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A METHOD TO ANALYZE AND COMPENSATE FOR TIME-OF-DAY EFFECTS ON BIRD COUNTS

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Abstract.—Variations in activity levels and behavior throughout the day often cause changes in the detectability of bird species, which may result in a time-of-day effect that biases the results of counts. Using a methodology based on moving averages it is possible to generate, from count data, a curve portraying these changes in detectability; the curve can then be used to compensate for the time-of-day effect in the results of the counts. Using the computer program TIMEOUT, this method was successfully applied to real data.

MÉTODO PARA ANALIZAR Y COMPENSAR POR LA HORA DEL DÍA EN QUE SE HACEN CENSOS DE AVES

Sinopsis.—Variaciones en los niveles de actividades y cambios en conducta a través del día pueden causar cambios en la detectabilidad de especies de aves y por ende introducir sesgo en los resultados de censos. Utilizando una metodología basada en promedios movibles es posible generar, de los datos de censos, una curva que muestre estos cambios en detectabilidad. Esta curva luego puede utilizarse para compensar los efectos de la hora del día a la cual se efectúan los censos. Utilizando el programa de computadora TIMEOUT, se pudo aplicar el método con mucho éxito a datos reales.

Knowledge of the abundance of bird species is an essential component in a wide range of ecological studies. In many situations it is not cost effective to census all individuals in the studied area, so it is often necessary to resort to methods that yield indices of abundance, which may, in some instances, be converted to density values. Counts, along transects or at fixed stations, are the basis of many of these methods.

The conspicuousness of many species varies throughout the day owing to changes in activity levels or to other behavioral traits. This change often introduces an important bias in the results of counts done at different times of the day (Rollfinke and Yahner 1990, Shields 1977, Skirvin 1981). To minimize the time-of-day effect, observers often limit counts to certain periods of the day during which detectability is high and assumed to be constant. For passerine birds, for example, counts are most often done during the first hours after sunrise (e.g., Blondel et al. 1970, Slagsvold 1973). Counts often include several species, however, and the periods of highest detectability may not be the same for all of them (Järvinen et al. 1977, Robbins 1981). In some communities better estimates of species richness are obtained by sampling over a period of several hours than by using the same sampling effort over a more restricted period (Verner and Ritter 1986). Furthermore, shortening the period of the day during which counts are done can be a serious constraint on the number of stations sampled in the time available (Verner and Ritter 1986).

The results of counts of a species done in different periods of the day can be corrected, if the pattern of change in detectability is known. When this parameter varies linearly with time, a simple linear regression can produce the needed correction factors. This approach, however, is not applicable unless the relationship is linear. Hill et al. (1985) successfully fitted polynomials to curvilinear declines of observed kangaroo densities as the time from sunrise or sunset increased. Their models correctly portrayed the changes in detectability in the studied species and allowed for the estimation of correction factors. Algebraic equations are practical, however, only when the curve portraying the pattern of change is relatively simple. Although this is often the case, there is a need for a method to build detectability curves without the constraints of algebraic expressions.

This paper describes and discusses a new methodology, based on moving averages, to generate a curve portraying the pattern of change in detectability with time-of-day. This curve can be used to estimate correction coefficients to compensate for the time-of-day effect in counts. The methods described here are computationally similar to the techniques used to smooth scatterplots (e.g., Cleveland 1979).

METHODS

The proposed method is illustrated using the results of circular-plot counts (e.g., Reynolds et al. 1980), a commonly used technique to estimate bird abundances. The study site was in southern Portugal, near the Sado estuary, and all the data were collected during the breeding season, from late April to early June. Eight non-overlapping stations located in a fairly homogeneous cork oak (*Quercus suber*) parkland were used. Two hundred and fourteen 10-min long circular-plot counts were obtained by sampling each station about 25 times at different times of the day, from 0600 to 1400 hours. Counting stopped at this time due to logistic reasons. In each count the number of singing males of Short-toed Treecreepers (*Certhia brachydactyla*), detected within 100 m from a fixed observer, was recorded. It was found that almost all males singing within this radius were detected. As the same habitat patch is repeatedly sampled, any differences in the number of individuals detected at various times of the day are certainly the result of changes in detectability, rather than differences in density.

