The parameter to be estimated.---If population trends are of interest, methods discussed in Sauer and Droege (in review) can be used. If average counts by habitat or region are of interest, standard statistical procedures can be applied (Thompson and Schwalbach, in this volume). All sample size allocation procedures require some initial estimates of the parameter of interest and the variance of individual observations (Johnson, Pendleton, in this volume). These initial estimates can come from either a pilot study in the area, or from existing data from a comparable study. The type of display of the data can also be important, such as the discussion by Sauer and others (in this volume) of the use of maps in showing bird distribution.

(3) The target species.-If many species are of interest, one has to adopt a strategy to either: (a) allocate sufficient samples to accurately estimate the populations of all species; (b) select a subset of crucial species, and allocate samples only with regard to the subset; or (c) allocate samples to adequately estimate populations of a fixed percentage of the different species of interest. In practice, strategy "a" is unlikely to be feasible, and "c" will poorly sample important species. Therefore, option "b" may be best, requiring identification of critical species and sampling so that all species in this group are adequately estimated.

The number of stations adequate to characterize the birds of a given area, such as a watershed, or a habitat within a watershed, depends upon the number and dispersion of birds in the area and the probability of detecting birds. Only a few common species are detected at many of the stations, even in uniform habitat. In the absence of pilot data, an absolute minimum of at least 30 stations should be established in a given habitat. The discussion in Barker and Sauer (in this volume) also addresses this question. The minimum of 30 is based on several lines of evidence, given below.

(1) Buskirk and McDonald (in this volume) found that after 100 minutes of observation at a single point (the equivalent of 20 5-minute counts), the number of new individuals and species accumulated became very stable.

(2) Morrison and others (1981) also found stabilization in density estimates after about 100 minutes of counting. While a larger area of a given habitat would have greater variance, we would expect that 30 5-minute counts (150 minutes) would largely account for the difference.

(3) Petit and others (in this volume) found that more than 15 stations were needed to document the number of species, although in larger stands (70 ha - 200 ha), the rate of accumulation of new species was declining when 15 stations had been counted.

(4) DeSante (1986) felt that about 50 points were needed to distinguish common from rarer species.

(5) Smith and others (in this volume) determined that 20 point counts accommodated variability in total individuals, and 40 counts for number of species. Although they found that minimum sample size varied widely, most of the values were less than 70 counts, and many fell into the range of 40 to 60. They felt that about 50 counts per factor level should be sufficient to detect most of the biologically meaningful differences in a study, for instance between different forest patch sizes or habitat types.

With 30 stations or fewer, analyses will be possible for only the most common species. Sample sizes for rare or difficult to detect species may require a substantially greater number of sampling stations than 30.

Required sample size to characterize a larger area, such as a National Forest, would be higher, probably in the range of 300 to perhaps 1000 points, depending upon the rarity of the species involved. Thompson and Schwalbach (in this volume) found that 100, to as much as 1000, points would be able to detect a 20 percent change in the commoner species in their area, with three 10-minute counts at each point. Hanowski and Niemi (in this volume) calculated that 360 to 450 point counts, located in 120 and 150 stands, respectively, sampled with 10-minute counts, could detect a 25 percent change in bird numbers for the common species in a National Forest. For the Spotted Owl, Bart and Robson (in this volume) suggested about 750 stations per state would be necessary. If one assumes that 25 points can be censused in a day (Ralph and others 1993), 500 stations would require 20 person-days, or one person-month.

Count Period at Each Station

*** 6. Time spent at each count station should be 5 minutes, if travel time between counting stations is less than 15 minutes, and 10 minutes if travel time is greater than 15 minutes.**

The amount of time spent counting birds at each sampling station is a compromise between acquiring an accurate picture of the birds present at a single station and increasing the statistical power of the effort by sampling a larger number of stations and birds. A number of researchers have investigated this relationship (Verner 1988; Barker and Sauer, in this volume). All studies have found that at any single sampling station an observer quickly records the majority of the species and individuals within the first few minutes (Gates, Petit and others, in this volume). The statistical efficiency, as measured by the total number of new individuals per hour of field work, reaches a peak at 3-5 minutes (Buskirk and McDonald, Lynch, Savard and Hooper, Thompson and Schwalbach, Welsh, in this volume). The greatest efficiency of shorter counts, however, occurs as a result of increasing the number of stations. The number of stations counted can be more than doubled by the use of 3- versus 10-minute counts.

