Passive acoustic monitoring of an elusive rail, the corncrake (*Crex crex*): calling patterns, detectability and monitoring recommendations

Andrea Parisi1,3, Marie Greaney1, John Carey2, James Moran1, Joanne O’Brien1

1 Atlantic Technological University, Galway, Ireland

2 National Parks and Wildlife Service, Dublin, Ireland

3 Corresponding author email: andrea-parisi@outlook.com

<https://www.sciencedirect.com/journal/global-ecology-and-conservation/publish/guide-for-authors>

# Abstract

Due to their elusive nature, some species are hard to survey. Conservation projects, however, need up to date figures to understand the status of the target species to preserve. We acoustically monitored the corncrake (*Crex crex*), a nationally endangered rail in Ireland, of which little is known about the calling pattern. Twelve long-term acoustic deployments were manually scanned to extract the male broadcast calls. The calling activity was modelled as a response variable predicted by weather, moon and temporal variables. Additionally, detectability according to weather and moon variables was assessed using a single-species occupancy model. We found marked diel (hour, P<0.001) and seasonal (date, P<0.001) patterns in calling activity. The later was also significantly negatively affected by temperature (P<0.001) and wind speed (P<0.001). Furthermore, a significant interaction (P=0.023) between cloud cover and moon illumination existed. The detectability analysis highlighted a 64% probability of detecting a corncrake at an occupied site during a night visit. Wind speed and cloud cover negatively affected the probability of detection, while moon fraction had a positive influence. We concluded that corncrake surveys should focus the effort between 0100-0200hrs in May and June preferring cool nights with clear sky, high moon illumination and wind speed below 20km/h.

*Keywords: Passive acoustic monitoring; endangered species; species conservation; survey recommendations; calling activity; species detectability; ground-nesting bird*

# 1. Introduction

Species monitoring is an essential task for species conservation projects (Hellawell, 1991). Some species, however, due to their intrinsic elusive nature, are hard to detect using canonical survey techniques (Todd et al., 2018; Znidersic et al., 2021). As a result, monitoring efforts are carried out based on anecdotal knowledge of the species activity patterns and in suitable weather conditions only, and, as a result, estimates may be biased (Morelli et al., 2022; Robbins, 1981). For most species, the interest is limited to the presence or absence, while the influence of environmental and temporal factors is neglected (Morelli et al., 2022). However, identifying the drivers that shape activity patterns of a species may improve survey efforts and, consequently, species estimates and conservation (Robbins, 1981; Santos et al., 2009).

Novel technologies, such as passive acoustic monitoring (PAM) through autonomous recording units (ARUs) may be deployed to survey vocal animals (Shonfield & Bayne, 2017). PAM holds the benefits that sampling may be carried out long-term and under any environmental situation to assess patterns and detectability across a range of conditions. Furthermore, the number of signals detected through this PAM outstand traditional ground surveys (Digby et al., 2013; Van Wilgenburg et al., 2017). Researchers have been able, for instance, to detect elusive species (Znidersic et al., 2021), shed light on their vocal activity (Pérez-Granados & Schuchmann, 2021), adjust occupancy estimates (Jahn et al., 2022) and provide best monitoring recommendations (Digby et al., 2014).

In Europe, ground-nesting bird populations are declining due to their susceptibility to habitat changes and predation (Reif et al., 2023). Additionally, surveys are typically difficult for this group of birds due to their elusive nature (Shewring & Vafidis, 2021; Xiao et al., 2017). 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 the Eastern populations have been found to be at safe numbers (BirdLife International, 2021), the Western populations have dramatically declined in the last half-century (Green, 1995; Stowe et al., 1993), and their current numbers are still low. Threatened with fast-mowing machines and intense predation, the corncrake Irish population is currently estimated in 233 calling males (2024 survey), primarily confined to the West Coast and Islands of Ireland (REF).

Species 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 review). Males emit their broadcast call, primarily at night, up to ten thousand times (Schäffer, 1995) to attract a female in April and May for the first brood. As a double-brood species, calling is resumed at the end of June and July to complete another brood (Green et al., 1997; Stowe & Hudson, 1988). Male corncrakes are typically surveyed at night between 2200-0400hrs in the core breeding areas (Arbeiter et al., 2017), and calling locations are found by visiting the previous year's breeding grounds or following reports from farmers and the lay public. A big unexplored gap remains in the ecology of the species, as calling activity patterns have been poorly explored. As a consequence, no evidence-based monitoring guidelines exist for the corncrake.

Knowledge on the vocal diel patterns come from Stowe and Hudson (1988) and Tyler & Green (1996) who identified the calling peak between 2300-0300hrs as the best window to locate calling males, though with little information on the exact calling peak and seasonal pattern. Marginal and contrasting data are available about the effects of environmental variables on the calling rate of the corncrake. Tyler and Green (1996) found no significant effect of weather on the calling incidence, while others anecdotally observed a negative impact of wind on the male calling (Henderson, 1983). Nonetheless, environmental variables were suggested to affect monitoring programme and the consequent counts, especially for long-range communicating bird species (Budka & Kokociński, 2015). Hence, estimates may be improved by focusing survey efforts during the most favourable conditions.

Furthermore, accuracy of estimates may be improved by adding information on the detectability of the calling males (Arbeiter et al., 2017). 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). Despite the substantial body of literature on the corncrake detectability, no studies accounted for the influence of weather or moon in the analyses. Given the elusive nature of the species, PAM through ARUs may help disentangle poorly studied aspects of the behaviour of the corncrake and adjust estimates.

