Passive acoustic monitoring of the nationally endangered corncrake (*Crex crex*): calling patterns, detectability and monitoring recommendations

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# Abstract

Due to their elusive nature, some species are hard to survey. Conservation projects, however, need up to date figure to understand the status of the species to preserve. We acoustically monitored the corncrake (*Crex crex*), a nationally endangered rail species in Ireland. Twelve acoustic deployments were manually scanned to extract the calls of the corncrake. The calling rate was then modelled as a response variable with weather, moon and temporal variables as predictors. Additionally, detectability according to weather and moon variables was assessed using a single-species occupancy model. We found significant unimodal effects of date (P=) and hour (P=) on the corncrake calling rate. The later was also significantly negatively affected by temperature (P=) and wind speed (P=). Furthermore, a significant interaction (P=) between cloud cover and fraction existed. The detectability analysis highlighted that wind speed and cloud cover negatively affected the probability of detection of a corncrake, while moon fraction had a positive influence on the detection. The probability of detecting a present corncrake at a site at a given night was of 64%. We concluded that corncrake surveys should focus the effort between 0000-0300hrs, preferring nights with clear sky, high moon illumination and wind speed below 20km/h.

*Keywords: Passive acoustic monitoring; endangered species; species conservation; survey recommendations; species detectability.*

# 1. Introduction

Species monitoring is an essential task for species conservation projects. Some species, however, due to their intrinsic elusive nature, are hard to detect using canonical survey techniques. As a result, monitoring efforts are often based on anecdotal knowledge of the species activity pattern, and estimates may be biased. Moreover, for most species, the interest is limited to the presence or absence, while environmental or meteorological factors are neglected. However, identifying the factors that affect the activity pattern of a species may improve survey efforts and species estimates.

Novel techniques, such as passive acoustic monitoring (PAM) through autonomous recording units (ARUs) may be deployed to survey vocal animals. PAM holds the benefit that sampling may be carried out long-term and under any environmental situations to assess patterns and detectability across a range of conditions. Researchers have been able, for instance, to shed light on vocal activity patterns of elusive species (Pérez-Granados & Schuchmann, 2021), adjust occupancy estimates of hard-to-survey species (Jahn et al., 2022) and provide the best monitoring conditions for the studied species (Digby et al., 2014).

Ground-nesting bird populations are particularly declining due to their susceptibility to habitat changes and predation (Reif et al., 2023). Additionally, surveys are typically made difficult for this group of birds by their secretive nature and absence of best-monitoring guidelines (REF). This is the case of the corncrake (*Crex crex*). As a ground-breeding species, its status is locally endangered to extinction throughout Europe with current habitat management practice not sufficient to sustain the species (Bellebaum & Koffijberg, 2018). While Eastern European populations have been counted to safe numbers (BirdLife International, 2021), Western conspecifics have undergone massive declines in the last half-century (Green, 1995; Stowe et al., 1993). Threatened with fast-mowing machines and intense predation due to an over-simplified habitat, the Irish populations of corncrake account XX calling males (2024 survey) are entirely confined to the West Coast and Islands of Ireland (REF).

Species population estimates are inferred from calling male numbers, as females seldom call and are hard to detect with other techniques such as airborne thermal imaging (Parisi et al., in preparation). Males emit their broadcast call, primarily at night, up to ten thousand times (Schäffer, 1995) to attract a female from April and May for the first brood. As a double-brood species, calling is then resumed at the end of June and July to complete another brood (Green et al., 1997; Stowe & Hudson, 1988). The species is typically surveyed at night between 2200-0400hrs in the core breeding areas (Arbeiter et al., 2017). Male calling locations are typically found by visiting the previous year's breeding grounds or following reports from farmers and the lay public.

However, a big unexplored gap remains in the corncrake ecology, as calling activity patterns have never been thoroughly investigated. Calling, for instance, is reduced when the male finds a mate and breeds (Tyler & Green, 1996), and daylight calling is more frequent when a female is close by (Schäffer, 1999). Furthermore, conflicting findings from radio-tracking studies exist about the peak corncrake calling time. Stowe and Hudson (1988) identify the calling peak between 0000-0300hrs as the best window to locate calling males, although empirical knowledge on the exact interval is lacking.