Evaluation of the data, largely from wooded and brushy habitats, lead us to propose a standard of 5 minutes (Gates, Lynch, Petit and others, Savard and Hooper, Thompson and Schwalbach, in this volume). A minimum count length of 3 minutes is possible under certain circumstances for a direct comparison with Breeding Bird Surveys. However, a 5-minute count period should be the standard for counts that have travel times between stations of less than 15 minutes, and 10-minute counts should be the standard for regions with travel times of greater than 15 minutes (Buskirk and McDonald, Petit and others, Savard and Hooper, Welsh, in this volume).

During the workshop, many felt that the minimum time could have been set at 6 minutes, because it conveniently separates into two 3-minute segments, the Breeding Bird Survey standard. However, 5 minutes is the most commonly used duration in the literature and is the European standard (Koskimies and Vaisanen 1991); thus 5 minutes would promote comparisons with already existing data sets.

*** 7. When a 5-minute point count is used, data should be separated into those individuals seen or heard during the first 3 minutes and those additional individuals heard in the remaining minutes. If a 10-minute point count is used, data should be separated into three segments of 3-, 2-, and the final 5-minute periods.**

This will facilitate comparisons of data collected by projects using shorter point counts.

Distance Between Stations

*** 8. The minimum distance between point count stations is 250 m.**

*** 9. Birds previously recorded at another sampling station should not be recorded again.**

There are many reasons for having point counts as far apart as possible. The closer the distance between stations, the more likely an observer will count the same bird twice, thus overestimating the number of individuals. In addition, the farther apart the stations, the more likely that vegetation and other factors have changed, providing greater statistical independence between stations. On the other hand, the greater the distance between sampling stations, the longer it will take to travel between those stations, and the larger the area required to establish a given number of stations. Fortunately, relatively few birds have voices that travel great distances, and because these are normally easy to track when the observer is moving between stations, the chance of double counting is low. The choice of a standard minimum distance of 250 m between counts is based upon the fact that for most species, in virtually all habitats, more than 95 percent of individuals are detected within 125 m of the observer (Scott and others 1981). In addition, the maximum detection of virtually all individuals of most species is less than 250 m (Wolf and others, in this volume). In open environments, this minimum distance should be increased due to the greater detectability of birds. Along roads, where travel by vehicle is possible, distances of 500 m or more should be used (Freemark and Rogers, in this volume).

Counting Radius

*** 10. All individual birds detected at a station should be recorded.**

Care should be taken to tally only the minimum number of different individuals as determined by concurrent recordings, counter singing, or other individual recognition methods, such as plumage differences. The use of a map (see below) can help in this effort. This will help to prevent the counting of individuals more than once (Welsh, in this volume), resulting in an overestimate of the individuals present.

*** 11. Birds detected within a radius of 50 m surrounding the census station should be recorded separately from those at all distances.**

Species vary in their conspicuousness and thus their detection probabilities. These differences in detectability make between-species comparisons of absolute abundance difficult (Dawson and others, Lynch, in this volume). If point counts are used primarily to monitor population changes, counting individuals of all species seen or heard at a single station will maximize the amount of data taken (Gates, Petit and others, in this volume). If, however, comparisons of abundance between species are important, then data collected from within a 50-m radius of the station center can be used for among-species comparisons of abundance (Verner 1985) by assuming that: (a) all the birds within 50 m of the observer are detectable; (b) observers do not actively attract or repel birds; and (c) birds do not move into or out of the count circle during the counting period. A variety of standard distances have been employed by observers, with 50 m in forested environments being the most common. If the habitat is exceptionally dense, a distance of 25 m may be used, and observations should be separated into 25, 50, and greater than 50 m, to allow comparisons between studies. This occurs in many habitats, but especially the tropics (Lynch, in this volume). In open habitats, such as in crops or grasslands, 100 m may be most appropriate (Savard and Hooper, Cyr and others, in this volume).

Alternatively, if the distances to observed birds can be accurately estimated, it is possible to calculate the density of the more common species by estimating detection rates with variable circular plot methods (Reynolds and others 1980). Relatively precise estimation of distances is necessary to use this technique appropriately, and it is best applied using highly trained observers and only in bird communities with relatively few and conspicuous species (Verner 1985).

If unlimited distance point counts are being used to investigate the relationship between birds and interior (as opposed to edge) habitats, then it is very important that the stations be located well within the interior of the habitat so that birds from outside habitats are not recorded. If the habitat being investigated is to include edge habitats, then stations can be located with impunity.

