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THE APPLICATION OF SONG DETECTION THRESHOLD DISTANCE TO CENSUS OPERATIONS

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ABSTRACT.—Subjective estimates of the distance to unseen singing or calling birds are a serious source of error in all detection count operations where adjustments are required for variation in species conspicuousness or where areal denominators are needed for deriving absolute density values. The problem becomes acute where estimates are independently made by several observers differing in experience and estimating skills.

In this report we propose that measurements of the detection threshold distance (DTD) of a song, the maximum distance from which the song can be heard by an experienced observer with full hearing ability, can provide more reliable estimates than the elusive and highly subjective reference standards currently in use. We also hypothesize that DTD values will prove sufficiently objective and uniform when obtained in a standard manner to permit the preparation of reference tables applicable for census work by competent observers in a variety of situations.

To test this hypothesis we measured detection threshold distances for small samples of 12 bird species in one habitat type, the deciduous forests of southern Wisconsin. Mean distances ranged from 72 m for the Blue-gray Gnatcatcher to 186 m for the Wood Thrush. Coefficients of variation from the means for the various species ranged from 8.9 to 25.4%.

In a separate test we examined variation between observers. For this we played taped songs of 11 species at approximately natural volume levels and recorded the maximum distance at which they could be detected by 14 experienced observers with full normal hearing and four observers with variously deficient hearing. The field performance of these observers was then matched with their hearing performance in standard audiology tests in the laboratory and correlations sought for those with full and deficient hearing.

Environmental and observer variables affecting the distance to which songs can be heard are discussed. Some advantages and limitations of the proposed application to census operations are considered.

The songs of most birds are species-characteristic in features of pitch, song quality and pattern, and, when delivered on the home territory in the breeding season, usually also in intensity. Intensity varies greatly between species, however, and where songs are used in census work the distance at which a species can be heard will profoundly affect the area the observer covers and the number of birds he records. Recognizing this principle, and acutely aware of the crudeness of subjective estimates of distance to unseen birds, we attempted to test the hypothesis that the detection threshold distance of specific songs is uniform enough under specified field conditions to provide a reasonably reliable and objective base for calculating areas of coverage in census operations.

We felt that if the hypothesis were supported in a sample of species in one habitat type, and if the concept proved feasible under working field conditions, the sample could be extended to other species, other habitats, and other conditions to produce a body of data for constructing reference tables widely applicable in census operations. Detection threshold distances (DTDs) presented in these table and translated to detection areas (DAs) could then be applied directly as the denominators for the tallies of singing birds detected along a census route. Observers would be free of the onus of distance estimating and able to apply their full attention to detecting.

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The procedure as outlined in the following pages is formulated for singing males during the breeding (singing) season, and the density values obtained would be for songs and therefore still subject to adjustments for song frequency and sex ratio before translation into bird densities (Emlen 1977). The technique could conceivably be applied with appropriate modifications to other aural cues for census operations and in other seasons.

THE MODEL

Sound attenuates with distance according to definite physical laws, but the detection of a low-intensity or distant sound is an all-or-nothing phenomenon. Therefore, as in an audiologist's test for intensity thresholds of human hearing performance, all sounds in nature should, at least theoretically, be detected when they are above a critical threshold intensity or within a critical threshold distance, and go undetected when they are below that intensity or beyond that distance. Thus, in contrast to the gradual and continuous decline in detections postulated in earlier models, the curves of detection densities should, we believe, be level to the threshold distance and then drop precipitously (Curve a, Fig. 1). The gradual decline recorded in most field studies using strip-transect counts (Curve b, Fig. 1) are, we suggest, due to a combination of three factors: (1) the larger proportion of visual and call-note cues at short range in counts recording all detections, (2) the shorter time that the birds near the outer bounds of detectability

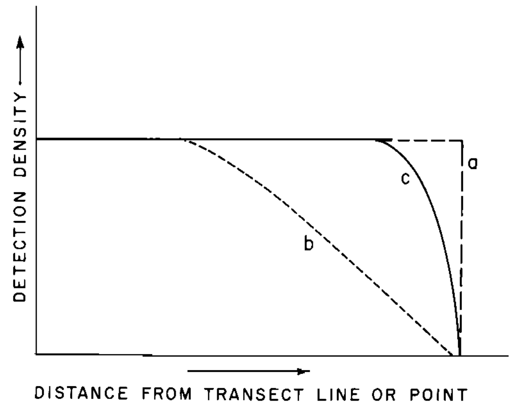

FIGURE 1. Curves of declining detection-density with increasing distance from the observer: (**a**) Theoretical pattern based on physical principles predicting an abrupt drop at the detection threshold point; (**b**) Characteristic sloping curve recorded in field studies based on subjective estimates of visual or aural detection distances; (**c**) Hypothetical curve based on the theoretical square pattern (a), rounded as a result of the environmental and acoustical variables characteristic of natural situations.

