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The efficiency of territory mapping, point-based censusing, and point-counting methods in censusing and monitoring a bird species with long-range acoustic communication – the Corncrake *Crex crex*

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Capsule A comparison of various methods of counting a Corncrake population revealed that the accuracy of the methods depends on population density, which could have important ramifications for a monitoring scheme.

Aims We examined the accuracy of three counting methods – territory mapping, point-based censusing, and point counting – in evaluating the population size and spatial distribution of the Corncrake, a species that uses long-range acoustic communication.

Methods We performed single-visit counts within ten study plots (1 km^2). Each study plot was censused in a single night using all counting methods. With territory mapping, we approached each calling male and recorded his position with a Global Positioning System (GPS) receiver. In point-based censusing, we estimated the distance and direction to calling males from five points in each study plot, while with the point-counting method, we only recorded the number of males within each of four distance categories, which estimated the distance from the same five counting points in each study plot. To estimate males' density within the study plot using the last method, we used only the data obtained from the central point of each study plot (middle-point counting approach).

Results We found significant differences among the three methods in the number and distribution of males counted within the study plots. The middle-point counting approach consistently underestimated population size regardless of the number of males present, while the point-based census approach overestimated population size when a small number of males were present within a study plot, but underestimated it when males were numerous.

Conclusions Our study showed that the accuracy of counting methods may depend on bird density. Moreover, point-based censusing may prove quite inaccurate in pinpointing the locations of calling males. When censusing species with long-range acoustic communication, it is challenging to estimate distance to calling birds, which means that the standard point-counting method should be applied carefully.

Effective protection and management of bird populations require, as a starting point, reliable knowledge about the distribution, density, and population trends of the target species. Biologically and ecologically, birds are one of the most diverse groups of animals, and it is not possible to use a single universal method to monitor and census populations across all species (Bibby *et al.* 2000). Therefore, researchers commonly make use of a variety of techniques, for example, line-transect sampling (Oppel *et al.* 2014), point-sampling (Kalyn Bogard & Davis 2014), or territory mapping (Wesołowski *et al.* 2010). Most often, these methods are used to monitor population densities and trends of common and abundant bird species that have relatively small home ranges. The accuracy of these methods varies and depends on many factors, including the characteristics of the species under study, the sampling season and time of day, the number of visits to the study plot, the habitat type, the skill of the observer, and the weather

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conditions (Alldredge *et al.* 2007a, Buckland *et al.* 2008, Gottschalk & Huettmann 2010). However, these standard methods are inadequate for monitoring and censusing populations of species that are less abundant, sparsely distributed, or that have large territories (Solonen & Jokimäki 2011). In these cases, alternative methods, which take into account the biology, ecology, and behaviour of a particular species, must be found (Hardey *et al.* 2009, Wiens *et al.* 2011, Nielson *et al.* 2014). Similarly, colonial breeders and lek-forming species cannot be counted and monitored using standard line-transect sampling, point-sampling, or territory mapping (Bibby *et al.* 2000, Johnson & Rowland 2007, Šúr *et al.* 2013), because the number of nests or individuals present in the colony or lek varies both daily and across the breeding season (Harding *et al.* 2005, Blomberg *et al.* 2013).

Monitoring and censusing bird species that utilize long-range acoustic communication often relies on listening to vocalizations using the point-based censusing approach: researchers designate observation points within a study area and, from these points, listen for calling individuals (Longoni *et al.* 2011). Such an approach is especially useful for censusing species that inhabit dense, difficult-to-access habitats or that are vocally active at dusk or at night. Additionally, in some species like owls, rails, herons, or woodpeckers, playing back a recorded vocalization from a census point can improve detection rates (Wesołowski *et al.* 2005, Richmond *et al.* 2008, Jobin *et al.* 2011, Ibarra *et al.* 2014). After the detection of an individual, the observer tries to estimate the distance and direction to the bird and records the location of that individual on a field map. Data regarding directions and distances to individuals from counting points can then be used to estimate the positions of calling birds by acoustic triangulation (Longoni *et al.* 2011, O'Donnell *et al.* 2013), which can help to avoid the double-counting of the same individual from adjacent points or within a single point. However, it is unknown whether the accuracy of point-based censusing is affected by population density. It is likely that, when censusing areas of higher bird density, it may be more difficult for observers to correctly estimate the number of calling males. Bird calls that originate from the same direction might overlap, and observers could have problems determining whether the call belongs to one or to two individuals, especially when individuals are far away from the counting point.

