

Point Counts of Birds: What Are We Estimating?¹

Douglas H. Johnson²

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 counts are 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

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.

² Chief, Northern Plains Ecology Section, USDI Fish and Wildlife Service, Northern Prairie Wildlife Research Center, Jamestown, ND 58401; present position: Leader, Grasslands Ecosystem Initiative, USDI National Biological Service, Northern Prairie Science Center, Jamestown, ND 58401

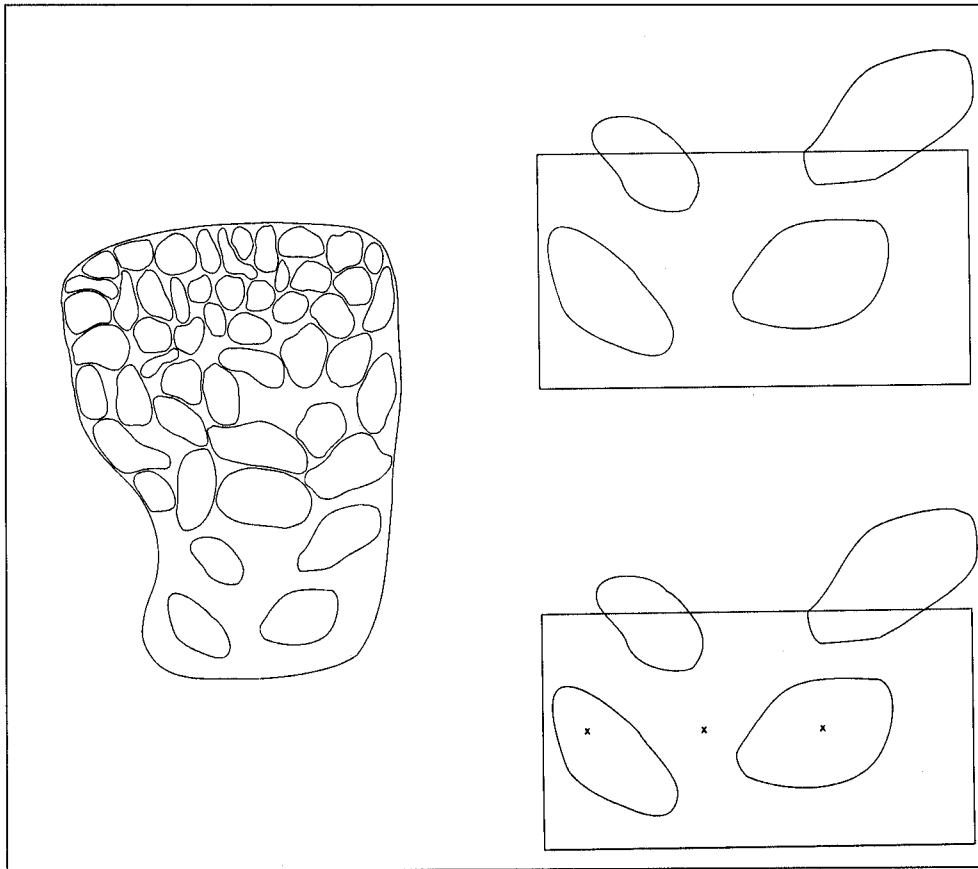


Figure 1--Left: Simplified example of a breeding range of a bird, partially filled with territories. Top right: Simplified example of a rectangular study area containing portions of four territories. Bottom right: The same study area in which three stations for point counts (located at the x's) have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

$$Y = (1-b)X + \epsilon, \tag{1}$$

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

$$\bar{Y} = (1-b)X \tag{2}$$

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

$$\begin{aligned} \text{True error} &= Y - X = (1-b)X + \varepsilon - X \\ &= -bX + \varepsilon, \end{aligned} \quad (3)$$

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:

$$Y = (1-a)X\varepsilon, \quad (4)$$

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

$$\begin{aligned} \text{True error} &= Y - X = (1-a)X\varepsilon - X \\ &= [(1-a)\varepsilon - 1]X, \end{aligned} \quad (5)$$

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

$$Y = CX, \quad (6)$$

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,

$$\text{Var}(Y) = C^2\text{Var}(X) + X^2\text{Var}(C) + \text{Var}(X)\text{Var}(C), \quad (7)$$