(Zone C in Figure 2) are within detection distance of the observer as he advances along the center line of the strip, and (3) the unreliability of subjective estimates of distance where the birds are no longer visible or readily locatable. We suspect that the actual pattern of decline for song cues in natural settings will depart from the square form and assume a rounded form (Curve c, Fig. 1) as a result of variations in habitat uniformity, song perch location and orientation, and factors associated with variable sound deterioration and background noise. These considerations are the subject of a further study by the authors.

MEASURING DETECTION THRESHOLDS

The distance at which a bird song becomes inaudible in a natural setting would be very difficult to calculate from physical parameters since it is subject to many complex and fluctuating variables in sound structure, transmission, and reception. It can, however, be measured empirically, and the variance in a set of measurements for a given species in a specified habitat under uniform conditions may be relatively small.

To test the prediction of reasonably small variances and the feasibility of reference tables for census operations, we measured the threshold distances for a series of common song birds in closed-canopy, deciduous forest habitats in southern Wisconsin. Two procedures were used: (1) measurements of the DTDs of "live" songs and calls by a single observer under standard conditions, and (2) measurements of the DTDs of standardized taped songs by a series of observers under a variety of conditions.

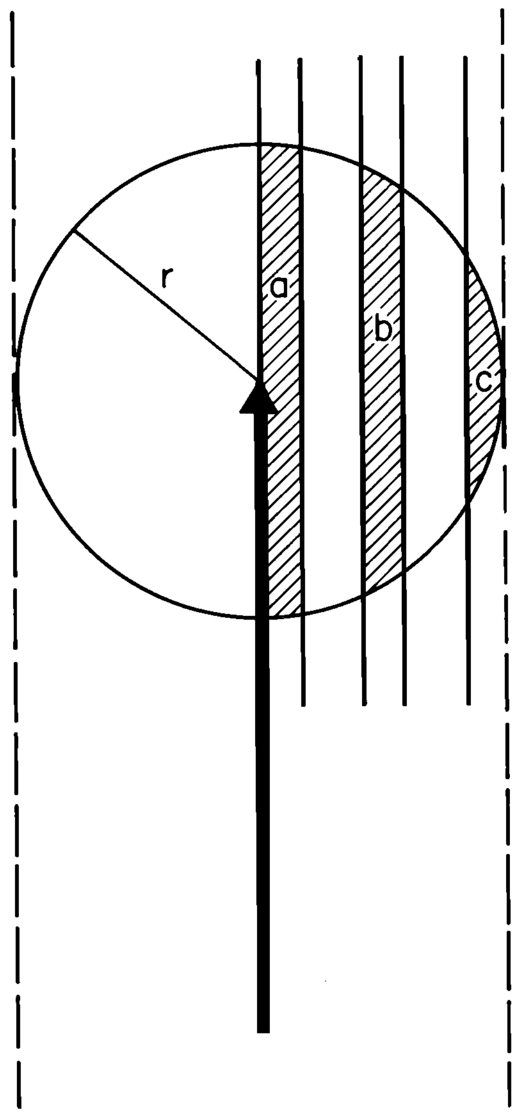

FIGURE 2. The length of time a bird is detectable within the area of detectability (circle) of an observer (arrow head) as he advances along a census trail declines rapidly in the peripheral zones (C) of a transect strip according to simple laws of geometry.