Marginal information exists about the effects of environmental variables on the calling rate of the corncrake. Such data, however, were suggested to affect monitoring programme and the consequent counts, especially for long-range communicating bird species (Budka & Kokociński, 2015). Population estimates may be improved by focusing survey efforts and resources during the most favourable conditions. Tyler and Green (1996) found no significant effect of weather on the calling incidence, while other findings suggest a negative impact of wind on the calling (Henderson, 1983). Such anecdotical observations may be biased due to the radio-tracking technique deployed that could disrupt the calling behaviour (Peake & Mcgregor, 2001; Terry et al., 2005) and the considerable temporal gap with the present study.

Furthermore, accuracy of estimates may be improved by adding information on the detectability of the calling males (Arbeiter et al., 2017), about which contrasting findings exist. Two independent radio-tracking studies found that 75-80% of present males call at a given night in the peak season (Stowe & Hudson, 1988), while another with a bioacoustics application estimated a probability of hearing a corncrake on a given night of 66% (adjusted with individual recognition) (Peake & Mcgregor, 2001). A lower encounter probability of 60% was estimated with just two visits at peak calling time, increasing to 86% with several visits every ten days (Arbeiter et al., 2017). Given the elusive nature of the species, PAM through ARUs may help untangle the corncrake detectability, useful for population estimation.

Using PAM, this study aimed to unravel the way temporal and environmental variables shape the calling behaviour of corncrakes. Our objectives were to collect extended audio data at known locations with calling and breeding males to extract as many calling events as possible. The duration of these events was related to local weather and environmental variables. Additionally, occupancy analysis was carried out to understand the corncrake male detectability.

# 2. Materials and Methods

## 2.1 Study area

ARUs were deployed at corncrake breeding sites to monitor population numbers across four regions on the West Coast of Ireland (Figure 1). Sites hosted at least one breeding corncrake during 2017 and 2021. Habitats comprehend dry and wet semi-natural grasslands grazed or mowed at the end of the corncrake breeding season, and improved grassland regularly fertilised and grazed or mowed.

*Figure 1: Locations of the nine (points) acoustic monitoring sites (twelve deployments) across four sampling regions: (A) Omey Island, (B) Belmullet Peninsula, (C) West Donegal, and (D) East Donegal.*

## 2.2 Acoustic recording

ARUs Song Meters SM4 (Wildlife Acoustics, Inc.) were deployed between April and July 2022. Each location was acoustically monitored for at least one week (168 h) each month at a sampling rate of 44.1kHz, 16-bit in stereo (WAV format) with a continuous schedule and one-hour file duration. A built-in 220 Hz high pass filter was applied to reduce the impact of wind and minimise the likelihood of low-frequency artefacts from the recorder. Recorders were placed on a fence or timber post, as far away from buildings as possible, at a variable height between 0.2-1 m from the ground. Deployments varied in duration according to weather conditions, fieldwork requirements, and battery life. A corncrake called always within 500m, and was therefore detected on the spectrogram.

## 2.3 Acoustic analysis

The acoustic analysis was carried out on twelve randomly selected deployments with corncrakes calling for at least five nights (i.e. confirmed breeding) in the first and second broods. Raw recordings were visually and manually inspected for corncrake vocalisations and supported by direct listening to the sound recording. Automated detections were not used because of the long-duration repetitive nature of the corncrake broadcast calls. Spectrograms were calculated using Kaleidoscope Pro v. 5.6.4 (Wildlife Acoustics Inc.) with an FFT window size of 2048, 0dB gain and -96 dB dynamic range, and default colour palette. Recordings were visualised in 600s intervals (each file was split into six windows) to allow sufficient resolution to identify the corncrake broadcast calls. The start and end of each call were selected using the cursor to display the timestamp, which was reported on a separate Excel table. The minimum temporal interval to consider two calling events as independent was one minute between the end of one event and the start of the next. Hence, each line represented a single calling event, and call duration was calculated as the difference between end and start times.

