Plate 3. Male Corncrake calling from early cover vegetation, Waternish, Skye, Highland, May 2015. © *A. Barany*

Bioacoustic tracking of Corncrakes on the Isle of Skye

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This paper describes an attempt to track the movements of male Corncrakes on the Isle of Skye in 2020–23 by analysing the fine structure of their calls, using an established technique, but using new technology, mobile phones and free audio software. It was confirmed that this equipment was adequate for the task, provided the quality of the recording was evaluated appropriately. The intention was to add movement information to the collection of short audio recordings that had already been made for several years. The analysis of results required a modification of the established technique to distinguish individuals more reliably, because of the sharing of patterns by different birds. Movements of individuals were mapped with reasonable certainty and some possible returning birds identified.

Introduction

Breeding Corncrakes *Crex crex* are secretive, live in dense vegetation and often the only sign that they are present is hearing their call. The males call for long periods in the night, both to attract a female and to repel rivals (Cramp & Simmons 1980). The method used for monitoring the Corncrake population in the UK and Ireland relies on these vocal signals, with interpretation and analysis based on radio tracking studies of tagged males (Stowe & Hudson 1988, 1991). Peake *et al.* (1998) established that there is a high level of individuality in the fine structure of Corncrake calls and further study suggested that using the calls as a non-intrusive technique could be applied to test the efficacy of census and monitoring methods (Peake & MacGregor 2001) and also could generate useful conservation information on the behavioural habits of individual birds (Terry *et al.* 2005).

During the Corncrake annual census and land management work by the RSPB on the Isle of Skye, a collection of about 300 short mobile phone recordings of calling males had been accumulated between 2012 and 2019. The majority were made by the RSPB Skye Corncrake Project Officer, Shelagh Parlane. In 2019, we decided to see if this archive could reveal more information on individual Corncrake

behaviour, using insights about call structure from the work of Peake *et al.* (1998). Birdwatchers are often keen to hear the calls and a number of interested people contact the RSPB Skye Corncrake Project Officer to report hearing a bird and, increasingly, they have been able to share short recordings made on their mobile phones, along with temporal and geographical information.

However, further unpublished work suggested that many Corncrake calls can be similar and so identifying individual birds using this method may be unreliable. In discussions about Corncrake calls the analogy of a fingerprint is sometimes used to explain the significance of the PPD pattern (Pulse to Pulse Duration), described in more detail below (Peake *et al.* 1998). Unfortunately, fingerprints alone cannot work for identifying individuals if several individuals share the same pattern. Many researchers have noted this problem (Peake & McGregor 2001, Mikkelsen *et al.* 2013, Linhart *et al.* 2019).

The proposed approach in this study, to limit false identification of individual birds with similar PPD patterns, was to analyse the PPD patterns, coupled with geographical and temporal data, sequentially through the season. These matches are repeatedly reviewed for visual similarity of PPD, in order to make a considered judgement of identity and probable movements by the end of the season.

The Corncrake population on the Isle of Skye is small and widely dispersed across the crofting townships on the north of the island. This, coupled with advances in technology, presented an opportunity to adapt the method established by Peake *et al.* (1998) to track individuals through the season and possibly between years, non-intrusively. As Frank Rennie suggests, PPD analysis "may provide a useful way to distinguish between individual birds for the duration of the breeding season, and possibly over a short (two-season?) cycle" (Rennie 2022).

Methods

Data collection

Citizen science and RSPB survey

The collection of a recording is a fairly simple addition to the reporting of a calling bird for people with a mobile phone. The report of a calling bird is often by text message or email. No playback calls were used to stimulate calls from birds and no captures were needed for this study. Efforts were made to record every bird reported throughout the Corncrake season.

The annual RSPB survey follows a set route and is carried out over several nights, due to the distance involved in covering the island. Mobile phone recordings can be made when a bird is encountered. The size of Skye makes it challenging to survey for Corncrakes without some citizen scientist help. Skye is 75 km long measured in a straight line, and it is 60 km by road between the two main Corncrake areas, excluding outlying sites.