For the measurements of live songs the authors moved through the forest, separated ≥50 m, until one of us located a bird in full song. Communicating by portable two-way radios we then moved apart, one to the singing bird's location, the other (with demonstrated full hearing ability) away from the bird until the song could no longer be heard. While the first observer kept watch of the movements and activity of the bird and communicated these over the radio, the second moved back and forth to establish points where the

TABLE 1
DETECTION THRESHOLD DISTANCES[a] IN METERS FOR COMMON SONGBIRD SPECIES IN SOUTHERN WISCONSIN DECIDUOUS FORESTS[b]

Species	Observations (n)	Mean ($\bar{x}$)	SD	C.V.
Great Crested Flycatcher (*Myiarchus crinitus*)	6	98	15.4	15.7
Eastern Wood Pewee (*Contopus virens*)	14	124	23.1	18.6
White-breasted Nuthatch (*Sitta carolinensis*)	9	106	26.9	25.4
House Wren (*Troglodytes aedon*)	11	146	21.8	14.9
Gray Catbird (*Dumetella carolinensis*)	13	113	25.6	22.7
American Robin (*Turdus migratorius*)	7	150	21.3	14.2
Wood Thrush (*Hylocichla mustelina*)	7	186	16.5	8.9
Blue-gray Gnatcatcher (*Polioptila caerulea*)	6	72	6.4	8.9
Red-eyed Vireo (*Vireo olivaceus*)	15	135	24.8	18.4
American Redstart (*Setophaga ruticilla*)	7	93	10.7	11.5
Cardinal (*Cardinalis cardinalis*)	9	185	35.0	18.9

[a] Maximum distance at which vocalization was detected by an observer (M.D.) with full normal hearing as tested from 1000 to 8000 Hz by a licensed audiologist.
[b] All data were collected under favorable conditions (see text).

song (a) could still be heard consistently though very faintly, (b) could definitely be heard but only after prolonged and intensive listening, and (c) could not be heard. One or the other of us then paced the distance between the bird and the middle (b) point, also recording the height of the singer, a subjective appraisal of the foliage density between the bird and observer (from 0 to ++++) and a notation concerning any masking or interfering background noises of potential significance. All measurements were made during morning hours in July 1979 and 1980 under favorable conditions of light wind and low traffic noise.

In our tests with taped songs we placed an Electrovoice Sonocaster 1 speaker 5 m above the ground at the end of a 310 m long transect in a large tract of level and relatively uniform deciduous forest. A second speaker was placed 40 m in front of the first speaker (see Fig. 3). Each speaker used a separate but identical Kudelski DH amplifier and a Uher 4400 tape player with an operating speed of 38 cm/sec. The volume controls were set to give detection threshold distances for each test species roughly matching those already obtained from the measurements on living birds.

Fourteen experienced field ornithologists with full normal hearing to 8000 Hz and four with variously deficient hearing (tested by a licensed audiologist at the University of Wisconsin Hospital), were deployed successively at 26 listening stations spaced at 10 m intervals along the line. Each observer started at the farthest station and moved towards the speakers on signal, listening attentively for 10 minutes at each station and recording all the songs he could detect, live or taped. The taped songs, representing 11 familiar local species, were played in irregular sequences (so as to prevent anticipation of specific songs) and alternately from the two speakers (so as to counter any expectation the songs once detected at a distant station would be heard at all closer stations). The exact time of detection for each song was recorded by the observer and these times matched against the playing

TABLE 2
DETECTION THRESHOLD DISTANCES (MEAN, IN M, AND COEFFICIENT OF VARIATION AMONG OBSERVERS) OF TAPED SONG PLAYBACKS IN A CLOSED-CANOPY DECIDUOUS FOREST AT FOUR WIND SPEEDS (BACKGROUND WIND NOISE) AS RECORDED BY 14 OBSERVERS WITH FULL NORMAL HEARING

Date (1979) Wind speed No. observers	August 30 0.0–2.7 m/s 3		September 8 2.2–3.6 m/s 7		August 31 3.6–6.7 m/s 4		September 1 5.4–9.4 m/s 3		
	Mean	C.V.	Mean	C.V.	Mean	C.V.	Mean	C.V.	Mean C.V.
Crested Flyc.	180	11.1	149	20.7	110	22.3	77	19.9	18.5
Wood Pewee	190	13.9	174	3.1	138	3.6	123	20.4	10.3
W. B. Nuthatch	180	11.1	163	11.4	123	18.2	97	6.0	11.7
House Wren	190	10.5	190	13.2	143	3.5	153	13.6	10.2
Catbird	107	19.5	120	22.6	78	19.2	50	34.6	24.0
Robin	180	16.7	170	18.6	135	4.3	83	25.0	16.2
Wood Thrush	253	2.3	227	7.9	240	4.2	190	9.1	5.9
B. G. Gnatcatcher	63	48.2	77	22.1	80	17.7	50	34.6	30.7
R. E. Vireo	177	3.3	179	6.0	130	16.6	113	13.5	9.9
Redstart	120	22.0	128	15.2	88	5.7	90	0.0	10.7
Cardinal	267	10.8	244	11.0	225	10.6	213	2.7	8.8