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

$$Y_1 - Y_2 = C_1X_1 - C_2X_2. \quad (8)$$

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

$$Y_1 - Y_2 = C_1(X_1 - X_2) + (C_1 - C_2)X_2, \quad (9)$$

or equivalently

$$Y_1 - Y_2 = C_2(X_1 - X_2) + (C_1 - C_2)X_1. \quad (10)$$

(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 $\text{Var}(C)$ 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 $\text{Var}(C)$? 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, \dots, 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:

$$z_i^L \leq z_i \leq z_i^U, \text{ for } i = 1, 2, \dots, p. \quad (11)$$

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, \dots, 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

$$Y = \sum_j \Pr\{\text{bird } j \text{ present}\}. \tag{14}$$

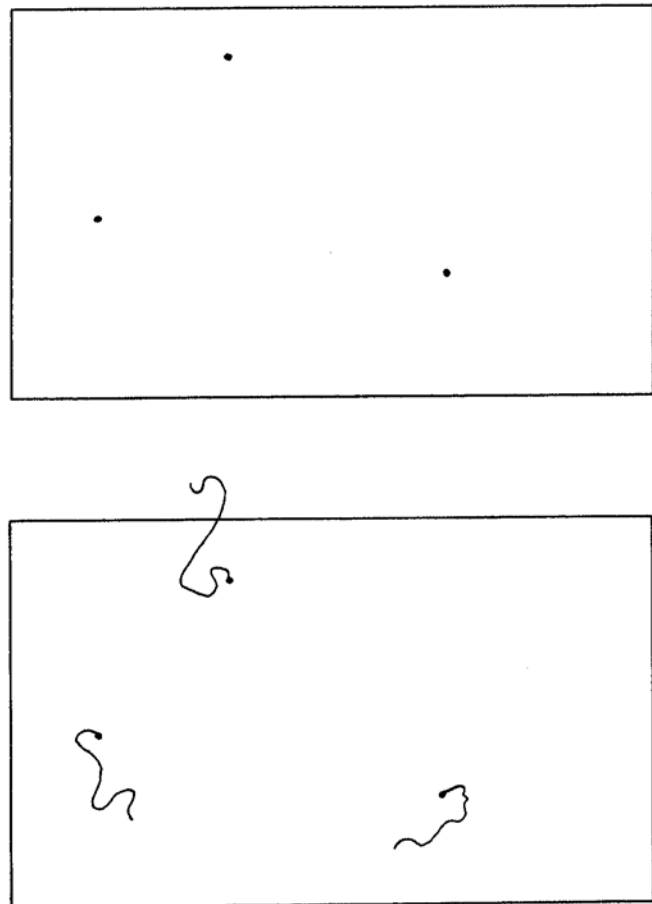


Figure 2--Top: The location of birds within the study area at one particular instant. Bottom: Hypothetical paths of birds in the study area taken during a period of time.

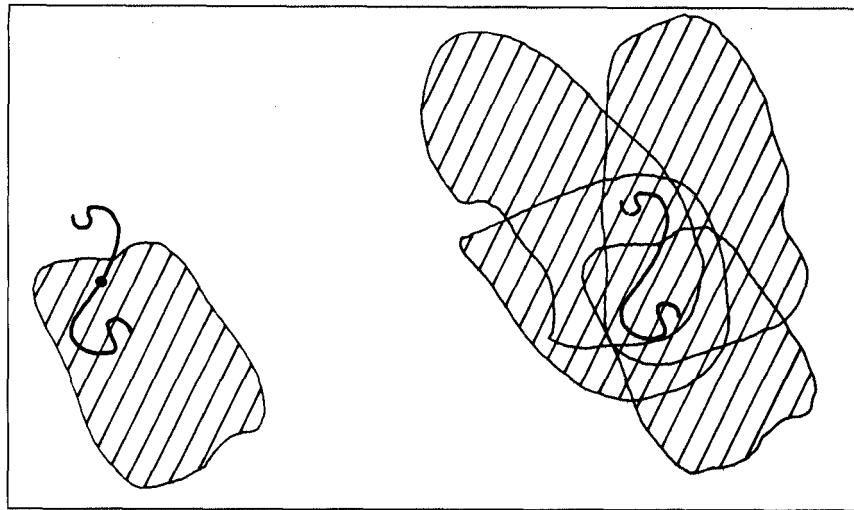


Figure 3--Left: The area in which a bird can be detected by the observer at a particular instant is called the detection zone. Right: The cumulative detection zone for a bird by an observer during the period of counting.