*Figure 2: Spectrogram of a 3-minute segment from a long-term recording showing two separate (>1 minute apart) and consecutive corncrake calling events. The X-axis represents file time in seconds, whereas the Y-axis is the frequency. Spectrograms were inspected using Kaleidoscope Pro (v. 5.6.4) with an FFT window size of 2048, 0dB gain and -96 dB dynamic range, and a default colour palette.*

## 2.4 Environmental variables

For each deployment, meteorological data was extracted from the Copernicus Climate Change Service (Hersbach et al., 2023) using the latitude and longitude of each ARU. Hourly observations were extracted for temperature at 2m, windspeed as a product of the U and V wind component at 10m, and total cloud cover. As having a significant influence on the bird activity (Kronfeld-Schor et al., 2013), the moon illuminated fraction was also calculated for each hour using the R package *suncalc* (Thieurmel & Elmarhraoui, 2022). A summary of the weather and moon variables is in Table 1.

*Table 1. Summary table of environmental data extracted from the twelve deployment locations using Copernicus Climate Change Service (Hersbach et al., 2023).*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Temperature (°C) | Cloud cover (%) | Wind speed (Km/h) | Moon fraction  (0-1) |
| Mean | 12.07 | 79.16 | 21.33 | 0.46 |
| Std.Dev. | 2.65 | 27.85 | 10.12 | 0.35 |
| Max. | 26.87 | 100.00 | 67.66 | 1.00 |
| Min. | -0.35 | 0.00 | 0.18 | 0.00 |

## 2.5 Statistical analyses

All statistical analyses were carried out using R v.4.3.1 (R Core Team, 2024). Call duration was summed for each hour to avoid temporal pseudo-replications and to match the hourly temperature, wind speed, cloud cover, and moon fraction.

### 2.5.1 Calling activity

A generalised additive model (GAM) was built using the R package mgcv (Wood, 2011) with call duration as the response with a log transformation. Predictors were temperature, cloud cover, wind speed, and moon fraction. Julian date (since 2022-01-01) was included with a cubic regression spline to account for the effect of the change in day length throughout the study period, while hour (from 0 to 23) had a cyclic spline. Additionally, two tensor products were included. One, between cloud cover and temperature due to the influence of the first on the latter and between fraction and cloud cover, to assess how visibility of the illuminated fraction affected the corncrake vocal activity. The site was the random effect, and a Gaussian distribution with an identity link function was applied to the model.

All possible combinations of the explanatory variables were tested using the dredge function from the R package *MuMin* (Bartoń K, 2023)*.* Models were ranked according to the Akaike Information Criterion (AIC) (Burnham & Anderson, 2004). The model with the lowest AICc excluded cloud cover and the tensor product between temperature and cloud cover and was therefore selected. Model assumptions were checked using the residual diagnostic tool in the *DHARMa* R package (Hartig, 2022). The significance of predictors was assessed for alpha = 0.05.

### 2.5.2 Occupancy and detectability

To analyse the chances of hearing a corncrake, we used a presence/absence approach whereby a corncrake was considered acoustically active if the total call duration was above one hour between 2200-0400hrs, and a value of 1 was attributed in the detection matrix, otherwise 0. The interval between 2200hrs and 0400hrs was used as when most of the corncrake census effort is concentrated (NPWS, 2022). The resulting dataset had 12 surveyed sites with a minimum of eight and a maximum of fourteen replicates, as battery duration and weather conditions were variable.

We estimated the corncrake detection probability (p) using the R package unmarked (REF). We were not interested in calculating the presence probability or occupancy (ψ) as we only deployed recorders at occupied sites. Hence, site covariates to describe occupancy variation were not included. Observation covariates that accounted for the variation in detectability were mean night temperature, wind speed, cloud, fraction and the interaction between cloud and fraction. All explanatory variables were scaled and centred before their use in modeling due to the significant difference in magnitude. Subsequently, covariate effects were assessed by assessing all possible model combinations with the dredge function in the Mumin package and selecting the model with the lowest Akaike’s Information Criterion (AIC) (Burnham & Anderson, 2004).

# Results

Recording duration was variable among recorders due to battery life and weather conditions for deployment and retrieval (Table2). In total, 2878h were recorded and analysed across the 12 deployments (Mean ±SD 239.8h ±53.5). The shortest deployment was 178.4h, while the longest 327.3h. The average (±SD) extracted corncrake call duration was 180.31s (±1387.93), highlighting significant variability among call duration, with the longest event of consecutive calling lasting 7.76h.