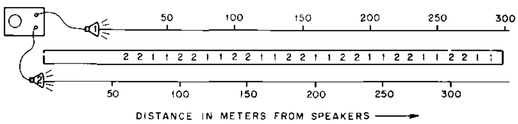

FIGURE 3. Arrangement of speakers and listening stations for the observer variability tests. Observers moved towards the speakers (right to left) listening for 10 minutes at each station while all 11 taped songs were played. The number at the station indicator shows which speaker was being used at the time. See text for more explanation.

time for confirmation that the recorded detections actually reflected a playing. All tests were run on clear mornings in August and September 1979, when the confusion created by natural song activity had subsided. Wind speeds and a subjective appraisal of distant traffic noises were recorded on each test day for correlation with observer hearing performance. The sound pressure level (SPL) of taped songs and background noise were measured at the test site under similar conditions in September 1980 using a General Radio Company Sound-Level Meter Type 1551-C.

RESULTS

Mean detection threshold distances for the 11 species tested directly ranged from 72 m for the high, thin lisping song of the Blue-gray Gnatcatcher to 186 m for the rich and varied song of the Wood Thrush (Table 1). The magnitude of the coefficients of variation (from 8.9 to 25.4%) in this series undoubtedly reflects in part the small sample sizes and the masking effects of variable background noise. Few clues were obtained concerning individual variation in song intensity within a species although some variation is suspected in several species, notably the Catbird and the Cardinal where one bird gave DTD readings consistently one-third less than the mean for the others.

The tests using playbacks of taped songs were conducted in order to analyze observer and environmental variables under standard sound intensity, and these detection-distance values consequently have no significance for further use as 'live' DTD values. Mean coefficients of variation for the 11 species in this series (based on 14 observers with full normal hearing acuity on 4 days with tree-top wind speeds <10 m/sec) ranged from 5.9 to 30.7% and averaged 15.8% (Table 2).

The hearing deficiencies revealed in the audiologist's test for four observers correlated with reduced field performance. The deficiency in one representative observer, classified by the audiologist as having "mild to moderate losses in high-frequency ranges characteristic of persons in their 60s and 70s but not appreciably affecting hearing in the human speech range" was reflected in DTD reductions of about 10% for the low-frequency song of the Cardinal and Wood Thrush, about 45% for the middle-frequency songs of the pewee and catbird, and about 75% for the high-frequency song of the gnatcatcher.

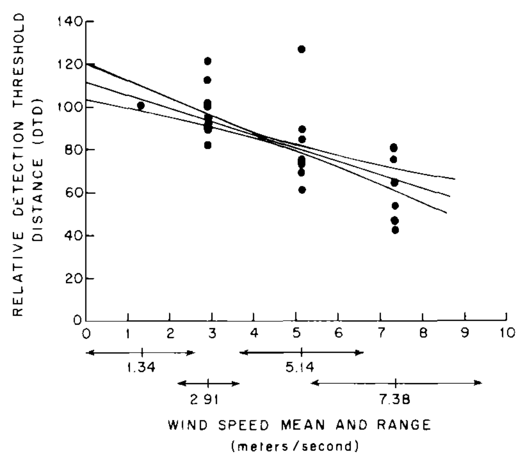

FIGURE 4. Masking effect of wind noise on detection threshold distance in deciduous forests. Data points represent mean DTD values for each of the 11 bird species on each of four days as recorded by the 14 observers with full normal hearing. Species DTD values for the windy days are relativized to the mean DTD for that species on the calmest day, thus all 11 species are located at the same point (100%) for the calmest day. The regression value (r) is -0.749 and the outer lines are 95% confidence limit boundaries.

Wind noise in the tree foliage had an appreciable effect on DTD values (Table 2). A regression analysis of average wind speeds against the mean DTDs for each species on the four test days revealed a significant negative value of -0.749 (Fig. 4).

VARIABLES AND THEIR CONTROL

The distance at which a bird song can be detected on a census count is subject to at least three major types of observer variables and three of environmental variables, all of which must be controlled as much as possible by restricting operations to specified situations or by applying appropriate adjustment factors.