The typical point-counting method, in which birds are counted around a fixed station (Bibby *et al.* 2000) is easy to apply, and appears to be reasonably accurate for species that use short-range communication (Gottschalk & Huettmann 2010, Reidy *et al.* 2011). However, species that use long-range acoustic communication can be heard from locations up to a few kilometres away, and this distance may be strongly affected by habitat type or weather conditions. In such cases, it can be quite problematic to estimate the correct distance to a calling individual (see Alldredge *et al.* 2007b, Pacifici *et al.* 2008, O'Donnell *et al.* 2013), and so it is probable that errors will be made when estimating bird density and location.

In the present study, we evaluated the accuracy of three censusing methods – point-based censusing, point-counting, and territory mapping – in estimating the density and spatial distribution of calling males of the Corncrake *Crex crex*, a species that uses long-range acoustic communication. During the breeding season, Corncrakes inhabit wet meadows, abandoned areas, and agricultural grasslands in Europe and Asia (Berg & Gustafson 2007, Budka & Osiejuk 2013). Males are vocally active at night and produce their characteristic loud, disyllabic 'cracking' call. The call can be heard from more than 1 km away (Schäffer & Koffijberg 2004). Because this species is nocturnally active and lives in tall and dense vegetation, virtually the only effective method of censusing and monitoring the Corncrake population is to count calling males at night (Tyler & Green 1996). This is a relatively effective method, even when only a single visit is performed (Tyler & Green 1996). The Corncrake is a polygamous species, meaning that both males and females change partners during the breeding season, and pair bonds are formed only briefly. When they do not have mates, males sing almost continuously at night (92% of night-time checks) but are silent when they are paired with females (Tyler & Green 1996). Therefore, a single-visit count performed after males arrive at the breeding grounds but before they pair with females detects around 90% of the males present within a study area. Our goal was to compare estimates of the density and spatial distribution of calling Corncrake males that were obtained from territory mapping, point-based censusing, and point-counting methods during single-visit counts. Additionally, we examined whether the accuracy of the two latter methods was influenced by population density, and evaluated the percentage of total males calling at a given time within the study area that could be heard at various distances (divided into four distance categories) from counting points. We also briefly discuss the potential implications of our findings for the long-term monitoring of Corncrake populations.

METHODS

Study area

The study was conducted in the Upper Nurzec River Valley (centre coordinates: 52°36′N, 23°14′E), a bird area of international importance in Eastern Poland (BirdLife International 2014). The study site encompassed approximately 46 km^2 of drained agricultural meadows, pastures, and abandoned areas situated along a small river. The river valley varies in width from 0.5 to 5.5 km and is cut by a dense network of channels. Floods are rare, brief, and cover only the areas that are located close to the river. A considerable part of the meadows (ca. 60–70%) is mowed each year. Forests are located on the edges of the valley, while shrubs grow mainly along the channels and in low densities on unmanaged meadows (Budka & Osiejuk 2013).

Counting methods

We employed three different methods to count calling Corncrake males: territory mapping, point-based censusing, and point-counting. First, we randomly selected ten 1 × 1 km study plots. More than 80% of each study plot was covered by open habitat (e.g. meadow, pasture, and abandoned meadow).

Each study plot was censused using all three methods in a single night, and methods were employed simultaneously in a given study plot by two different observers. The first counted birds using territory mapping, while the second counted with point-based censusing and point-counting methods. We counted calling males from 30 May to 4 June 2014; this period corresponds with the peak of male vocal activity in Poland (Schäffer 1999), when males occupy their territories, are not accompanied by females, and utter calls almost continuously. As Corncrakes are vocally active at night, we started counting calling males after 22:00 and we stopped counting before 02:30 (local time). There was no rain or strong wind during this period, so weather conditions did not interfere with counting.