Replication of Stations Versus Establishing Additional Stations

*** 12. It is usually better to increase the number of statistically independent sampling stations than to repeatedly count a smaller number of stations.**

Replication of counts at a single station, either during same day or on different days, will yield better estimates of species abundance and community composition of birds at that single station (Petit and others, Smith and others, in this volume). In some cases there is not enough room in an area

to establish additional stations without overlapping with those already established. In this case, as in the case of increasing the number of total sampling stations, replicating the point counts will increase the precision of the estimates of bird population size, albeit less efficiently than adding new independent stations. The choice depends upon the definition of the population that the investigator wishes to sample: is the population from a small area, or a large one?

In general, a station should be sampled only once each season. Counts can be repeated if the goal is good estimates of the community at certain, specific stations, such as a small area of rare wetland habitat.

Under circumstances where replication is required, determining the optimal number of replicates requires the accumulation of pilot data for each species. At some number of replicates, the gain in numbers of individuals detected will be offset by the amount of additional time it takes to collect those data, as shown by papers from this workshop (Petit and others, Smith and others, in this volume).

Time Periods for Counts

*** 13. Breeding season point counts should be conducted during the time of day and time of year when the detection rate of the species being studied is most stable.**

The visibility or detectability of a species varies with time of year and time of day (Best 1981; Robbins 1981a; Lynch, Buskirk and McDonald, in this volume). At some point during the breeding season, most species exhibit a period of several weeks when detectability is relatively stable. Unfortunately, among species, those time periods often only partially overlap (Buskirk and McDonald, in this volume). Within the breeding season, late May, the month of June, and the first week in July are best for counting most passerines in temperate North America. However, stable counting periods can be in early May in more southern areas and may extend later in the boreal zones.

The rate of calling and singing also varies with the time of day. Examining pilot data is the best way to determine when detection rates are the most stable. In general, the period between official sunrise and the ensuing 3-4 hours is usually relatively stable (Lynch, in this volume). Buskirk and McDonald (in this volume) found no significant decline, except for short, 3-minute counts, in the 5 hours after dawn. For most species, the number and rate of birds singing in the period between dawn (first light) and sunrise, are somewhat higher than those in the rest of the morning. For maximum comparability in detection probabilities for species among stations, it will be best to start counting birds at sunrise rather than at first light.

An exception to the rule of starting counts at sunrise can be made if: (1) counts are used to calculate population trends and (2) the order of the counts are the same in relation to the time of day. For example, if stations 1-3 are always counted during the first one-half hour before sunrise; 4-20 are always counted during the stable early morning period; and 21-30 are always during the late morning hours, then comparisons among years using these stations counted in this order are possible.

Appropriate Weather Conditions

*** 14. Birds should not be surveyed when it is raining, during heavy fog, or when noise from wind-blown vegetation interferes with counting.**

Very windy and rainy conditions almost always decrease the number of birds detected on point counts (Robbins 1981b). The degree to which these conditions affect the counts will depend upon the species and habitats surveyed. In some cases slight breezes can significantly depress the number of birds heard. In open environments, lack of trees and their associated noises permit the collection of count data under relatively heavy winds (D. Bystrak, pers. comm.). Verner (1985) has recommended that no surveys be conducted with winds greater than 11 km/hr, during precipitation, and under foggy conditions. Others have suggested limits between 12 and 20 km/hr (Anderson and Ohmart 1977, Robbins 1981b). If an observer feels that noise from wind or rain is causing a loss of observations greater than 10 percent, then counting should end. An appropriate way to determine the loss of detections is the inability to detect birds at longer distances as the wind or rain increases.

Number of Observers at a Single Station

*** 15. Only one observer should be permitted to count birds at a single station.**

Additional observers at a station modify the rate of detection of birds and therefore reduce comparability with other stations with a single observer (Howe and others, in this volume). This recommendation is based on our experience that even the best observers do not record all the potentially detectable species or individuals during the count period. It is easy for a bird to fly by while an observer records data or looks the other way. When many birds are calling, it is also easy to miss a bird that calls once or only faintly. Because all point counts are only partial samples, consistency of effort is critical in maintaining the comparability of counts.

Observer Training

*** 16. Only observers able to identify all the targeted birds by sight and sound should participate in a monitoring or research project using point counts.**

It cannot be overemphasized that the success of any bird monitoring or research project hinges on the caliber of the observers collecting the data. Given the normally high turnover in the technicians that do the bulk of data collection, comparability among observers is critical. If differences among observers are very great, they could eliminate most (if not all) of the power of a monitoring program to detect changes in bird populations (Faanes and Bystrak 1981, Kepler and Scott 1981). The high number of species in the tropics presents special problems for training, as is discussed elsewhere in this paper.