Passive recording with an Audiomoth

A single Audiomoth recorder (Open Acoustic Devices) was used sometimes to collect calls over longer periods. Recordings can be clear enough to analyse the PPDs, despite being a passive device and not directed optimally at the calling bird.

Quality of recordings

Mobile phone recordings, typically about 20 seconds long, work adequately to emulate the first part of the Peake method, extracting PPD patterns from recordings (Peake *et al.* 1998, Arnold & Parlane 2023). It was obvious that certain quality conditions were required to get reliable patterns. A scale of one to five was used to label each recording during the PPD analysis, using Raven Lite (qu1, qu2–3, qu3–4, qu4, qu4–5 or qu5 are added to the recording name). Only 'qu4–5', 'qu4' and 'qu5' recordings were used in the database, unless there was a special reason, such as being the only recording at a particular location.

The criteria for allocating the quality score are:

1. Five syllables can be analysed.
2. A sharp rise at the start of the pulses.
3. The signal to noise ratio is moderately good.
4. The first pulse in a syllable is identifiable and not indistinct.

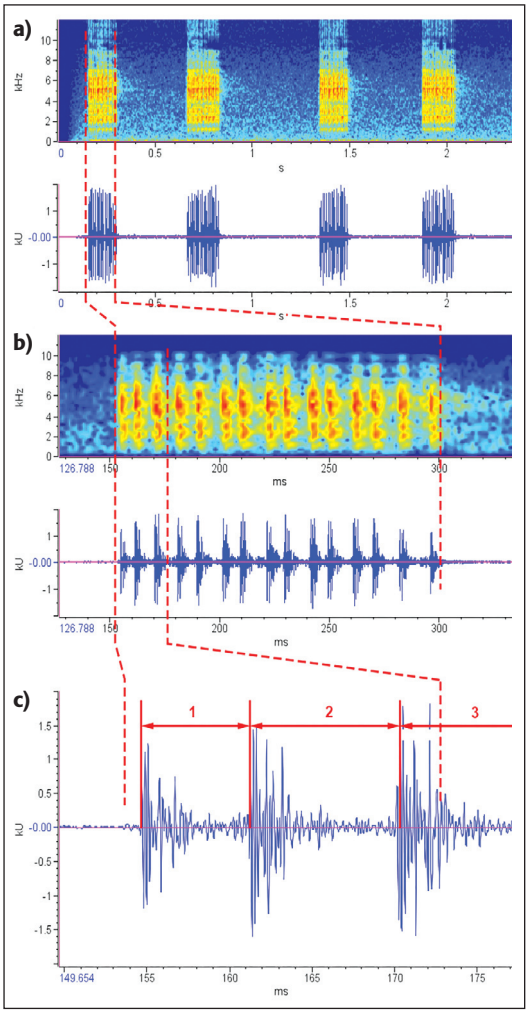

Figure 1. a) This is an example of a mobile phone recording of two calls, four syllables. The top chart is the signal amplitude in arbitrary units, for about two seconds. The x-axis is time in seconds (s). The lower chart is the spectrogram derived by Raven Lite (Cornell Lab of Ornithology). The y-axis is the frequency of the sound in kilohertz (kHz). The Corncrake call is mainly within 2–7 kHz. **b)** A single syllable about 0.15 s long. Wind noise has been digitally removed by Raven Lite (Band pass filter 600 Hz to 10 kHz). **c)** The amplitude chart expanded for the manual marking of the start of the individual pulses. The x-axis spans 0.025 s or 25 ms. The first two PPDs (pulse to pulse durations) are shown.

All four criteria being satisfied well makes the recording a 'qu5'; none of them being satisfied is an unusable recording and 'qu1', with a range of judgements in between.

Recording name and location

The recording is named with date, time and colloquial location name when it is made or received from a citizen scientist. The quality is assessed during analysis in Raven Lite and added to the name. A six or eight figure OS grid reference is also included for mapping. To include the location in the mapping software QGIS, the grid reference is converted to 12 figure OSGB36.