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 $\text{Pr}\{\text{bird } j \text{ present}\} = r_j$ 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 detectability 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

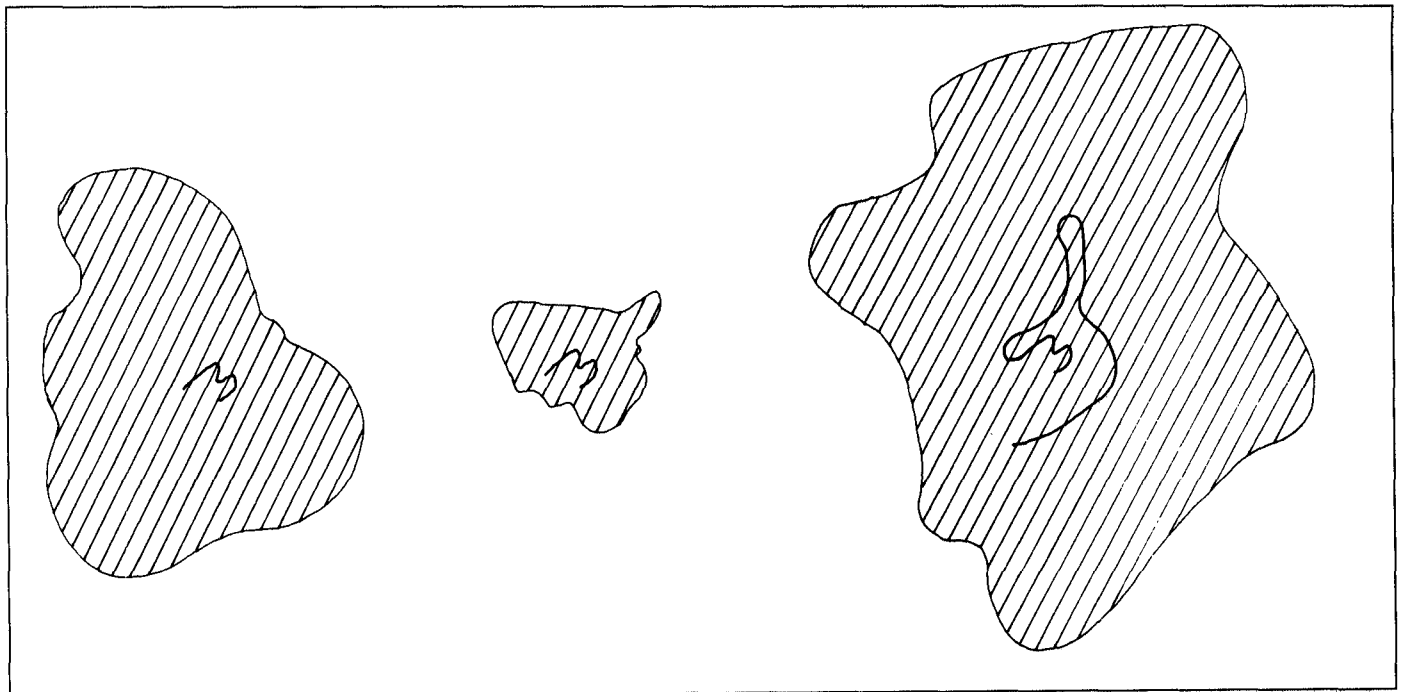


Figure 4--Cumulative detection zone of the same bird for a highly skilled observer (left) and a less-skilled observed (center). Right: Cumulative detection zone of bird increases with longer duration of counting period.