The ability to identify birds by sight, and especially by sound, is a skill that usually takes several years to develop, unless an intensive training program can be undertaken. An ornithology course or several trips into the woods is only partial

preparation. Any individual who will be participating in a program to monitor birds should have identification skills comparable to that of the local experts. Training may not be difficult if only one species is being monitored, but if every species at each station is counted, then the training of raw recruits is almost certainly too time-consuming to be feasible. Training in estimating distances to individual birds is also important if any density estimates are to be made, as Welsh (in this volume) found.

We recommend that any applicant's ability to survey birds should be tested. Unfortunately, no completely valid testing procedure exists (see Hanowski and Niemi, in this volume). However, by using known, qualified observers as a gauge, it is possible to quickly ascertain the suitability of an observer. Both the benchmark observer and the new observer need to simultaneously count birds under circumstances similar to those to be imposed by the project. Any deficiencies in the new observer's ability to identify birds will be quickly apparent.

While most projects will rely on observers already trained in the art of bird identification to do their field work, new observers will eventually be needed to replace those who depart. To help in the long-term development of a pool of observers who have the skills necessary to identify bird by sound, agencies can promote the learning of bird songs. Permitting novice bird counters to work with experienced birders is the quickest way to learn bird songs. Bird tapes will also help new observers work on their identification. We suggest that the following is adequate for training: (a) use a syllabus that outlines a standard training program for censusing; (b) a regional vocalization tape should be available (these usually do not have complete songs and calls of all species and every effort should be made to obtain a complete one); (c) a test tape should evaluate each observer's correct identifications; (d) simultaneous consumng with an experienced observer during 3- or 5-minute road counts, with immediate feedback as to the number and directions of birds, will speed learning; and (e) all observers should have a hearing test. Based on our collective experience in training observers, we feel that as a general rule of thumb, species composition between simultaneously counting observers should be near 90 percent, and the number of individuals should be within 80 percent.

Recording Data

*** 17. A standard field form should be used to ensure compatibility of data taken between participants in the program.**

Appendix A contains a sample field sheet, and standard database software can be used for recording point count information from this sheet.

Using a map is an efficient way to record data, especially in counts longer than 3 minutes. Maps help in keeping track of locations of birds, allow accurate quality checks, and permit a variety of data to be taken. Shortcuts can facilitate data taking, such as: use of single letters for the commonest 10 to 15 species, as well as standardized behavior codes for separating birds, recording movements, and showing simultaneous observations.

Age, Sex, and Behavioral Classification of Birds

*** 18. Juvenile birds or birds that fledged during the current breeding season should be recorded separately.**

*** 19. Birds that were detected flying over the station, rather than detected from within the vegetation, should be recorded separately.**

Birds detected while counting can often be identified to the age and sex of the individual. However, because birds are largely detected through the sounds they make, and because there are numerous differences among species as to which sex vocalizes, regular collection of sex data should be considered of secondary importance. By contrast, numbers of fledgling birds increase as the breeding season advances. To reduce the bias associated with seasonal increases in the numbers of fledglings, numbers of fledglings should be recorded separately.

Birds that are detected flying over the plot are less likely to be breeding or associated with the habitat surrounding the station than an individual near the ground or in vegetation. Exceptions, of course, include such species as raptors, swallows, and swifts. Birds flying over do, however, live in the general area and can be recorded.

The Priority of Breeding Season Surveys

*** 20. Most effort expended conducting point counts should occur during the breeding season.**

While the focus has been on breeding season for many surveys, migration and winter habitats are vital to many species' survival. Species have been found to show habitat dependencies during this season, while they were non-specific in breeding (Manuwal and Huff 1987). Winter counts are important because many species are limited by their ability to survive the winter and many spend 8-10 months on the wintering grounds. Fixed-width transect counts and playbacks may be necessary in this season, although they limit comparisons with other methods. Migration counts can be used for northern or high altitude species and to identify important stopover sites. However, migration and winter counts are difficult to interpret because of high variability, and their feasibility remains to be determined (Robbins 1972, Cyr and others, in this volume).