Hearing acuity.—Observer variables associated with hearing deficiencies necessitate limiting participation in census work to observers proven to have full hearing acuity (detection at 20 dB or less in best ear in standard audiogram tests, Davis and Silverman 1960) at all frequency levels from 1000 to 8000 Hz. Exceptions to this rule may be made for skilled observers with

TABLE 3
PROCEDURE FOR CALCULATING ABSOLUTE DENSITIES FROM PREDETERMINED DTD VALUES IN A SAMPLE (HYPOTHETICAL) BIRD COMMUNITY CENSUSED BY THE TRANSECT COUNT METHOD[a]

				Density		
Species	DTD[b] (m)	DA[c] (ha)	Birds[d] heard	Heard[e] per km²	♂♂[f] per km²	Birds[g] per km²
Eastern Wood Pewee—song	124 ± 23	77±	5	6.5	13.0	26
Black-capped chickadee—call	87 ± 24	56±	10	17.8	35.6	36
House Wren—song	146 ± 22	102±	10	9.8	19.6	39
Gray Catbird—song	113 ± 28	63±	10	15.9	31.8	64
Wood Thrush—song	186 ± 17	122±	5	4.1	8.2	16
Blue-gray Gnatcatcher—song	72 ± 6	51±	5	9.8	19.6	39
Red-eyed Vireo—song	135 ± 25	87±	10	11.5	23.0	46
American Redstart—song	93 ± 11	65±	10	15.4	30.8	62
Cardinal—song	185 ± 38	146±	10	6.8	13.6	27

[a] For communities censused by the point method, the DA (detection area) is $\pi \times DTD^2 \times$ number of points on the census.
[b] DTD values taken from Table 1.
[c] Detection area (km²) covered in 3 km of transect (2 DTD × 3,000/10,000).
[d] Number of songs heard on census (hypothetical).
[e] Density (songs heard per km²).
[f] Density of males, adjusted for singing frequency (these values are for species in which only males sing and assume that 50% are singing or calling when the observer is within hearing range).
[g] Density of birds, adjusted for equal sex ratio.

slight deficiencies if appropriate adjustments are applied. The audiogram test should be taken two or more times in order to get a mean hearing level at each frequency since these can vary by 5 or more dB between successive tests (Peterson and Gross 1974). Censuses should not be undertaken when an observer is suffering temporary hearing impairment as with a bad cold.

Familiarity with songs and calls.—Familiarity with all of the songs anticipated in the census area is a prime requirement for participation in census work. A skilled observer can detect and identify small fragments of a threshold level song that a less experienced person might not even recognize as a bird sound. In the absence of recognized standards, the general and local experience of each participant in a census should be recorded.

Attentiveness.—Attentiveness is an elusive variable that can influence the performance of any census taker and can be controlled only by self-discipline. In our experience observers must always work alone in order to continuously apply full attention to the job at hand. To reduce distractions observers may wish to close their eyes at listening stations. Fatigue or physical discomfort should be minimized; three to five hours of full attentiveness on a census route is apparently close to the maximum for most observers.

Inability to fully control attentiveness probably accounts for the nonmatching performance commonly experienced when two or more competent observers work concurrently but independently along the same census route (cf. Lack 1976, Preston 1979). This psychological phenomenon of liminal and subliminal detection is presumably related to consciousness levels and will continue to elude clear definition or effective control.

Habitat structure.—The effects of habitat structure are reasonably predictable and therefore controllable. While every site is ultimately unique, a limited number of habitat types with similar sound-transmitting properties may be recognized, and separate reference tables of DTD values, such as the one presented in this paper for closed-canopy deciduous forests in summer (Table 3), must be constructed for each.

The position of a singing bird with respect to height above the ground and perch exposure can affect the attenuation of the signal and hence the distance to which it can be detected although its effect does not seem to be a severe problem for deciduous forests in the summer (Morton 1975, Martin and Marler 1977).

Meteorological conditions.—Temperature, relative humidity, fog, and particularly wind can influence the propagation characteristics of sound waves through a habitat and hence the distance at which songs can be detected. Theoretical considerations suggest that all of these should be standardized as much as possible by limiting operations to days when conditions are favorable (moderate) and similar. Standardizing operations with relations to time of day is one way to minimize these variables. Wind direction can profoundly affect DTD values in open habitat, but under a forest canopy its effects were negligible at tree top wind speeds of 5 or even

10 m/s. The effect of wind as a producer of background noise is discussed below.