PPD Analysis

Each syllable of the call is made up of a series of pulses of sound separated by a short interval. The pattern of these intervals, PPD pattern (Peake *et al.* 1998) is readily analysable from short recordings.

Eleven pulses are marked from the start of five different syllables (Figure 1). Raven Lite generates a list of times for the start of the pulses. The intervals between these are calculated and averaged to become ten PPDs for the recording used for comparison with other recordings in the database (Figure 2).

The spectrogram is not used for this PPD analysis. This is an unusual characteristic of the bioacoustic studies of Corncrake calls. Most bird call acoustics studies use the spectrogram produced by mathematical transformation of the audio signal and it is necessary to obtain reproducible and good quality recordings for this. In the Corncrake case, only the amplitude chart is used and it is simply the plot of amplitude values through time.

Correlation and matching

The second part of the Peake *et al.* method concerns matching pairs of PPD patterns to identify an individual bird. It is generally accepted that birds keep this marker over seasons and years, with only slight or very temporary variations. (Peake *et al.* 1998).

A database of PPD measurements was compiled, which can generate charts of PPD patterns for

visual comparison and matrices of Pearson correlation coefficients, 'r', for all pairs to make selections of PPDs to find visually similar patterns. MS Excel was used for this.

When correlating PPDs, Peake *et al.* chose a cut off point for 'r' of 0.7 to distinguish different birds by statistical means. In this study, the correlation coefficient is only used for an initial selection of pairs of PPD patterns that may be compared visually. To find near identical patterns 'r'>0.97 is applied to a matrix of all pairs to limit the number of pairs needing to be tested visually. A matched PPD pattern is added to the plotted chart of PPDs already collected for a particular 'Record' and may have an 'r' value lower than 0.97 in comparison to other patterns in the 'Record', if the matching is very likely. For instance this could happen in a location and a period of time when only one bird has been heard calling and is some distance from another bird.

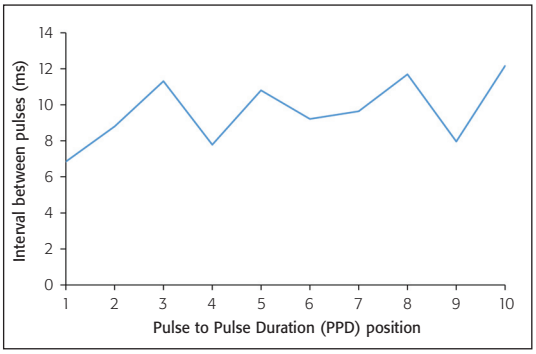

Figure 2. This is an example of what I define as a PPD pattern. It is a line chart derived from the PPD analysis of the sound recording in Raven Lite. The ten numbers that are displayed in the chart are stored in a database with the original recording name, which includes the date and time, and the geographical location and the quality estimate.

The visual matching of pairs to identify a 'Record' takes account of all the characteristics listed as criteria below and it is done iteratively as the season progresses. See flow chart (Figure 3). The shape of the PPD pattern, whether it is nearly identical and not just similar, is obvious to a human eye in a way that the magnitude of the Pearson correlation coefficient can miss. The Pearson correlation coefficient 'r' is useful for separating 'definitely different' birds (Figure 4) but only of limited use for finding near identical PPDs (Figure 5) to make a match to add to a 'Record'.

Matching strategy

Criteria for matching PPD patterns

1. Judged to be reliable quality ('qu4', 'qu4–5' or 'qu5').
2. Geographical location is possible, not in two places at the same time.
3. Pearson correlation 'r' is greater than 0.97 between the recordings for initial sorting. Reviewed repeatedly as recordings are added to the database.
4. Convincing visual similarity of the PPD pattern.

This process is done with caution through the season, reviewing the allocation of 'Record' numbers from time to time. A bird with the same pattern might lead to an apparently false movement, but if the pattern occurs in the original location again later on, it confirms it as a new 'Record'. Similarly, when a bird with a certain PPD pattern stops calling and another one with the same pattern starts somewhere else, it is likely to be a detected movement and may involve merging two 'Records'.