Based on our experience, we suggest that for the northern United States and Canada, breeding season counts should make up 70 percent to 80 percent of the effort in any area, and migration and winter counts, 10 percent to 15 percent each. In the southern United States and Latin America, we suggest 50 percent to 70 percent during breeding, 10 percent to 20 percent during migration, and 20 percent to 40 percent in the northern winter. We feel that this will allocate effort according to the likely management importance of the data in different seasons, as well as reflect funding priorities.

Modifications for Specialized Groups of Birds

*** 21. Point count techniques can often be modified to better survey cryptic or uncommon birds.**

Playbacks of species calls can dramatically increase the detection of almost any species (Johnson and others 1981). They do, however, preclude comparisons with unaided surveys. Nocturnal point counts can be used to survey owls and caprimulgids and are especially effective when used in conjunction with taped calls. Playbacks have been used to good effect during the winter season and in the tropics (Sliwa and Sherry 1992; Lynch, in this volume; Gauthreaux, personal communication). Methods of censusing raptors, night-singing birds, and marsh birds are suggested in the excellent compendium of Koskimies and Väisänen (1991).

Additional Recommendations:

The following recommendations should help further standardize the collection of point count data among projects.

*** 22. Counts should begin immediately when the observer reaches the census station.**

*** 23. A bird flushed within 50 m of a station's center, as an observer approaches or leaves a station, should be counted as being at the station if the observer feels that this individual was not seen during the count period. It is advisable that this be recorded separately.**

*** 24. If a flock is encountered during a census period, it may be followed after the end of the period to determine its composition and size. An observer should follow such a flock for no more than 10 minutes. This is especially useful during the winter.**

*** 25. A bird giving an unknown song or call may be tracked down after count period for confirmation.**

*** 26. No attracting devices or records should generally be used, except in counts for specialized groups of birds.**

*** 27. Latitude and longitude for each location should be recorded at least to the nearest 10 seconds from accurate topographic maps.**

*** 28. Recording data into a tape recorder can help to minimize the time that an observer spends looking at the sheet of paper while recording, thus maximizing visual observations.**

Conclusions

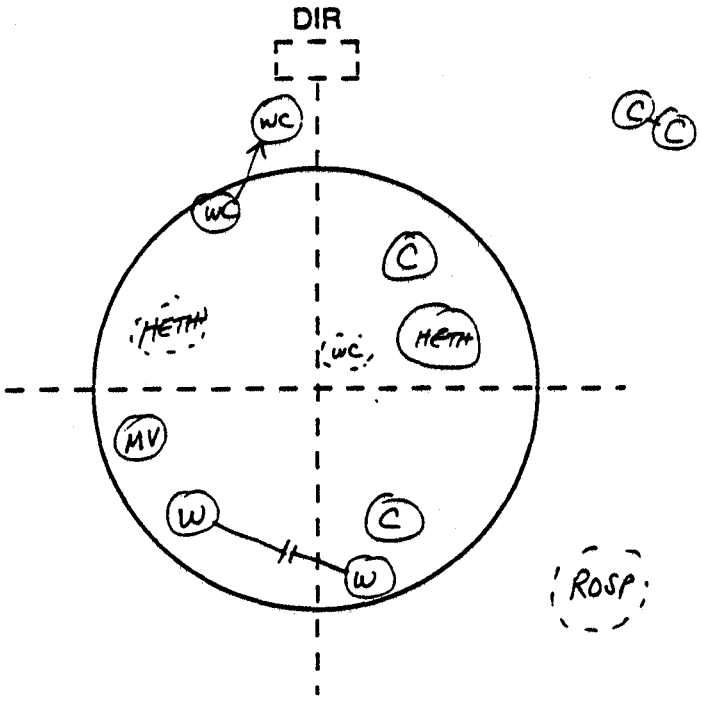
The use of standardized methods that we suggest will enable comparisons with other studies. The quality of the data, however, is at least as important, and depends upon the continued dedication and training of the observers, cooperation of various agencies and investigators, and the rapid and accurate compilation of results. We feel that the cooperative effort that went into these standards shows the sincerity that all involved will continue to put toward this effort.