*Table 2. Summary of deployment duration and the total corncrake duration extracted for each station. SM4s were deployed at known breeding locations on the West Coast of Ireland, as part of the corncrake monitoring programme.*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Deployment | Deployment start | Deployment end | Hours recorded | Total call duration |
| 13\_S07 | 2022-04-21 10:06 | 2022-04-30 09:40 | 215h 34' | 63h 35' |
| 14\_S14 | 2022-05-03 15:39 | 2022-05-12 15:14 | 215h 35' | 7h 0' |
| 14\_S19 | 2022-05-03 11:03 | 2022-05-12 12:21 | 217h 18' | 58h 59' |
| 15\_S12 | 2022-05-25 13:18 | 2022-06-02 14:00 | 192h 42' | 3h 34' |
| 15\_S17 | 2022-05-26 11:19 | 2022-06-02 22:40 | 179h 21' | 35h 51' |
| 15\_S20 | 2022-05-26 11:47 | 2022-06-02 22:10 | 178h 23' | 3h 31' |
| 16\_S13 | 2022-06-08 13:23 | 2022-06-20 14:30 | 289h 7' | 49h 53' |
| 16\_S15 | 2022-06-08 11:54 | 2022-06-20 15:30 | 291h 36' | 83h 23' |
| XX\_S04 | 2022-06-13 22:30 | 2022-06-27 13:47 | 327h 17' | 21h 4' |
| 17\_S09 | 2022-06-23 14:51 | 2022-07-05 16:07 | 289h 16' | 30h 56' |
| 17\_S15 | 2022-06-23 15:15 | 2022-07-05 16:15 | 289h 0' | 47h 36' |
| 18\_S04 | 2022-07-07 18:13 | 2022-07-15 17:21 | 191h 8' | 25h 23' |

## 3.1 Calling activity

The corncrakes at the deployment sites called throughout the diel cycle with most calling activity concentrated at night-time: 81.6% of calls occurred between 2200-0400hrs. The GAM with the lowest AIC explained 42.7% (R2 = 0.412) of the variability in the data and included temperature, wind speed, moon fraction, hour and date, and cloud cover \* moon fraction with significant effects on the calling activity of the corncrake (TableXX). The wind speed had the strongest effect size with a significant negative impact on the calling rate of the corncrake (P=; TableXX; FigureXX). Warmer temperature decreased the calling until approximately 12°C, when the rate levelled off (P=; TableXX; FigureXX). The significant interaction between moon fraction and cloud cover (P=; TableXX; FigureXX) indicated that male corncrakes are acoustically more active during brighter nights. The model also highlighted a large effect size for the hour of the day (P=) and date (P=) with marked diel and seasonal patterns (TableXX; FigureXX). The peak calling activity was approximately between 0100-0200hrs, steeply decreasing after 0700hrs and increasing again at the end of the daylight hours after 2000hrs. Julian date showed a clear unimodal pattern with the peak between 150-170 days, corresponding to May. No issues were highlighted when checking model assumptions, and residual dispersion and autocorrelation were not detected.

*Table 3. Summary table of parametric coefficient (intercept) and smooth terms from the GAM performed to model the effect of weather, moon and temporal variables on the corncrake calling activity. Effective degrees of freedom (Edf) determine the wiggliness of the smooth function, and values closer to 1 describe a linear relationship, while larger values a more curved smooth. Estimated residual degrees of freedom (Ref.Df) are used for computing the P-values (significance at alpha = 0.05). Chi-Squared (X2) is a measure of effect size, with larger values identifying variables with a greater influence on the calling activity.*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Estimate | SE | Z | P |
| Intercept | 5.097 | 0.332 | 15.331 | <0.001 |
|  | Edf | Ref.Df | X2 | P |
| s(Temperature) | 4.476 | 5.623 | 30.988 | <0.001 |
| s(Wind speed) | 3.334 | 4.186 | 108.804 | <0.001 |
| s(Fraction) | 1.770 | 2.199 | 7.644 | 0.026 |
| s(Hour) | 5.674 | 6.000 | 345.000 | <0.001 |
| s(Date) | 2.920 | 3.506 | 25.218 | <0.001 |
| ti(Fraction\*Cloud) | 3.280 | 3.703 | 10.462 | 0.023 |

