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

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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

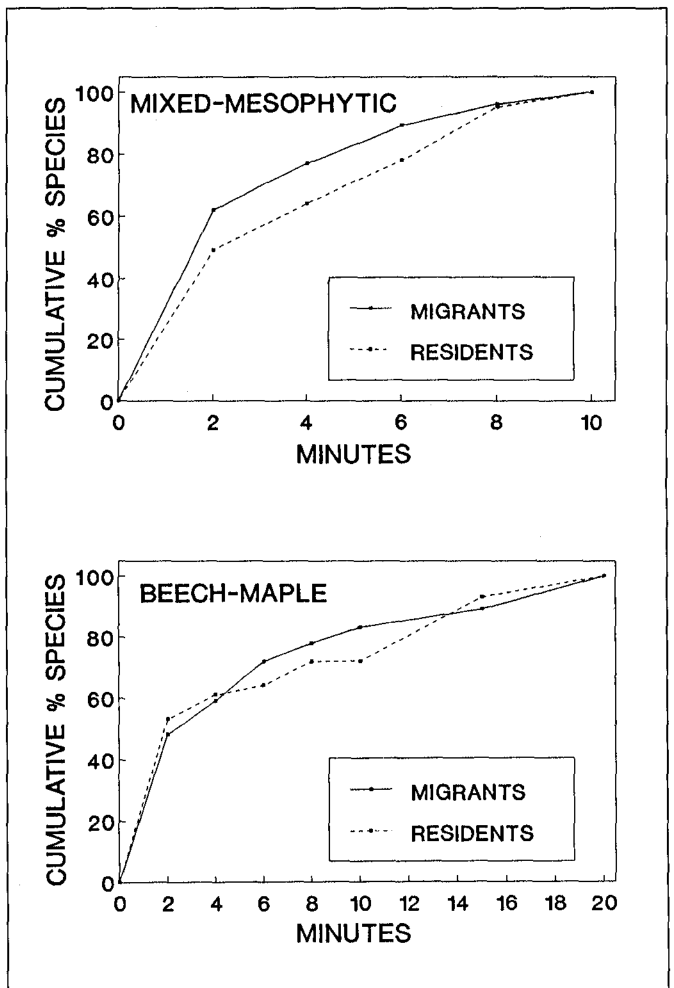

Figure 1-Species accumulation curves over time in mixed-mesophytic (top) and beech-maple (bottom) forests. Points in each curve represent the means from 27 counts in mixed-mesophytic and 17 counts in beech-maple forests.

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, $P > 0.10$).

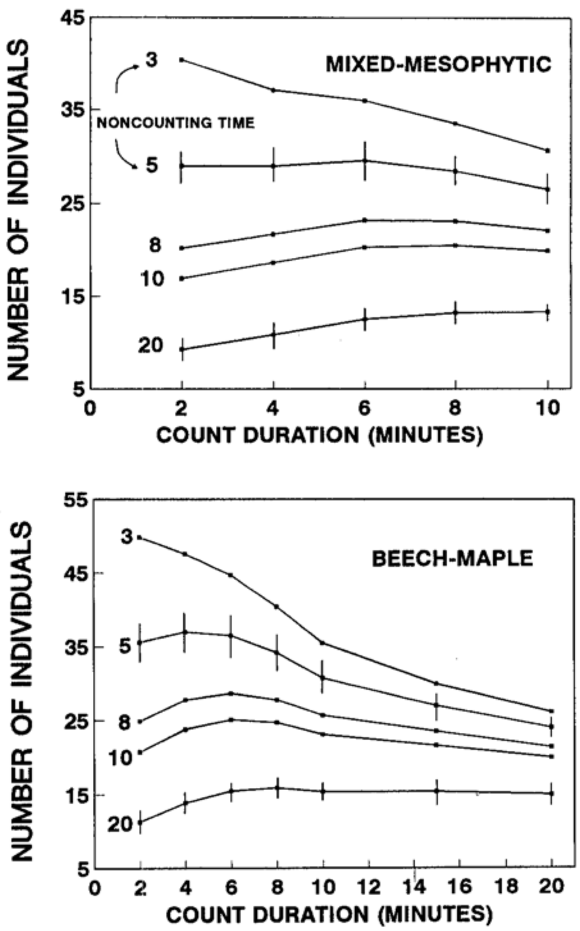

Figure 2--The expected mean number of individuals detected per hour of effort for different counting times as a function of different noncounting times (indicated by numbers next to curves within the graph) in mixed-mesophytic (top) and beech-maple (bottom) forests (see Methods: Equation 1). Vertical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