DESCRIPTION OF THE PROPOSED METHOD

Generating the detectability curve.—The results of the above described counts are shown in Figure 1. The number of individuals counted at each station is, on average, proportional to the detectability at the time of the sampling, so the trends in numbers of birds observed throughout the study period reflect changes in detectability.

To portray these changes in detectability, it is possible simply to divide

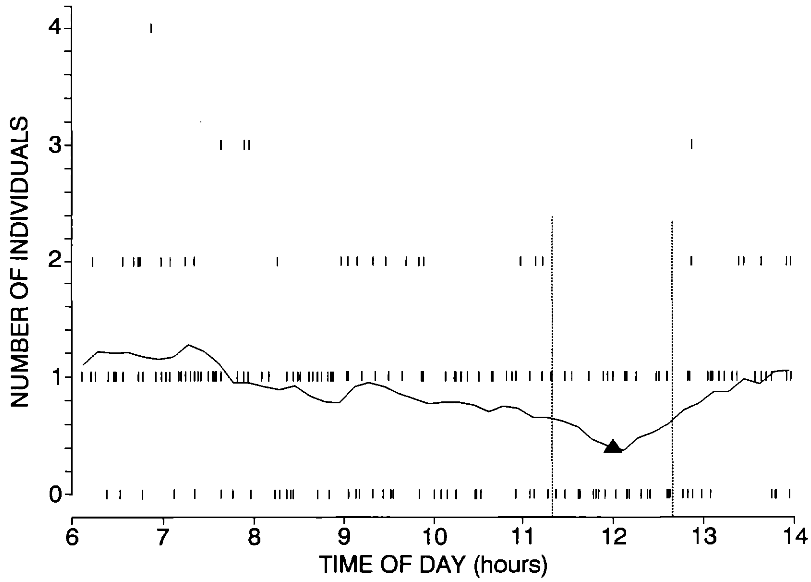

FIGURE 1. Results of counts of the Short-toed Treecreeper done at different times throughout an area of homogeneous density (small vertical lines), and moving average of these counts (irregular line). The dotted lines delimit the window used to estimated the value of the moving average of 1200 hours (triangle).

the time into intervals, and then construct a histogram of the average number of individuals counted in the stations within each time interval. This approach would, however, produce rough results because in a histogram, even if the data are regularly or randomly spaced, the height of a bar is actually unbiased only for its central value, with the bias growing with increasing departures from that value. Narrowing the time interval represented by each bar would eventually pose the problem of too few counting stations falling within each interval.

More accurate results can be obtained using moving averages to determine the detectability level at each point in time. Using this procedure, the detectability level at 1200 hours (triangle in Fig. 1) is, using an 80-min window centered at this time, proportional to the average of the results of the counts done between 1120 and 1240 hours. Repeating this procedure for many points in time, a line depicting the changes in detectability is obtained (Figs. 1 and 2). This line can be rescaled by assigning the value 1 to the mean number of birds detected during the period of highest detectability, thus obtaining a convenient detectability index (Fig. 2). In this example each sample was the number of birds observed in a sample station, but it could also have been any index of abundance.

To generate the detectability curve of Figure 2, the data were scanned with a window with a fixed time width of 80 min, which included a