With the territory mapping approach, each study plot was censused along transects that were less than 500 m distant from each other. A fieldworker walked along each transect until a calling male was heard; at this point, the fieldworker approached the bird, marked his position with a Global Positioning System (GPS) receiver, then continued the census of the plot. Approaching a calling bird did not cause bird movement; we stopped approaching when the bird stopped calling or when the distance to the bird was ca. 5 m. The territory mapping method allowed us to hear each male from a distance of less than 250 m, which reduced the probability of overlooking a calling male virtually to zero. The time spent in each study plot ranged from 68 to 104 min (mean of 89 min) and depended on habitat type and the number of calling males within the plot. We assumed that the territory mapping approach enabled the detection of the highest number of calling males present within a given study plot during the time of the survey. Moreover, the territory mapping method should allow the most accurate determination (ca. a few metres; based on the accuracy of the GPS receiver and the distance between the GPS receiver and a calling bird) of males' spatial distribution.

A point-based census was conducted by counting calling males from five points within each study plot. The points were located in the corners and centroid of the plot, thus ensuring good coverage of the whole area because no location within a study plot was more than 500 m distant from a counting point. A few study plots bordered each other and thus shared counting points; therefore, the total number of counting points was 44. At each point, a fieldworker counted the number of males that called during a period of at least 5 min (longer when males were too numerous to note within this time frame), then walked to the next point. For each measurement, the fieldworker recorded the azimuth and approximate distance to each calling male in one of four ranges: (1) 0–50 m; (2) 50–200 m; (3) 200–500 m; (4) 500–1000 m. This method was only a little less time-consuming than territory mapping. The time spent in each study plot ranged from 47 to 77 min (mean of 60 min) and mainly depended on the kind of travelling between points (by car or by foot).

With the point-counting method we counted calling males within the study plots from the same points (n = 44) as the point-based census. From each point we counted the number of calling males within each of four distance categories (0–50 m; 50–200 m; 200–500 m; and 500–1000 m). To estimate the density of males within a study plot, we used the middle-point counting method, in which we only used the data from the central point of each study plot. The central point was located at the intersection of the diagonals of the study plot and we counted all calling males from this point. The middle-point counting method was the least time-consuming: approaching the middle point and counting birds usually took less than 15 min.

In all methods, the counting points and the borders of the study plots were marked using Garmin GPS receivers, and azimuths were determined using standard compasses. All fieldworkers had experience in counting Corncrakes.

Data analyses

We analysed our data using ArcGIS 9.3 software. To determine the number and spatial distribution of calling males in the point-based census, we used acoustic triangulation. First, we drew lines from all counting points, where the direction of the line corresponded to the azimuth to the calling male and the length of the line represented the estimated distance to the calling male. The locations at which lines crossed indicated the location of the males present within the study plot. Sometimes males were heard only from one counting point; in these cases, we set their positions at the ends of their respective azimuth-distance lines.

To determine differences in the estimates obtained by various methods we employed two approaches. In the first, we compared the number of males estimated within each study plot using the different methods (territory mapping, point-based censusing, and middle-point counting) using a repeated-measures ANOVA (type III sum of squares). We analysed dependencies between the accuracy of the methods and bird density using linear regression models (the intercept was included in the equations). As a dependent variable, we used the number of males obtained by territory mapping. As independent variables, we used the differences between the number of males obtained by territory mapping and the number obtained by point-based census or middle-point counting.

In the second approach, we analysed differences between the number of males estimated by territory mapping and those estimated by point-censusing, but taking into account the distance of birds from the counting point. Using a Wilcoxon two-related-samples test, we compared the data set for the numbers of males heard within each distance category (0–50 m; 50–200 m; 200–500 m; and 500–1000 m) that was obtained from counting points ($n = 44$) with that obtained from territory mapping. We also examined how many males were heard within a 500 and 1000 m radius of the counting points in comparison with the number of males detected by territory mapping within the same distance categories.

Additionally, we compared the differences in distribution between the exact positions of the calling males, as recorded by the GPS receivers during territory mapping, and the estimated positions determined by the point-based census. Statistical analyses were performed using IBM SPSS Statistics 21. Normal distribution of variables was examined using the Kolmogorov-Smirnov test. All *P*-values are two-tailed.

RESULTS

Using the territory mapping method, we found between 2 and 11 calling male Corncrakes per square kilometre (mean = 5.8), while the density obtained from the point-based census ranged from 3 to 8 males/km^2 (mean = 5.2). From a single counting point, we heard from 0 to 6 calling males (mean = 3.5); when we considered only the counting points located in the middle of the plots, this range changed to 2–6 calling males (mean = 3.9) per point. More details are shown in Table 1.