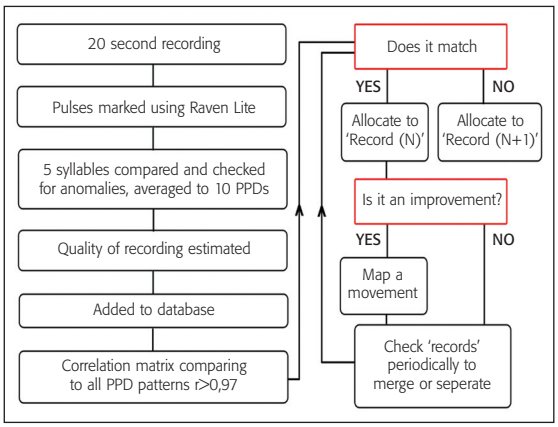

Figure 3. Flow chart of the process used sequentially through the season to derive a 'Record (N)' from Corncrake call recordings for use in tracking. 'Record (N)' is numbered 1,2,3... starting at 1 each year as recordings are received. In some cases two 'Records' can be recognised later in the season as being one bird that has moved and they become a merged 'Record (x) + Record (y)'. Conversely, if a 'Record (N)' is separated, after erroneously adding recordings to an existing 'Record', it keeps the original label and the extra part gets a new 'Record' number.

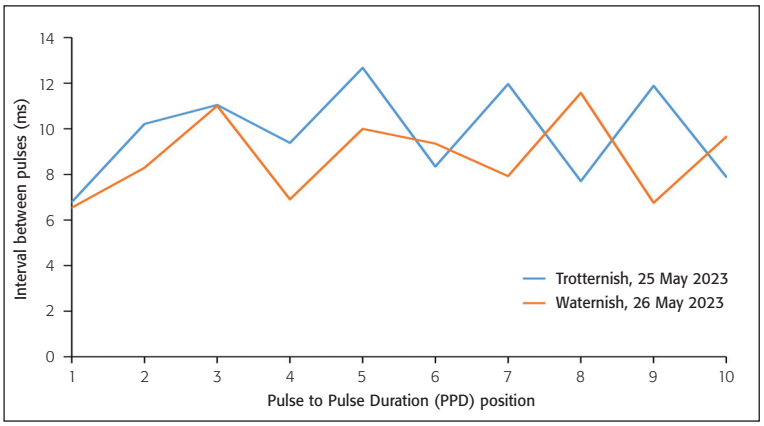

Figure 4. This is an example of two definitely different PPD patterns. The recordings came from different places in a series of similar recordings over the same time period, the correlation coefficient for them is 'r' = 0.12 and the PPD patterns are visually very different.

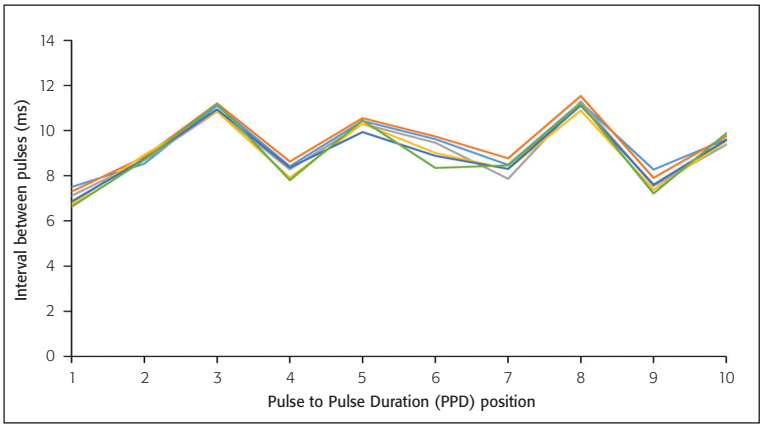

Figure 5. This is an example of a male recorded six times, by two different people, over 47 days and it included a distance of seven kilometres. (Record 14 from 2023). The PPD pattern is constant and it is a probable movement of a male Corncrake included in the 2023 Corncrake call summary (Arnold & Parlane 2023).