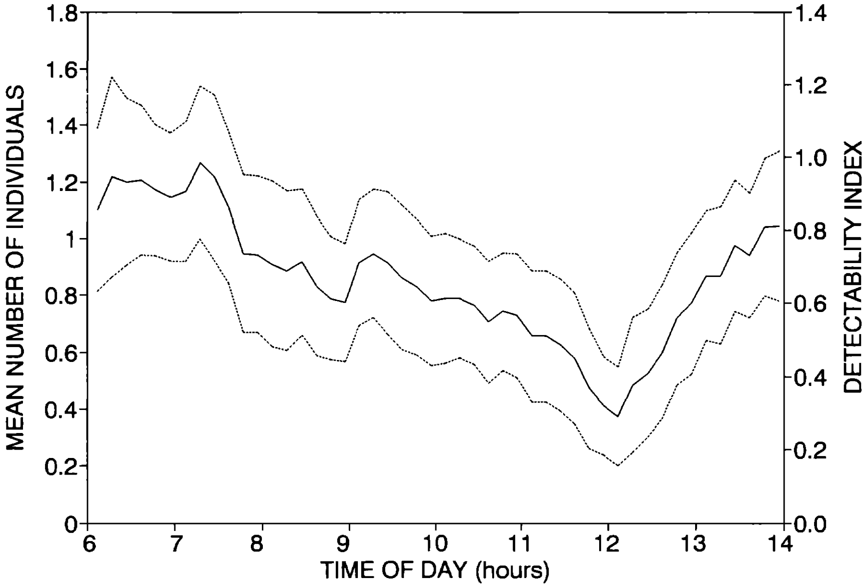

FIGURE 2. Line representing the moving average of the count results, rescaled to make the highest recorded value equal to one, thus providing an index of detectability varying between zero and one. The dotted lines delimit the approximate 95% confidence region.

variable number of stations. An alternative approach is to use a window with a variable time width but comprising a fixed number of sampling stations. In the examples above the estimated detectability value is a function of the arithmetic mean of the results of the counts that fall within the window. It is also possible, however, to use the mean weighted by the time distance between the center of the window and the time at which each station was sampled. For example, to estimate the detectability at 1000 hours a station sampled at 1005 hours would be weighted more heavily than one sampled at 1015 hours.

The general procedure suggested to set an approximate confidence region around a detectability curve based on the arithmetic mean of observations, is to calculate confidence limits for many points along the curve

$$\bar{x} - 2(s^2/N)^{1/2} < \mu < \bar{x} + 2(s^2/N)^{1/2},$$

where N is the number of stations in the window, s^2 is the sample variance, $\bar{x}$ is the sample mean, and μ the parametric mean (Clarke 1980). When samples are large enough, this approach is valid even if the count values are not normally distributed, because the means of these counts will themselves follow an approximately normal distribution (Clarke 1980). To illustrate this method, it was used to estimate an approximate confidence region for the curve in Figure 2, although in this instance it may

TABLE 1. Example of the calculations involved in the correction of abundance estimates.

Time of count	Birds counted	Detectability	Corrected counts
1023 hours	1	0.77	1.3
1113 hours	1	0.66	1.5
1137 hours	0	0.69	0
1155 hours	0	0.41	0
1211 hours	0	0.43	0
1231 hours	1	0.56	1.8
	$\Sigma = 3$[1]		$\Sigma = 4.6$[2]

[1] Uncorrected abundance estimate = 3/6 = 0.50.
[2] Corrected abundance estimate = 4.6/6 = 0.77.

somewhat underestimate the standard errors because the same sites were repeatedly sampled, which is not true in most studies. Other methods should be used for small sample sizes (e.g., Sokal and Rohlf 1981) or when applying windows using the weighted mean (Cleveland 1979).

The confidence region obtained (Fig. 2) shows that the observed changes in the detectability of the Short-toed Treecreeper are statistically significant.

Correcting for the time-of-day effect in counts.—Having generated a curve of detectability change throughout the sampling period, it is possible to estimate a correction coefficient for an abundance estimate based on any subset of the counts available, using the following procedure.

(1) Read from the rescaled curve (Fig. 2) the value of the index of detectability corresponding to the time at which each count in the subset was done. These values can also be obtained by dividing the value of the moving average for the time of the count by the highest value of the moving average.

(2) Divide each count value by the corresponding correction coefficient (the index of detectability estimated above) to obtain corrected count values.

(3) Compute the mean of the corrected count values, which is the corrected abundance in the area sampled.

The sequence above can be illustrated by estimating the corrected abundance using a small subset of the data (Table 1). In this example the corrected abundance is 54% higher than the uncorrected abundance because most of the stations included were sampled at times of low detectability. Had they been sampled at times of high detectability, the correction coefficients would be very close to 1 and the estimate of abundance after the correction would be similar to that before the correction.

An independent density estimate was obtained using the counts done in each hourly period (Fig. 3). Density was estimated by dividing the average number of males in each count by the area of the circle sampled. The results show how counts done during different hourly periods yield disparate density estimates; the estimates based on counts done between 1100 and 1300 hours are less than half of the estimate based on the counts