We found significant differences among the three counting methods in the number of males found within study plots (repeated-measures ANOVA; $F_2 = 5.7$, $P = 0.012$). Pairwise comparisons (paired samples *t*-test) showed significant differences in the number of males observed within study plots as estimated by territory mapping vs. middle-point counting ($t_9 = 2.6$;

Table 1. Number of males estimated by three different counting methods within 1 ×1 km study plots.

	Number of males		
Study plot	Territory mapping	Point-based censusing	Middle-point counting
1	2	3	2
2	3	3	2
3	4	5	2
4	4	5	5
5	6	6	5
6	6	5	3
7	6	6	5
8	7	6	6
9	9	5	5
10	11	8	4
Total	58	52	39

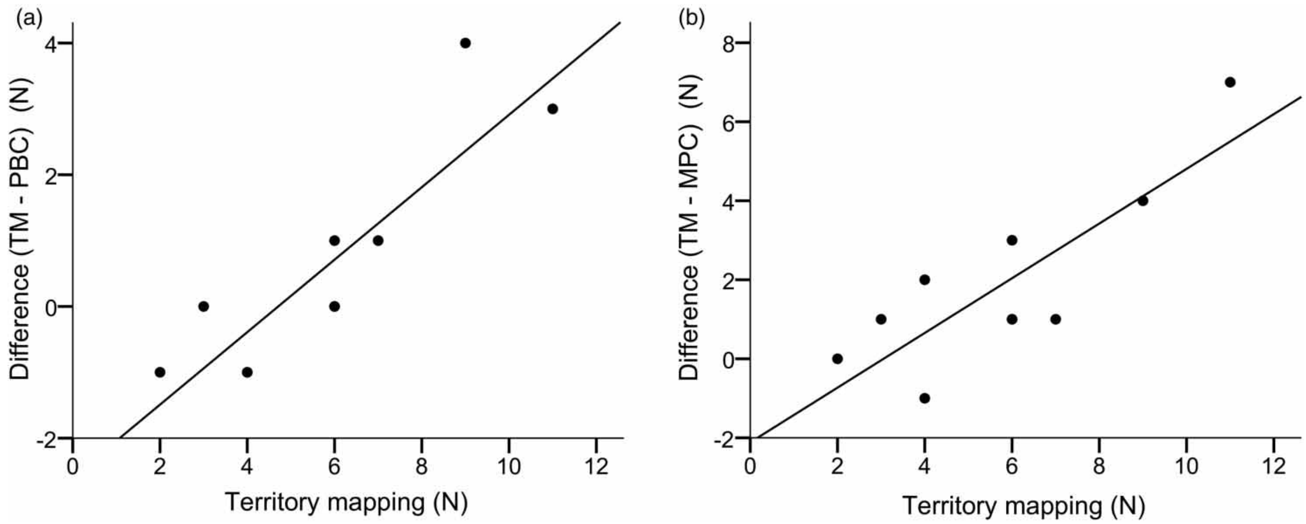

Figure 1. Linear regression models showing dependencies between the number of males detected within study plots by territory mapping (TM) and differences between the number of males detected by: (a) territory mapping and point-based censusing (PBC) ($R^2 = 0.78$; $P < 0.01$) and (b) territory mapping and middle-point counting (MPC) ($R^2 = 0.69$; $P < 0.001$).

$P = 0.027$) and no differences between the number of males estimated by territory mapping vs. point-based census ($t_9 = 1.1$; $P = 0.30$). On average, point-based censusing captured 99.7% (±27.8%) while middle-point counting captured only 73.6% (±27.0%) of males detected by territory mapping. In general, middle-point counting underestimated population size (as measured by territory mapping) regardless of the number of males observed within the study plots (linear regression: $R^2 = 0.69$; $F_{1,8} = 17.9$; $P < 0.01$). In contrast, point-based censusing overestimated population size when few males were present within a study plot but underestimated it when males were numerous (linear regression: $R^2 = 0.78$; $F_{1,8} = 27.6$; $P < 0.001$) (Fig. 1).