These are two examples of PPD patterns plotted together. The first is to illustrate how different PPD patterns can be (Figure 4) and the second is to illustrate how a 'Record' becomes established over time by accumulating matching PPD patterns and how movements can be revealed by this process (Figure 5).

Results

Recordings

This study confirmed that the quality of mobile phone recordings was good enough to extract the fine detail required in order to emulate the 1998 work (Peake *et al.* 1998). From our data, it was apparent that there were individual male birds with the same pattern, as well as many that were easily distinguishable (Figure 6).

In order to illustrate the shared pattern problem, using Skye data from 2023, an estimate was made of the proportion of pairs of PPD patterns that are too similar to distinguish by the original Peake *et al.* method. The PPDs were averaged for each of the probable individuals, which appear as the 18 'Records' or individual males detected in the 2023 analysis (Arnold & Parlane 2023). These are different birds, because we have detected them as such by our modified visual Peake method, not reliant only on the 'r' value. At least one tenth of the total number of pairs of detected males (153 pairs of PPDs for 18 birds, in 2023) have an 'r' value greater than 0.97 (used for our initial selection) and half of the pairs of detected males from 2023 have 'r' greater than 0.7 and would be indistinguishable using the original Peake method.

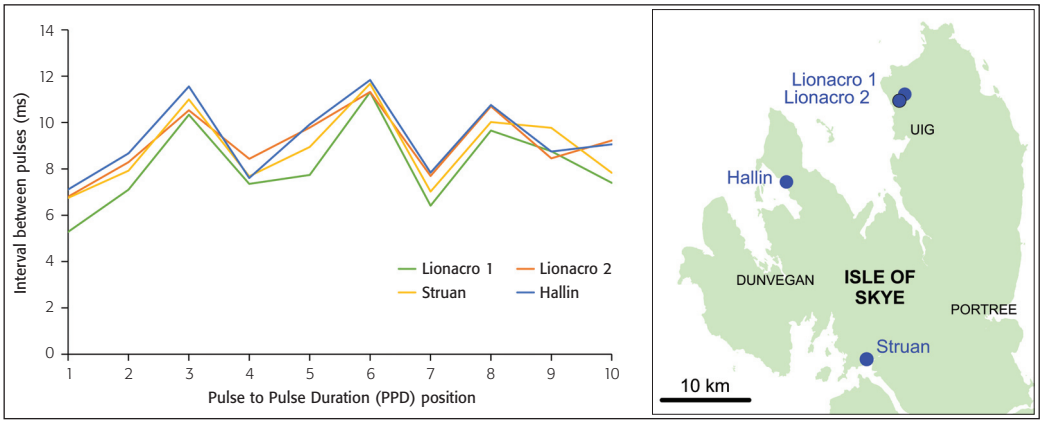

Figure 6. Locations and PPD patterns of four definitely different birds from 2022. Over the season it was clear that they were calling at their locations over the same period of time and could not be birds moving location. The patterns are slightly different but not enough to be completely certain about separating them as different birds by the PPD patterns alone.

However, it is possible to accommodate this problem using the proposed visual matching with place and time taken into account, but always with some caution. Skye's Corncrake population, being small and widely spaced, helps to simplify the problem. As there is no alternative method to confirm or deny a match, it has to be a matter of careful judgement of all the criteria.

Table 1. Total numbers of recordings, recorders and calling birds for 2020–23. There were 294 'qu4–5' recordings and 122 'qu1–3' recordings that were discarded. The number of males calling has increased and calling females were not detected in 2023. The number of citizen scientists is increasing. RSPB census figures are for comparison to show that the two ways of counting male Corncrakes are not widely divergent.

Year	Number of qu4–5 recordings	Number of recorders	Number of males counted by PPD analysis	Number of males counted in RSPB census	Number of females
2020	47	14	11	COVID-19 restrictions, not published	2
2021	70	11	9	10	1
2022	82	13	14	14	2
2023	95	29	18	14	0

Tracked movements

Corncrakes are protected under Schedule 1 of the Wildlife and Countryside Act (1981) and for this reason the locations of calling males have not been presented in detail on maps in this paper. Information has been extracted from the annual summaries for 2020–23 (Table 2), (Arnold & Parlane 2023). A proportion (0.46, 24 from a total of 52) of the males make movements during the season of several kilometres and have been tracked for several weeks.