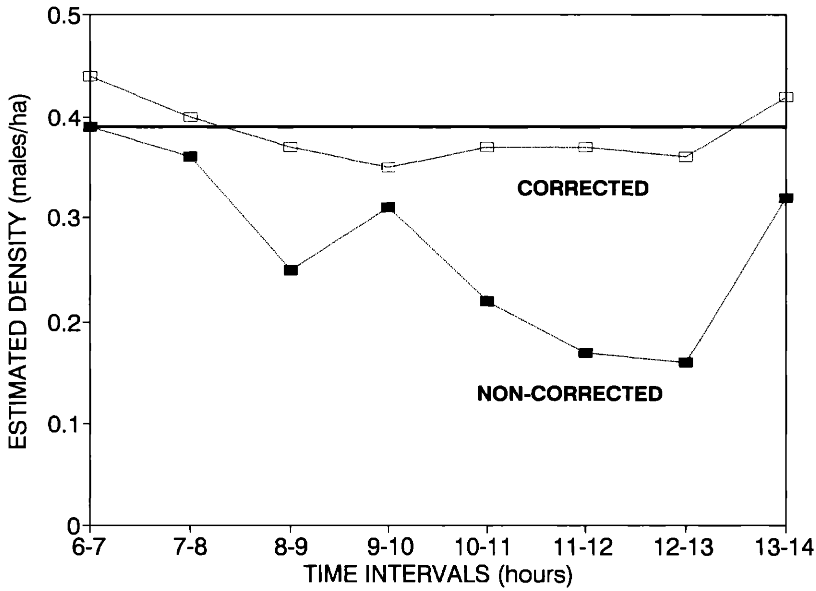

FIGURE 3. Hourly density estimates of the Short-toed Treecreeper in the same site, with and without the correction described. The horizontal line represents the density value estimated using data collected at the time of highest detectability.

done between 0600 and 0700 hours (Fig. 3). There is an important bias induced by time-of-day, which can be corrected using the generated detectability curve and the methodology described above. After this correction the hourly density estimates became similar to the estimate obtained at the time of highest detectability (Fig. 3). The time-of-day effect has therefore successfully been removed.

For sake of clarity, the effect of removing the bias caused by sampling at times of different detectability was here illustrated using density values. Although the proposed method should result in better estimates of abundance, it does not guaranty that the resulting indices can accurately be converted to density values; this will depend on the method used and on whether its assumptions are met.

DISCUSSION

Conditions under which the method is applicable.—The method described was designed for use with point and transect counts. In the first method the observer is stationary and records birds detected during a certain amount of time, most often just a few minutes. In the latter the observer moves along a transect, which may take hours. To be able to apply the method to data collected with transects lasting long periods it is desirable to record the data in subtransects. Changes in detectability are more likely to be overlooked if longer counting periods are used.

The counts used to generate the detectability curve do not have to be regularly spaced in time, and the number of counts available for different times of the day can even be different; a change in the number of available counts throughout the time used will result in changes in the accuracy of the detectability estimates, but will not bias those estimates. These properties make possible the use of most large collections of counting data to study change in detectability.

Stations from more than one region, habitat or season can be pooled to generate the same detectability curve, but only if there are no differences in their general patterns of change in detectability with time. For example, in the temperate zones, the pattern of change in detectability of passerine birds is often different in the summer and winter (Robbins 1981), and therefore the data of the two seasons should be treated separately. Before pooling different sets of data it is advisable to compare the curves obtained with each set separately. This comparison should be done taking in consideration the confidence regions of the curves. In most situations separate curves will have to be obtained for each species and for each season.

A relatively large number of stations sampled throughout the daily period included is necessary. In the example in this paper we used the results of 214 counts, but by randomly eliminating data we observed that 50 counts would have produced a similar detectability curve; even less data would be acceptable if a larger window had been used. The actual number of samples required depends on the length of the study period, the variability of the counts, the precision required, and the size of the window. Sampling too few stations is likely to yield a curve reflecting random variations inherent to any sampling procedure rather than changes in detectability. To avoid confusing these variations with real changes in detectability, it is desirable to plot the confidence region of the curve.

Selecting a size for the window.—The size of the window employed will determine the number of sampled stations that will be used in the estimation of the detectability level for each point of the curve. The larger this number, the more accurate will be each estimate. Many basic statistics books describe how to determine how large a sample is required to obtain an estimate of the mean with specified precision. To increase the sample size without obtaining more field data, one has to use wider windows. Wider windows may mask some changes in detectability, however, especially if they are abrupt. Although in nature these abrupt changes are rare, very wide windows may distort even gradual changes. A good way to select a window size to be used is to try different sizes and then compare the results. To obtain a curve that is precise and has a good temporal resolution, one may need a large data set. Fortunately, changes in detectability are usually gradual, allowing the use of wide windows. The use of narrow windows with small data sets is likely to result in a detectability curve reflecting random changes resulting from the small sample size used to estimate each point on the curve, rather then to actual changes in detectability. Using such a curve to estimate correction coefficients to apply to the results of bird counts can cause serious errors. The more conservative approach of using a relatively wide window is, therefore, strongly recommended.