When we compared (using a Wilcoxon two-related-samples test) the number of calling males estimated by territory mapping and by the point-counting method (44 points) while taking into account the distance to counting point, we found significant differences in three distance categories: 0–50 m ($Z = -3.6$; $P < 0.001$), 50–200 m ($Z = -3.7$; $P < 0.001$), and 500–1000 m ($Z = -5.7$; $P < 0.001$). No difference was found in the category of radius 200–500 m ($Z = -0.3$; $P = 0.787$). Within 500 m of the counting points ($n = 44$), territory mapping revealed significantly fewer males than the point-counting method did (Wilcoxon two-related-samples test: $Z = -2.6$; $P < 0.01$). However, within 500–1000 m of the points, the results were reversed: we noted less males by using the point-counting method than by territory mapping (Wilcoxon two-related-samples test: $Z = -4.5$; $P < 0.01$). More details are shown in Fig. 2.

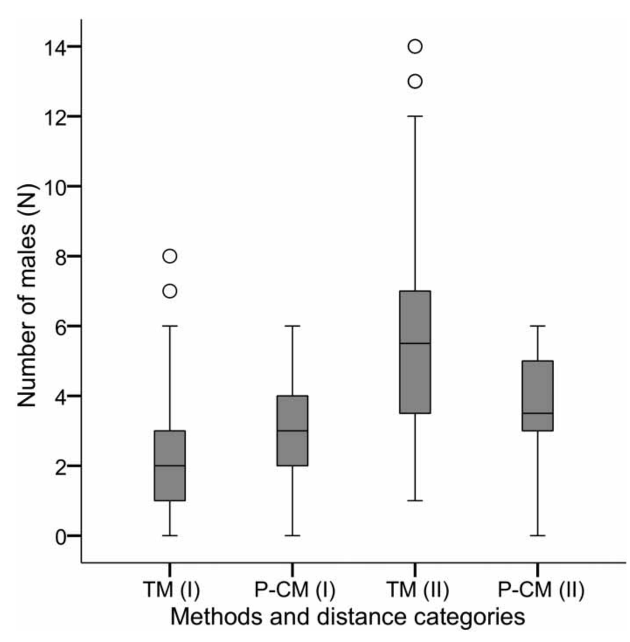

Figure 2. Number of males detected within a radius of 500 m (I) and within a radius of 500–1000 m (II) around counting points ($n = 44$) using territory mapping (TM) and the point-counting method (P-CM). Boxplot show the medians, interquartiles range, outliers, and extreme cases. Differences between methods are significant (Wilcoxon two-related-samples test; $P < 0.01$) in both distance categories.

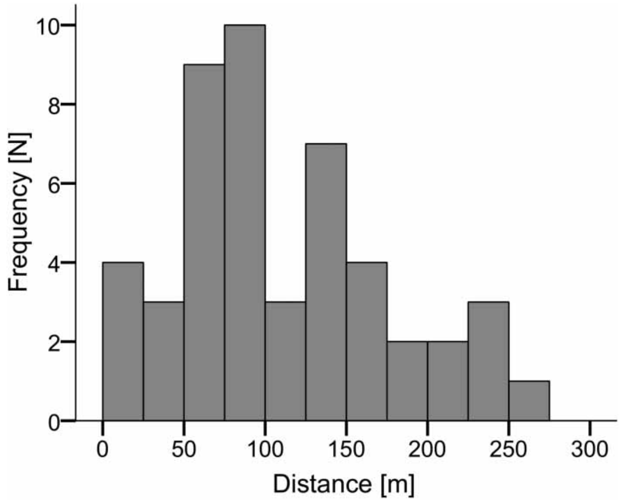

Figure 3. Distribution of the differences between the locations of calling males as determined by territory mapping (with a GPS) and by point-based censusing (acoustic triangulation). The locations of 48 males were examined.

We also found large differences between the positions of males as determined by GPS receivers during territory mapping and the positions estimated in the point-based census by acoustic triangulation. The average difference in position was 110 m ± 65.2 m (Fig. 3).

DISCUSSION

Efforts to census and monitor bird populations must trade off the quality of the data obtained and the effort required to collect them (Bibby *et al.* 2000, Solonen & Jokimäki 2011). In our study, we found no significant differences between the numbers of males detected within a given study plot when using two similarly time-consuming methods: territory mapping and point-based censusing. However, the total number of males detected by the point-based census was lower than that detected by territory mapping (52 vs. 58 calling males, respectively; see Table 1). Moreover, the point-based census overestimated population size when the density of calling birds was low and underestimated population size when birds were numerous (Fig. 1a). The relationship between the accuracy of a counting method and population density is commonly overlooked in studies of bird populations. However, this variation in accuracy could distort the results of monitoring efforts, causing real changes in population size to go undetected. We also found differences in the exact positions of calling males, as determined by territory mapping, and those estimated by the point-based census (which were, on average, 110 m off from the real positions).