Background noise.—Background or masking noise is a common and important variable in bird census work. Much of it is uncontrollable except by avoidance, and censuses should be attempted only when and where the background noise level is within acceptable limits of less than about 60 dB (20–20,000 Hz flat response). This requirement essentially eliminates census operations near highways, livestock concentrations or noisy machinery, or on days with appreciable falling rain or with tree-top winds in excess of about 10 m/s (22 mph).

The human ear and brain can, of course, discriminate and identify bird sounds at intensities far below background white noise levels, but discrimination, as with colors in vision, depends on contrast, and the nature (frequency structure) of background noises will have selective effects in masking different bird sound frequencies.

At tree-top winds between 3 and 10 m/s the masking effect of the noise in the foliage (essentially equal intensity between 50 and 6300 Hz) is predictable, and adjustments can be made for its effect on observer performance. Figure 4 shows that performance did not decline significantly on days with wind speeds less than 3 m/s but declined 20% on the days with winds about 5 m/s, and 35% on the day with winds ca. 7 m/s. Figure 5 compares the mean DTD values for all days after adjustments for the windy days were made (lower value) with the values obtained on the two calm days. It is clear that the two values are quite close for each species except that the adjusted values tend to be too large for birds normally detectable at long distances, and slightly too small for birds normally detectable at relatively short distances. This indicates that species detectable at relatively long distances are not masked by wind noise to so great an extent as species normally detectable only at shorter ranges. It may thus be necessary to apply species-specific adjustments for wind noise in DTD reference tables.

CONCLUSIONS AND CAVEATS

The major advantages for using the distance-carrying properties of a bird's song as the indicator of area of coverage in transect census operations lie in the simplicity, directness, and potential for standardization of the procedure. With this method the count of each species along a transect route or at a series of points is simply divided by the area of coverage obtained from a reference table to give a density in singing birds per unit of survey area (Table 3). The values in the reference table will provide a common base for all census-takers who, following standardized instructions, would only have to count the birds they detect, and record the length of their transect or the number of their observation points. Problems of bird movements across inner belt or circle boundaries would be eliminated, and no detections would be excluded from the record by arbitrary boundary lines.

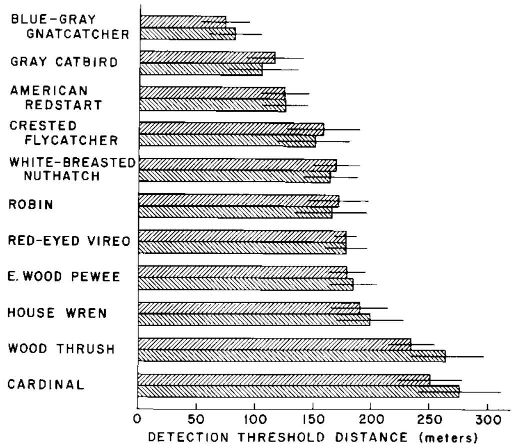

FIGURE 5. Effect of DTD value adjustments on taped songs for windy days. For each bird species, the lower value is the mean distance (meters) adjusted for windy days, while the upper value is the mean distance for only the two calm days. In each case the range of ± one standard deviation is indicated by the solid line.

While the potential of a DTD method is considerable, a number of caveats must be voiced. First, the validity of the DTD method rests on three inadequately tested assumptions: (1) that the distance-carrying properties of a bird are species-characteristic, i.e., do not vary appreciably within and between individuals; (2) that habitats can be categorized into a reasonable number of types with respect to sound transmission properties; and (3) the observers with similar hearing acuity, experience and self-discipline are, indeed, similar in performance. Secondly, application would be restricted to reasonably flat and regular terrain and, as far as we now know, to song cues. If total birds per unit area is desired, adjustments must thus be made for the concurrent singing rate (incidence per unit of time) of each species (Emlen 1977a) and for sex ratios in species where only one sex sings. These are unsolved problems lying beyond the scope of this paper. Finally, the potential effectiveness of the method is restricted by two intrinsic features of the model; for strip counts by the reduced detection coverage near the lateral strip boundaries (see Fig. 2), and for circle counts by the proportionately greater area of the outer boundary zone with its large detectability variables. More research is needed to evaluate and resolve these complications.

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