To test the robustness of the described method with respect to windows of different sizes, densities were estimated for hourly intervals, using correction factors based on detectability curves generated with windows of 30, 40, 50, 60, 70, 80, 90 and 100 min. Although the detectability curves varied considerably (smoother when generated by wider windows), the corrected density estimates were all quite similar, and never deviated from the reference density by more than 15%, whereas the deviations of the density estimates without the correction reached 56%.

Windows with fixed time width or fixed number of points?—If one wishes to set in advance the desired precision level for the estimates of detectability, it is necessary to use a window that includes a fixed number of points. With this approach it is also simple to obtain confidence limits for the estimates. It will yield a curve with constant statistical precision, but some points in it may be based on narrow time windows, and others on much wider windows. The effect of this difference is that in some parts of the curve minor or abrupt changes in detectability will be portrayed, whereas in others they will be "stretched." To get a more homogeneous picture of the detectability changes, it may therefore be advantageous to use windows with a fixed time width, although the precision of the estimates will vary along the curve.

When using a fixed time window, it is desirable to consider the changes in sample size, mostly to check if the observed patterns may not be a result of small sample sizes in parts of the curve; when using a fixed number-of-points window, the corresponding time widths should be analyzed to check if there are any regions of the curve where the time resolution is so low that changes in detectability are likely to be concealed. The two approaches will yield very similar curves if the sampling frequency is roughly constant throughout the period of the day included.

Window using the mean or the weighted mean?—The simplest of these alternatives is making the estimated detectability level of a point in the curve a function of the arithmetic mean of the number of individuals counted in each sample. The greatest advantage of this approach is that it is simpler to comprehend, and that the investigator has a better understanding of the value estimated. The alternative of using the mean weighted by the distance in time between each point and the center of the window has the advantage of allowing the use of wider windows, with confidence that distant points will not strongly influence the estimates. It is also more robust with irregularly spaced data, although this spacing should be a serious problem only in some extreme situations. Finally it has the advantage of generating smoother curves.

Should the highest detectability recorded be used as a reference for estimating correction coefficients?—The most intuitive way to compensate for the effect of time of day is to convert the results of the counts so that they become what they would be if they had all been done at the time of highest detectability. The assumption is that at the time of highest detectability a greater percentage of the individuals present are detected, and therefore the results of counts done at this time are the most accurate. Although potential sources of error are more acute at times of high detectability, such as the likelihood of counting the same individual more than once, the assumption probably still holds true for most situations. It is therefore critical that the highest detectability is correctly estimated, or all the correction factors will be biased. The estimated highest detectability value is often biased itself, however, because it is likely to be influenced by a few extreme high values that may occur due to chance during the period of high detectability. This bias occurs most frequently, and the bias is greatest, when narrow windows are used. As a result of this bias the correction factors often overcompensate for the time-of-day effect. The easiest way to minimize this problem is to use the widest possible window, thus obtaining a smooth detectability curve.

Another approach to avoid this bias is to analyze visually the obtained detectability curve and select, as a reference, the overall detectability value during the period of high detectability, thus eliminating any upward "bumps" on the curve that may result from chance. This method is probably the most appropriate one to select the reference detectability value whenever the detectability curve is "bumpy."

COMPUTER PROGRAM

Some statistical packages can be used to generate detectability curves, using their moving average modules. A user friendly computer program to generate detectability curves from the results of bird counts, TIME-OUT, is available from the authors. The program is free and runs under the MS-DOS operating system. It provides all possible combinations of the window types referred to in this paper, and allows for the monitoring of the changes in precision along the generated detectability curves. Coefficients to compensate for the effect of time of day can be obtained from the curves or from an output file containing its coordinates. The program also estimates densities from point and transect counts, with and without compensation for the time-of-day effect, but this part of the program may not be applicable to all types of data.

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