*Figure 3. Estimated significant effects of weather, moon and temporal variables on the calling activity of the corncrake from the GAM. Call duration was logged transformed. Shaded grey area represent the 95% confidence interval. Temperature, cloud cover and wind speed were extracted using the Copernicus Climate Change Service, while moon fraction was extracted in R, while hour and Julian date (days since 01/01) were retrieved from the file time stamp. Note that covariates are on different y-axis scale for detailed smooth effect. \* for 0.05>P>0.001; \*\*\* for P<0.001. Full model results in Table 3.*

## 3.2 Occupancy and detectability

The number of nights recorded was 121 across the 12 sites, with an average of ten nights recorded. Corncrakes were acoustically active (i.e., >1h acoustic activity) in 70 nights (58%) out of 121. The best model with lower AIC had a weight of 52.6%, while the second 13.3%. Selected covariates were wind speed, cloud cover and moon fraction. This model reported a probability of detecting a corncrake (back-transformed from the logit scale) on a single visit at an occupied site of 0.636 (SE = 0.079) with 95% confidence interval [0.596, 0.679]. Corncrake detectability was negatively affected by wind speed (P=; Table XX) and cloud cover (P=;Table XX), while moon fraction had a positive effect (P=; Table XX).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  | Estimate | SE | z | P(>|z|) |
| Occupancy ψ (logit-scale) |  |  |  |
|  | Intercept | 2.398 | 1.044 | 2.296 | 0.022 |
| Detection probability p (logit-scale) |  |  |
|  | Intercept | 0.858 | 0.265 | 3.242 | 0.001 |
|  | Wind speed | -1.377 | 0.307 | -4.486 | <0.001 |
|  | Cloud cover | -0.894 | 0.342 | -2.615 | 0.009 |
|  | Moon fraction | 0.716 | 0.251 | 2.848 | 0.004 |

# 4. Discussion

Corncrake surveys present some challenges due to the intrinsic with the secretive nature of the species. Moreover, guidelines on the best time to concentrate the efforts are lacking. In this study, a non-invasive approach, using ARUs was taken to determine what weather, moon and temporal factors affect the calling rate. Moreover, we investigated the influence of the same factors on the corncrake male detectability. Ultimately, we drew conclusions on the best conditions for survey calling males of corncrake.

## 4.1 Calling activity

The influence of weather events and moon illumination was examined in other research (Digby et al., 2014; Priyadarshani et al., 2018; Wilson & Watts, 2006; Woods & Brigham, 2008).

### 4.1.1 Temperature

Temperature has a significant effect on the attenuation of sound. In general, temperature has a negative relationship with sound propagation, so that sound absorption is higher at the increasing temperatures (Harris, 1966). From our analysis, corncrakes dropped significantly the calling activity until 10 C, when calling activity was constant. Interestingly, the experimental work carried out by Harris (1966) highlighted that low-frequency sounds of 4 kHz at high relative humidity (70-90%) were exponentially absorbed until 10 °C when stabilised. Corncrakes emit low-frequency (~4 kHz) high energy (96 dB) broadcast calls (Schäffer, 1995) for territorial purposes. Hence, we propose the calling activity is decreased as an evolutionary response to temperature, which decreases the ability to propagate the territorial call. The same result was found for a species of kiwi (*Apterygidae*), which dropped the calling activity after 10 °C (Digby et al., 2014). Although we did not include humidity or pressure that also play a role in sound attenuation, temperature has correlated effects (Yip et al., 2017).

### 4.1.2 Wind

Wind had strong negative effect on the corncrake calling activity. We propose two possible explanations for this result. Wind impacted the ability to detect a corncrake on the recording due to the masking of the signal, which could happen directly on the microphone or by increasing the movements of the vegetation and the concurrent noise (Thomas et al., 2020). The same may apply to canonical and acoustic surveys, lending support to previous observations from Tyler and Green (1996), Digby et al., 2014, and Yip et al. (2017). However, this was likely an issue with strong gust above 40 km/h, while we observed a decrease in calling activity already at 20 km/h. Alternatively, wind attenuates calling more effectively especially for low-frequency callers in open habitat (Priyadarshani et al., 2018) as is the case of the corncrake. Males may save up energy and avoid calling at nights with high wind intensity, as the signal may not be carried effectively.