Table 2. Tracking distances and number of days tracked for all 'Records' for 2020–23. Movements greater than 0.1 km are counted and the mean and range of distance moved and time tracked are listed.

Year	Total males	Males moving more than 0.1 km	Distance moved in km range	Distance moved in km mean	Number of days tracked range	Number of days tracked mean
2020	11	5	2–22	11.9	1–52	19
2021	9	3	3–15	7.3	1–77	22
2022	14	7	0.9–24	5.2	1–84	29
2023	18	9	0.6–42	10.3	1–101	32

Returning birds after migration

The PPD measurements of each detected bird have been averaged for each 'Record' in all years 2019–23 (Table 3). From correlation matrices for 2019–20, 2020–21, 2021–22 and 2022–23 in Excel, the pairs that match using the Pearson correlation coefficient 'r' greater than 0.95 (reduced from 0.97 to allow for the changes in PPD that might happen over a year) have been plotted in charts to compare the patterns visually, and any very similar pairs of patterns that could be relevant have been counted for each year (Arnold & Parlane 2023).

Table 3. Summary of the numbers of matching PPD patterns between years. 2019–23.

	Male birds returning after migration					
Year	Total number of birds by PPD analysis	Number of matches with previous year	Number that did not return from previous year	Proportion possibly returning	Proportion definitely not returning	Distances between arrival locations (km)
2019	6	nc				
2020	11	4	2	0.67	0.33	0.0, 0.7, 0.7, 4.2
2021	9	5	6	0.45	0.55	0.0, 6.2, 13.8, 16.8, 23.7
2022	14	5	4	0.56	0.44	0.0, 0.6, 2.7, 15.3, 15.6
2023	18	7	7	0.50	0.50	0.0, 0.0, 2.0, 4.0, 7.8, 15.0, 29.5

Audiomoth passive recording

This has been used mainly for simple detection of the presence or absence of male birds using automatic analysis on the Arbimon website (Arbimon by Rainforest Connection). The quality can be good enough to extract PPD patterns if necessary. In one case in 2023, a male calling over several days turned out to be two birds, one replacing the other, and in another case a bird which called in two nearby places was initially assumed to be two birds and the Audiomoth recording showed that it was one bird.

Discussion

Shared PPD pattern (Figure 6)

Other researchers (Peake & McGregor 2001, Mikkelsen *et al.* 2013, Linhart *et al.* 2019) have mentioned the problem of overlap between individuals, the limited possibility of discrimination, and that discrimination is different to identification and is less demanding. Budka *et al.* (2015) working in Poland and the Czech Republic concluded that it was not possible to unambiguously identify Corncrakes in the 177 territories they surveyed. They did detect apparent movements and estimated the errors caused by birds with identical calls. They also concluded that PPD analysis might still work for identification for numbers over 100 with caution. The number of male Corncrakes on Skye has been typically below 20, much lower than the number that they considered and also often widely spaced.

Citizen science and RSPB survey

There is a degree of luck, even for dedicated field workers, in finding calling Corncrakes. The best efforts of fieldworkers are enhanced by crofters, residents and visitors reporting calls. Inevitably, it is an incomplete survey and so tracking will have gaps in time and locations. The majority of birds are detected, but the tracking is imperfect. That is normal in tracking studies; radio-tracked birds are only located from time to time and can go beyond the study range.

Many crofters, visitors and residents carry their mobile phones even at night outside when they might encounter a Corncrake calling. The intention was to make use of as much of the data as possible, enabling a citizen science contribution to the Skye Corncrake call database, hence the need to define the quality of recordings and use only the better ones.