Appendix A--*Field sheets, involving mapping of birds and the use of `tick' marks.*

POINT COUNT LOCATION MAPPING

STATE	REGION	STATION	MONTH	DAY	YEAR	POINT
CA	MT SHASTA	BEVA	6	17	1992	2

TIME



MAPPING SYMBOLS

CODE		
S	MAWA	Position of singing male
S	MAWA	Approximate position of singing male
S	MAWA — MAWA	Simultaneous song of 2 males
S	MAWA → MAWA	Known change in position
S	MAWA ⇠ MAWA	Assumed change in position
N	MAWA *	Nest

CODE		
M	MAWA	Male observed
F	MAWA	Female observed
C	MAWA	Calling, sex unknown
P	MAWA	Pair together assumed mated
O	MAWA	Observed, sex unknown

POINT COUNT DATA FORM

STATE	REGION	STATION	MONTH	DAY	YEAR	VISIT NUMBER
CA	MT SHASTA	BEVA	6	17	1992	2

				≤ 50 M		> 50 m		FLY-OVERS	
PT. NUMBER		TIME	SPECIES	0 - 3 MIN	3 - 5 MIN	0 - 3 MIN	3 - 5 MIN	0 - 3 MIN	3 - 5 MIN
	1	0540	MTCH	2		2	2		
			HETH	2					
			MWSP	3					
			ROSP		1	1			
			BEWR	2					
	2	0552	RTHA	5				1	
			MTCH	2	1		1		
			RCKI	3	1				
			RECR			1			
			MWSP	1					
			FOSP		2				
	3	0559	HETH	3					
			SSHA						1
			MWSP	2			1		

3/26/92

Appendix *B--Families and common and scientific names of bird species*

Family name	Common name	Scientific name
Ardeidae	American Bittern	*Botaurus lentiginosus*
	Great-blue Heron	*Ardea herodias*
Anatidae	Mallard	*Anas platyrhynchos*
Rallidae	Yellow Rail	*Coturnicops noveboracensis*
Cathartidae	Turkey Vulture	*Cathartes aura*
Accipitridae	Northern Harrier	*Circus cyaneus*
	Sharp-shinned Hawk	*Accipiter striatus*
	Northern Goshawk	*Accipiter gentilis*
	Red-shouldered Hawk	*Buteo lineatus*
	Red-tailed Hawk	*Buteo jamaicensis*
Falconidae	Collared Forest-falcon	*Micrastur semitorquatus*
	American Kestrel	*Falco sparverius*
	Merlin	*Falco columbarius*
Cracidae	Plain Chachalaca	*Ortalis vetula*
Phasianidae	Ruffed Grouse	*Bonasa umbellus*
	Spruce Grouse	*Dendrapogus canadensis*
	Northern Bobwhite	*Colinus virginianus*
	Wild Turkey	*Meleagris gallopavo*
Laridae	Ring-billed Gull	*Larus delawarensis*
Charadriidae	Killdeer	*Charadrius vociferus*
Scolopacidae	Greater Yellowlegs	*Tringa melanoleuca*
	Spotted Sandpiper	*Actitis macularia*
	Upland Sandpiper	*Bartramia longicauda*
	Long-billed Curlew	*Numenius americanus*
	Common Snipe	*Gallinago gallinago*
	American Woodcock	*Scolopax minor*
Columbidae	Rock Dove	*Columba livia*
	Mourning Dove	*Zenaida macroura*
Psittacidae	Yellow-lored Parrot	*Amazona xantholora*
Cuculidae	Black-billed Cuckoo	*Coccyzus erythropthalmus*
	Yellow-billed Cuckoo	*Coccyzus americanus*
Strigidae	Great-horned Owl	*Bubo virginianus*
	Ferruginous Pygmy-owl	*Glaucidium brasilianum*
	Northern Saw-whet Owl	*Aegolius acadicus*
	Northern Spotted Owl	*Strix occidentalis caurina*
	Great Gray Owl	*Strix nebulosa*
Caprimulgidae	Whip-poor-will	*Caprimulgus vociferus*