### 4.1.3 Moon

Our results indicate that corncrakes increase the calling rate during nights with clear sky and full moon. The relationship between moonlight and bird activity is not yet comprehended. Previous research on owl made scientist hypothesise that moonlight increased vocal activity, as providing enhanced visual communication among individuals (Alonso et al., 2021; Penteriani et al., 2010). However, moon light may have as species-specific effect. For instance, seabirds may reduce their calling in bright nights with clear sky to decrease the likelihood of predation (Mougeot & Bretagnolle, 2000). As a nocturnal calling and ground-dwelling species, corncrakes do not use visual clues, and other mechanisms may explain our results. Another ground-nesting species, the common poorwill (*Phalaenoptilus nuttallii*), increases the calling activity during brighter nights (Woods & Brigham, 2008). The authors suggested that the advantage in increasing courtship at this time is that predators are more detectable. We think this is the most likely explanation, although caution should be taken, as corncrakes are typically not visually oriented predators, such as owls or caprimulgids, and other undiscovered explanations may be due to hidden biology mechanism in the corncrake.

### 4.1.4 Temporal variables

The majority of the calling activity was concentrated between midnight and 0300hrs with very few individuals continuing up to 0700hrs when the consecutive calling ceased. Same pattern for the corncrake was corroborated by a study in the United Kingdom (Stowe & Hudson, 1988). However, a non-invasive methodical sampling was not applied yet to investigate the diel calling pattern of the corncrake. Here, therefore, we offer this clarification in the hard-to-define corncrake biology.

Tyler and Green (1996) found a larger calling incidence in June than in May, suggesting that most males in May may be coupled before resuming the calling for the second brood in June. We observed a similar pattern, with the peak in the first week of June. As the season progressed, males decreased their calling activity as most of them were coupled (Arbeiter et al., 2017). Following the logic of a double-brooded species, however, we expected to find another peak in late June. Perhaps, males resume the calling for the second attempt, but with a lower calling activity than in the first attempt.

## 4.2 Detectability

Applying continuous PAM, we found a detection probability of 63% at occupied sites. During peak calling approximately three-quarters of radio-tagged males were calling (Stowe & Hudson, 1988) and Tyler and Green (1996) found that corncrakes were calling in 80% of the night visits. Our results could be underestimating the detectability due to two of the deployments having no corncrake calling for more than an hour over the nights. Given the low detectability of the species which may lead to important population underestimation (Arbeiter et al., 2017), future studies may deploy cheap and available recorders at known breeding sites to adjust the population figures.

Wind speed had the strongest effect in decreasing the probability of detecting a corncrake, supporting the findings from other studies (Digby et al., 2014; Todd et al., 2018; Yip et al., 2017). As discussed above, rather than a masking effect on the recordings, corncrakes may reduce the calling due to the high attenuation capacity of wind. Cloud cover and moon fraction had a negative and positive significant effect on the corncrake detectability, respectively. Although the interaction between the two was not significant, detectability increases at night with clear skies and bright moon illumination.

Together with former works (Thomas et al., 2020; Wilson & Watts, 2006) that found significant associations between environmental variables and detectability. Instead of increasing the number of visits during a breeding season (Tyler & Green, 1996), conservationist and fieldworker could optimise the effort of corncrake surveys on specific conditions. We suggest checking the weather of the night visit and prefer cool nights (<15 C), with low wind speed (<20km/h) and with clear sky and possibly high moon illumination. Although, we understand that combining these conditions is hard, having a few will improve the detections of corncrakes. Peak calling season was attested at around XXX with the best temporal window between 0000-0300hrs when survey should focus.

# Conclusions

Not much is known about the effect of wind on the calling of birds.

Therefore, here we added a new piece of knowledge to the relationship between moon illumination and bird vocal activity.

Female calls?

We hope our study encourages other scientists to carry out acoustic deployments to shed light on other secretive and inconspicuous ground-nesting species, such as red grouse, … Essential biological traits could be uncovered, which may improve the survey effort and strategies.

# Author contributions (CRediT)

* Conceptualization: AP, MG, JOB
* Data curation; AP, MG
* Formal analysis: AP, MG
* Funding acquisition: JC, JM, JOB
* Investigation: AP, MG
* Methodology: AP, MG
* Project administration: JC
* Supervision: JOB
* Writing – original draft: AP
* Writing – review and editing: AP, MG, JC, JM, JOB

# Data Availability

The R code and associated data used in the methods are available from XX (XXX). Other data (e.g., precise georeferenced locations of recorders) are available from the corresponding author on request.

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