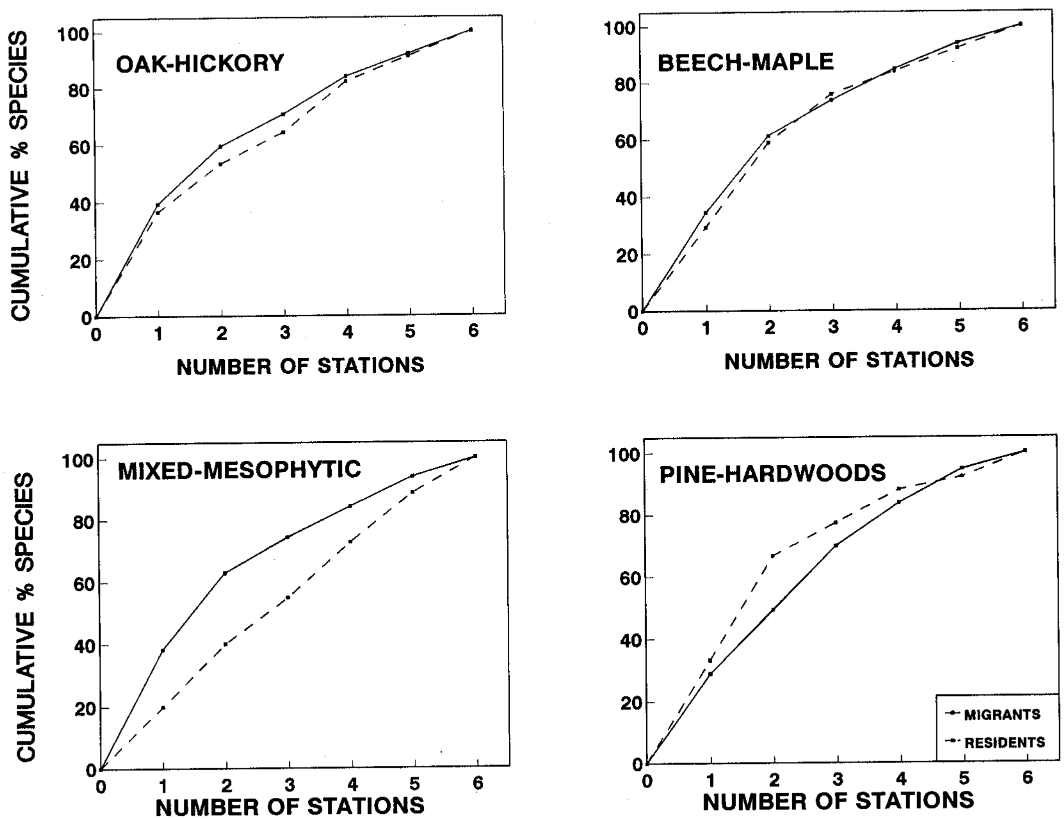

Figure 3--Effect of the number of stations on cumulative (mean) percentages of migratory and resident species detected in oak-hickory (*n* = 20 sites), pine-hardwoods (*n* = 17), mixed-mesophytic (*n* = 34), and beech-maple (*n* = 18) forests. Only sites containing six stations are included.

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

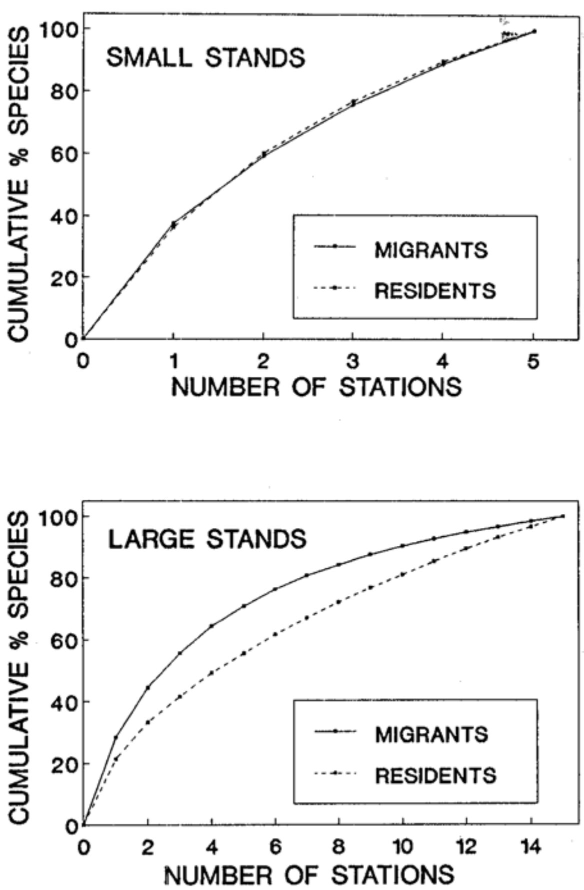

Figure 4--Effect of the number of stations on cumulative (mean) percentages of migratory and resident species detected in large (15 stations; *n* = 3) and small (5 stations; *n* = 4) stands of riparian cottonwoods. Values are based on 450 randomized draws for each station number.

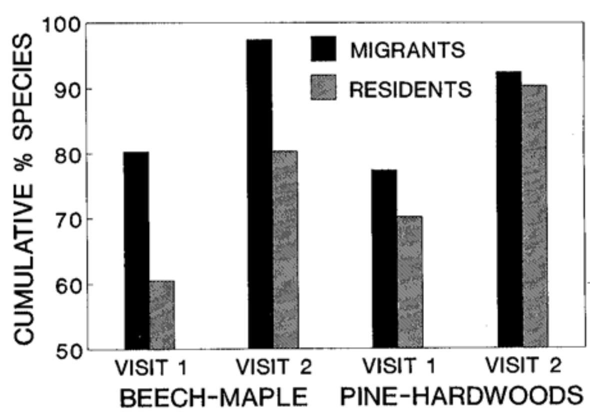

Figure 5--Cumulative (mean) percentages of migratory and resident species detected in the first two of three visits in beech-maple (*n* = 8) and pine-hardwoods (*n* = 9) forests.

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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