continued

Appendix B---*continued*

Family name	Common name	Scientific name
Apodiformes	Chimney Swift	*Chaetura pelagica*
Trochilidae	Ruby-throated Hummingbird	*Archilochus colubris*
	Calliope Hummingbird	*Stellula calliope*
	Rufous Hummingbird	*Selasphorus rufus*
Alcedinidae	Belted Kingfisher	*Ceryle alcyon*
Ramphastidae	Keel-billed Toucan	*Ramphastos sulfuratus*
Picidae	Red-bellied Woodpecker	*Melanerpes carolinus*
	Golden-fronted Woodpecker	*Centurus aurifrons*
	Yellow-bellied Sapsucker	*Sphyrapicus varius*
	Red-naped Sapsucker	*Sphyrapicus nuchalis*
	Downy Woodpecker	*Picoides pubescens*
	Hairy Woodpecker	*Picoides villosus*
	Three-toed Woodpecker	*Picoides tridactylus*
	Black-backed Woodpecker	*Picoides articus*
	Northern Flicker	*Colaptes auratus*
	Pileated Woodpecker	*Dryocopus pileatus*
	Pale-billed Woodpecker	*Campephilus guatemalensis*
Tyrannidae	Northern Bentbill	*Oncostoma cinereigulare*
	White-throated Spadebill	*Platyrinchus mystaceus*
	Olive-sided Flycatcher	*Contopus borealis*
	Western Wood-Pewee	*Contopus sordidulus*
	Eastern Wood-Pewee	*Contopus virens*
	Dusky Flycatcher	*Empidonax oberholseri*
	Hammond's Flycatcher	*Empidonax hammondii*
	Acadian Flycatcher	*Empidonax virescens*
	Alder Flycatcher	*Epidonax alnorum*
	Least Flycatcher	*Empidonax minimus*
	Eastern Phoebe	*Sayornis phoebe*
	Bright-rumped Attila	*Attila spadiceus*
	Dusky-capped Flycatcher	*Myiarchus tuberculifer*
	Great Crested Flycatcher	*Myiarchus crinitus*
	Eastern Kingbird	*Tyrannus tyrannus*
Alaudidae	Horned Lark	*Eremophilia alpestris*
Hirundinidae	Tree Swallow	*Tachycineta bicolor*
	Bank Swallow	*Riparia riparia*
	Cliff Swallow	*Hirundo pyrrhonta*
	Barn Swallow	*Hirundo rustica*
	Purple Martin	*Progna subis*
Corvidae	Gray Jay	*Perisoreus canadensis*
	Steller's Jay	*Cyanocitta stelleri*
	Blue Jay	*Cyanocitta cristata*
	Brown Jay	*Cyanocorax morio*

continued

Appendix B--*continued*

Family name	Common name	Scientific name
Corvidae *continued*	Clark's Nutcracker	*Nucifraga columbiana*
	American Crow	*Corvus brachyrhynchos*
	Common Raven	*Corvus corax*
	Black-billed Magpie	*Pica pica*
Paridae	Black-capped Chickadee	*Parus atricapillus*
	Carolina Chickadee	*Parus carolinensis*
	Mountain Chickadee	*Parus gambeli*
	Boreal Chickadee	*Parus hudsonicus*
	Chestnut-backed Chickadee	*Parus rufescens*
	Tufted Titmouse	*Parus bicolor*
Sittidae	Red-breasted Nuthatch	*Sitta canadensis*
	White-breasted Nuthatch	*Sitta carolinensis*
Certhiidae	Brown Creeper	*Certhia americana*
Troglodytidae	Rock Wren	*Salpinctes obsoletus*
	Carolina Wren	*Thryothorus ludovicianus*
	House Wren	*Troglodytes aedon*
	Winter Wren	*Troglodytes troglodytes*
Muscicapidae	Golden-crowned Kinglet	*Regulus satrapa*
	Ruby-crowned Kinglet	*Regulus calendula*
	Blue-gray Gnatcatcher	*Polioptila caerulea*
	Eastern Bluebird	*Sialia sialis*
	Mountain Bluebird	*Sialia currucoides*
	Townsend's Solitaire	*Myadestes townsendi*
	Veery	*Catharus fuscescens*
	Swainson's Thrush	*Catharus ustulatus*
	Hermit Thrush	*Catharus guttatus*
	Wood Thrush	*Hylocichla mustelina*
	American Robin	*Turdus migratorius*
	Varied Thrush	*Ixoreus naevius*
	Hawaiian Thrush	*Myastes obscurus*
Mimidae	Gray Catbird	*Dumetella carolinensis*
	Sage Thrasher	*Oreoscoptes montanus*
	Brown Thrasher	*Taxostoma rufum*
Bombycillidae	Cedar Waxwing	*Bombycilla cedrorum*
Sturnidae	European Starling	*Sturnus vulgaris*
Vireonidae	White-eyed Vireo	*Vireo griseus*
	Solitary Vireo	*Vireo solitarius*
	Yellow-throated Vireo	*Vireo flavifrons*
	Warbling Vireo	*Vireo gilvus*
	Red-eyed Vireo	*Vireo olivaceus*
	Lesser Greenlet	*Hylophilus decurtatus*