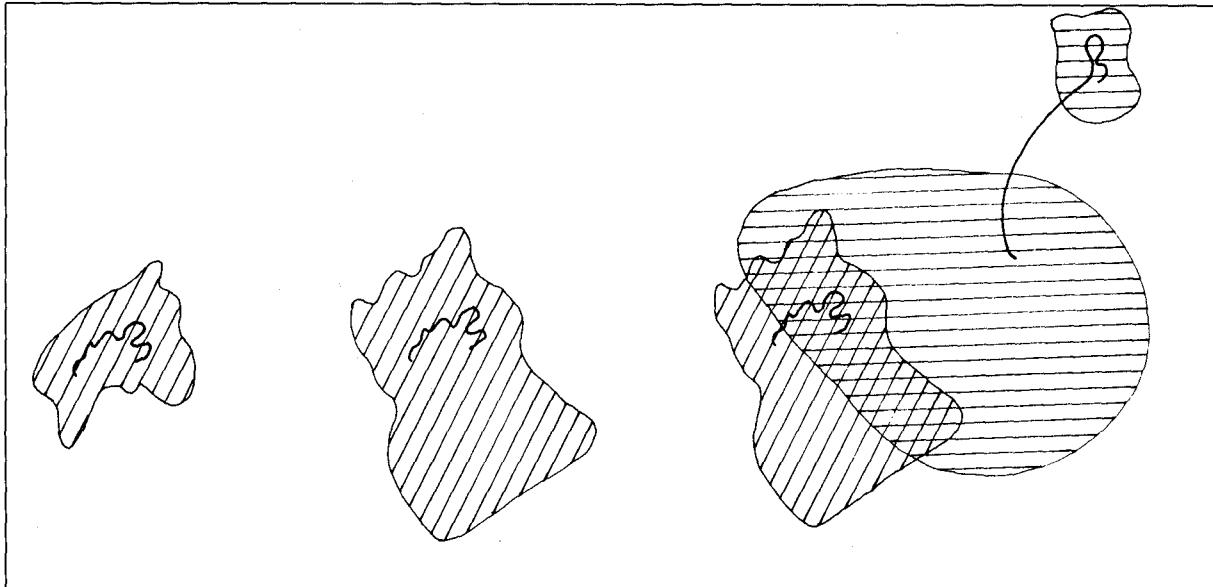


Figure 5--Cumulative detection zones can be increased from the normal (left) by using playbacks of calls or other attractors (center), but such devices may also induce birds from beyond the study area to move into it (right).

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, $\text{Var}(C)$, 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

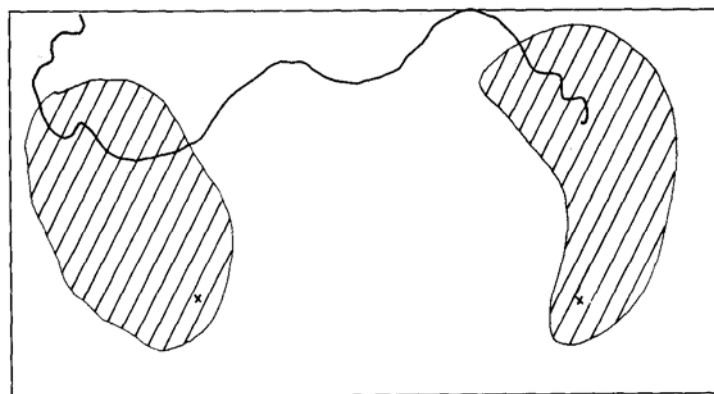


Figure 6--if stations are too close together, relative to the movement patterns of a bird, the bird may be double counted. The x's indicate stations at which the bird, whose path is shown, is counted.

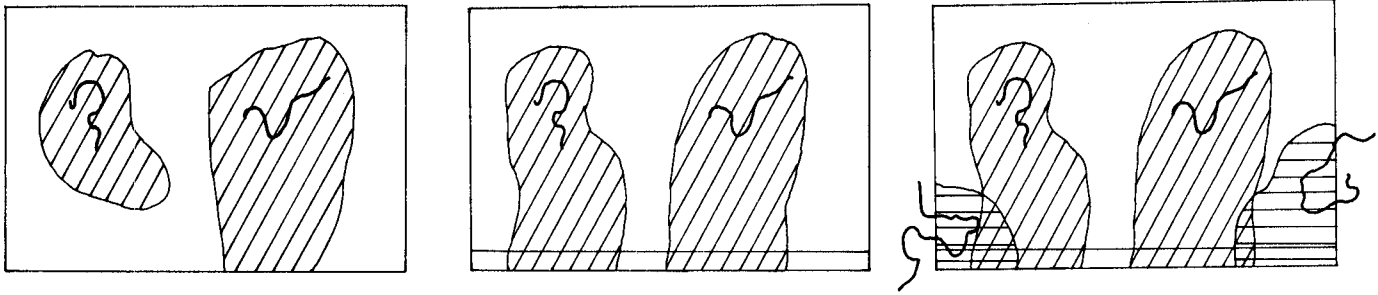


Figure 7—Compared with an area lacking roads (left), a road, indicated at the bottom of the area, may increase the count either by increasing the cumulative detection zones of birds (center) or by increasing the actual number of birds present (right), or both.

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.