Census, PPD analysis and tracking

Collecting recordings while doing the census can add behavioural information that is not available without PPD analysis. For instance, the possible indication of breeding success when a male stops calling, moves and starts calling at a new location and has not been predated (Tyler & Green 1996). The movement of birds between several sites during a season is revealed. In a sparse population like Skye, they may move due to lack of success in finding partners or also after breeding success. They may move longer distances on Skye than in more densely populated areas. Another effect of the low numbers and wide spacing of birds on Skye is that a female can land after migration and not find any males nearby and so try calling. There were two female calls recorded on Skye in 2020, one in 2021, two in 2022 and none in 2023 (Table 1), (Arnold & Parlane 2023). Ottvall describes the call in his paper, the "function of the female call described here is to attract males" (Ottvall 1999, *Downloadable sound file* MacGillivray 2020). Alternatively, a paired female is occupied for about 30 days with incubation (about 18 days) and attending to her brood of up to ten chicks (about 12 days) (Green & Riley 1999). After that, she will look for another male to start a second brood. The males move on after pairing and call nearby or move to another area looking for a new female. In 2022, a female called near to where two males had been calling about 30 days before. It might be that the female was ready to start a second brood, but found no males nearby. We were able to track the two departed males to an area several kilometres to the north before the female was heard calling (Tyler & Green 1996).

As a method for counting male Corncrakes, PPD does not improve on a count done by the standard RSPB method which has been used widely since 1993 (Wotton *et al.* 2015). PPD analysis will come up with a figure for the male population that is similar to the standard census, but probably higher because it is done over the whole season, not just a few nights. Both methods are imperfect counts of Corncrake numbers and they miss out females and juveniles (Peake & McGregor 2001) (Table 1).

Plate 4. Corncrake, nr Balranald, North Uist, Outer Hebrides, 6 June 2007. © *Iain Leach*

The actual number of birds present can never be known precisely. However, an estimate of the total number of calling males is available from the annual PPD call summary at the end of the season (Table 1). The standardised RSPB census method is preferable for population counting because it is unambiguous and can be applied nationwide and beyond for comparison of numbers between years.

There is some evidence that calling males not only repel other males, as described in the literature, to defend an area, but also they attract other males who may recognise the possibility of females already present in an area with a calling male. On Skye, this type of aggregation of two or three birds has been observed several times during this study.

Returning birds after migration

Returning bird counts have been done before by tagging a few selected individuals using rings, geolocators or satellite tags (Swann 1986, Green 1999, Green 2013, Peške *et al.* 2017, Green *et al.* 2019). This bioacoustic technique can be applied to a bigger sample of birds with no devices or capture required.

The birds that have a match with a PPD pattern from the previous year may have returned from migration and the proportion is an approximate measure of their annual survival rate (range 0.45–0.67, mean 0.55) (Table 3). The proportion of birds that did not have a matching PPD pattern in the following year can be counted as definitely not returning to Skye (Range 0.33–0.55, mean 0.46), and this is another more certain measure of survival rate.

Distances in kilometres between the arrival locations for these pairs is a measure of the site faithfulness of returning male Corncrakes (Table 3). It is notable that only five males out of 21 possibly returning birds chose exactly the same location as the previous year. There are plenty of suitable sites for Corncrakes to breed on Skye, but not many birds arriving, and so they can appear to arrive in different areas each year and they do not seem to be particularly faithful to their previous year's site. However, birds often arrive in the exact same locations in the following year, but do not have the same PPD pattern, so they might be returning juveniles with a memory of their birth site.

Summary

Bioacoustic data gathering is less intrusive than other tracking methods and adds movement data not available readily by other means and is collectable alongside standard census activity. Human ears are good at estimating an approximate position from one kilometre in the dark. A twenty second well-defined recording from a reasonable spot is all that is needed for PPD analysis. There is no technical complication for the data gathering other than map reading or noting a GPS coordinate and being out listening with a mobile phone in the middle of the night. It has some advantages over other methods; it is applicable to all the male birds in an area and over a whole season, not just a tagged or ringed sample. It does not require any potentially damaging capture and recapture. The effort can be spread, using citizen scientists, until the last calls are heard in the season.

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