Point-based censusing may inaccurately estimate population size and the locations of calling males because of the difficulties involved in both assessing the distance to a calling individual (Lefebvre & Poulin 2003, Alldredge *et al.* 2007b) and accurately determining the direction from which a bird is calling (Lefebvre & Poulin 2003); these difficulties are especially pronounced when working with species that use long-range acoustic communication. Indeed, inaccuracies in estimation of the direction of a 1 km-distant calling bird by just 10° leads to a 174 m error in that individual's presumed location (in addition to the fact that it is virtually impossible to accurately evaluate the distance to a bird that is 1 km away). The challenges involved in accurately determining direction were also shown in a study of another long-range communicator, the Great Bitterns *Botaurus stellaris*, where males calling normally under windless conditions could only be located with a mean bearing accuracy of ±13.6° (Lefebvre & Poulin 2003). Moreover, in areas with high population densities, it can be difficult to determine how many males are calling if they are calling from a similar direction. Calls can overlap each other or an echo can be erroneously taken to be a calling individual (O'Donnell *et al.* 2013). In addition, environmental characteristics – such as the presence of local depressions and hills, shrubs, forests, and bodies of water – as well as weather conditions, including wind speed and direction, rain, and humidity, can affect the distance and direction of call transmission (Pacifici *et al.* 2008, Gottschalk & Huettmann 2010, Ibarra *et al.* 2014). Therefore, the environment, the weather, and bird density may strongly influence the results of censusing and monitoring efforts that are based on a point-based census. This impact may be particularly pronounced in studies of species that use long-range communication, because the distances to the calling birds are usually in the hundreds or thousands of metres; in contrast, common and abundant short-range communicators are usually found within a 50 or 100 m radius of observers (Reidy *et al.* 2011).

The least time-consuming method, middle-point counting, was also the least accurate, because we were not able to hear all calling males within a study plot from the middle point of that plot. Using this method, we detected, in total, only 67% of all calling males that were recorded by using the territory mapping method within study plots. Generally, the middle-point counting method underestimated population size, on average, by 1.9 ± 2.3 males/km^2. The degree of this error may vary widely both among and within populations, as a consequence of variation in landscape, habitats, or weather conditions. This result shows that the range within which Corncrakes can be heard in the natural environment is much shorter than 1 km. We were not able to hear all calling males within a 1 km^2 study plot from the middle point of that plot, despite the fact that the maximum distance between the observer and any male in the plot would be 700 m. Moreover, using the classical point-counting method, the classification of Corncrake males into one of four distance categories (up to 50 m; 50–200 m; 200–500 m; and 500–1000 m) was inaccurate. We had a tendency to classify males as more or less distant than they were, which caused significant differences between estimates of bird density based on territory mapping and those based on the point-counting method. A similar situation was observed when we assigned calling males to one of only two distance categories: up to 500 m and 500–1000 m. Some of the males calling within 500–1000 m of the counting point were classified as less distant (up to 500 m), which caused an overestimation of the population size within 500 m of the point and underestimation within a radius of 500–1000 m. Therefore, we recommend that the point-counting method, which is commonly used to monitor common and abundant bird species, should be used only as an index to provide a general idea of population trends when monitoring Corncrake populations. We suggest that, when studying Corncrakes and other long-range communicators, the range at which the call is audible should be carefully considered because this distance may be quite variable under different environmental conditions (Alldredge *et al.* 2007a, Pacifici *et al.* 2008). Therefore, estimates of bird density obtained using the point-counting method may involve considerable error (Fig. 3), since the correct evaluation of the distance between a counting point and calling individual, even in broad categories, may be difficult.

In conclusion, our study shows that territory mapping and point-based census, in general, yield similar densities of calling males. However, the accuracy of the point-based census was dependant on bird density, indicating that surveys using this method may miss real changes in population trends. Moreover, these two methods yielded considerably different locations for calling males. The middle-point counting approach, as the easiest and the fastest method, might be used to provide an index of population trends; however, this method consistently underestimated population size. It is important to note, that in studies of Corncrakes, and probably other species that use long-range acoustic communication, the correct estimation of the distance to calling individuals, even within broad categories of distance, is extremely challenging.

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