continued

Appendix B---*continued*

Family name	Common name	Scientific name
Emberizidae	Orange-crowned Warbleer	*Vernivora celata*
	Nashville Warbler	*Vermivora ruficapilla*
	Northern Parula	*Parula americana*
	Prothonotary Warbler	*Protonotaria citrea*
	Yellow-throated Warbler	*Dendroica dominica*
	Yellow Warbler	*Dendroica petechia*
	Chestnut-sided Warbler	*Dendroica pensylvanica*
	Magnolia Warbler	*Dendroica magnolia*
	Cape May Warbler	*Dendroica tigrina*
	Black-throated Blue Warbler	*Dendroica caerulescens*
	Yellow-rumped Warbler	*Dendroica coronata*
	Townsend's Warbler	*Dendroica townsendi*
	Black-throated Green Warbler	*Dendroica virens*
	Pine Warbler	*Dendroica pinus*
	Prairie Warbler	*Dendroica discolor*
	Bay-breasted Warbler	*Dendroica castanea*
	Cerulean Warbler	*Dendroica cerulea*
	Black-and-white Warbler	*Mniotilta varia*
	American Redstart	*Setophaga ruticilla*
	Worm-eating Warbler	*Helmitherous vermivorus*
	Ovenbird	*Seiurus aurocapillus*
	Northern Waterthrush	*Seiurus noveboracensis*
	Louisiana Waterthrush	*Seiurus motacilla*
	Kentucky Warbler	*Oporornis formosus*
	Mourning Warbler	*Oporornis philadelphia*
	MacGillivray's Warbler	*Oporornis tolmiei*
	Connecticut Warbler	*Oporornis agilis*
	Common Yellowthroat	*Geothlypis trichas*
	Hooded Warbler	*Wilsonia citrina*
	Wilson's Warbler	*Wilsonia pusilla*
	Canada Warbler	*Wilsonia canadensis*
	Yellow-breasted Chat	*Icteria virens*
	Red-throated Ant-tanager	*Habia fuscicauda*
	Western Tanager	*Piranga ludoviciana*
	Scarlet Tanager	*Piranga olivacea*
	Summer Tanager	*Piranga rubra*
	Northern Cardinal	*Cardinalis cardinalis*
	Rose-breasted Grosbeak	*Pheucticus ludovicianus*
	Black-headed Grosbeak	*Pheucticus melanocephalus*
	Lazuli Bunting	*Passerina amoena*
	Indigo Bunting	*Passerina cyanea*
	Rufous-sided Towhee	*Pipilo erythrophthalmus*
	Chipping Sparrow	*Spizella passerina*
	Brewer's Sparrow	*Spizella breweri*
	Field Sparrow	*Spizella pusilla*

continued

Appendix B---*continued*

Family name	Common name	Scientific name
Emberizidae *continued*	Lesser Greenlet	*Hylophilus decurtatus*
	Vesper Sparrow	*Pooecetes gramineus*
	Lark Sparrow	*Chondestes grammacus*
	Sage Sparrow	*Amphispiza belli*
	Savannah Sparrow	*Passerculus sandwichensis*
	Le Conte's Sparrow	*Ammodramus leconteii*
	Fox Sparrow	*Passerella iliaca*
	Song Sparrow	*Melospiza melodia*
	Lincoln's Sparrow	*Melospiza lincolnii*
	Swamp Sparrow	*Melospiza georgiana*
	White-throated Sparrow	*Zonotrichia albicollis*
	White-crowned Sparrow	*Zonotrichia leucophrys*
	Dark-eyed Junco	*Junco hyemalis*
	Slate-colored Junco	*Junco hyemalis hyemalis*
	Bobolink	*Dolichonyx oryzivorous*
	Red-winged Blackbird	*Agelaius phoeniceus*
	Eastern Meadowlark	*Sturnella magna*
	Western Meadowlark	*Sturnella neglecta*
	Brewer's Blackbird	*Euphagus cyanocephalus*
	Common Grackle	*Quiscalus quiscula*
	Brown-headed Cowbird	*Molothrus ater*
	Northern Oriole	*Icterus galbula*
Fringillidae	House Finch	*Carpodacus mexicanus*
	Purple Finch	*Carpodacus purpureus*
	Cassin's Finch	*Carpodacus cassinii*
	Red Crossbill	*Loxia curvirostra*
	White-winged Crossbill	*Loxia leucoptera*
	Pine Grosbeak	*Pinicola enucleator*
	Pine Siskin	*Cardeulis pinus*
	American Goldfinch	*Carduelis tristis*
	Evening Grosbeak	*Coccothraustes vespertinus*
Passeridae	House Sparrow	*Passer domesticus*

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