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 males to extract and measure the duration of the calling events. Event duration was related to local weather and environmental variables, while an occupancy analysis was carried to understand the influence of the environmental variables on the corncrake detectability. As a results, we were able to provide best monitoring conditions for calling males.

# 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 between 2017 and 2021. Primary habitats included 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. Marine waters and coastal habitats were proximal to the deployments.

*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. Locations were acoustically monitored for at least one week (168 h) each month at a sampling rate of 44.1kHz, 16-bit in stereo with a continuous schedule and one-hour file duration (WAV format). A built-in 220 Hz high pass filter was applied to reduce the impact of wind and minimise the effect of low-frequency artefacts. ARUs 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. Corncrakes were reported in proximity to the recorder position.

## 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 listening to the sound signals. Automated detections were not used because of the repetitive pattern 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, -96 dB dynamic range, and default colour palette. Spectrograms were visualised in 600s intervals (each file was split into six windows) to allow sufficient resolution to detect the corncrake calls. The start and end of each call were selected using the cursor to display the timestamps, which were reported on an Excel table. On each line, call duration was calculated as the difference between end and start times. The minimum temporal interval to consider two separate calling events as independent was one minute between the end of one event and the start of the next.

*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 duration (HH:MM:SS), whereas the Y-axis is the frequency (kHz). Spectrograms were manually checked 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 every deployment, meteorological data was extracted from the Copernicus Climate Change Service (Hersbach et al., 2023) using the latitude and longitude of ARUs. Hourly observations were extracted for temperature at 2m, total cloud cover, and windspeed as a product of the U and V wind component at 10m. 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)*. Wind speed was calculated using the U-V components as √(windU2+windV2) × 3.6. SD = standard deviation.*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Temperature (°C) | Cloud cover (%) | Wind speed (Km/h) | Moon fraction  (0-1) |
| Mean | 12.07 | 79.16 | 21.33 | 0.46 |
| ±SD | 2.65 | 27.85 | 10.12 | 0.35 |
| Maximum | 26.87 | 100.00 | 67.66 | 1.00 |
| Minimum | -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, cloud cover, wind speed, 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 logarithmic transformation. Predictors were temperature, cloud cover, wind speed, and moon fraction with a cubic regression spline. The same spline was applied to Julian date (since 2022-01-01) included to account for the season effect, 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 cloud cover and moon fraction, 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 corrected Akaike Information Criterion (AICc) (Sugiura, 1978), and the model with the lowest value was selected for further analysis. Model assumptions were checked using the residual diagnostic tool in the R package *DHARMa* (Hartig, 2022). The significance threshold of predictors was at α = 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 (i.e., corncrake surveys window) each night, and a value of 1 was attributed in the detection matrix, otherwise 0. The detection dataset consisted of 12 surveyed sites with a minimum of eight and a maximum of fourteen replicates.

We estimated the corncrake detection probability (*p*) using the R package *unmarked* (Kellner et al., 2023). 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, cloud cover, wind speed, fraction and the interaction between cloud and fraction. All explanatory variables were scaled and centred before their use in modelling due to the significant difference in magnitude. Subsequently, covariate effects were assessed by assessing all possible model combinations with the dredge function in the R package *MuMIn* (Bartoń K, 2023) and selecting the model with the lowest AICc (Sugiura, 1978).

# Results

Recording duration was variable among recorders due to battery life and weather conditions for deployment and retrieval (Table 2). In total, 2878 h were recorded and analysed across the 12 deployments (Mean ±SD 239.8 h ±53.5 h). The shortest deployment was 178.4 h, while the longest lasted 327.3 h. In total, 8600 single calling events were manually recorded amounting to a call duration of 430.73 h with an average (±SD) of 180.31 s (±1387.93 s). The high standard deviation highlighted significant variability among call duration, with the longest event of consecutive calling lasting 7.76 h.

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

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Deployment | Deployment start | Deployment end | Hours recorded | 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 AICc (= 4189.4) explained 42.7% (R2 = 0.412) of the variability in the data. Predictors were temperature, wind speed, moon fraction, hour and date, and cloud cover \* moon fraction with significant effects on the calling activity of the corncrake. Among weather variables, the wind speed had the strongest effect with a significant negative relationship with the calling rate (P<0.001; Table 3; Figure 3). Warmer temperatures decreased the calling until approximately 12°C, when the rate remained steady (P<0.001; Table 3; Figure 3). Significant effects for moon illumination were found singularly (P=0.023; Table 3; Figure 3) and in the interaction with cloud cover (P=0.023; Table 3; Figure 3) indicating that male corncrakes are acoustically more active during brighter nights.

The model also reported a marked diel pattern for hour (P<0.001; Table 3; Figure 3) and seasonal pattern for date (P<0.001; Table 3; Figure 3). 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 the end of May start of June. No issues were highlighted when checking model assumptions, and concurvity and autocorrelation were not detected.

*Table 3. Summary table of the parametric coefficient (intercept) and smooth terms from the top-ranked GAM performed to model the effect of environmental 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. Chi-Squared (X2) is a proxy for 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(Moon 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 log-transformed. Shaded grey area represent the 95% confidence interval. In the interaction between cloud cover and moon fraction, NAs were set to transparent. Temperature, cloud cover and wind speed were extracted using the Copernicus Climate Change Service, moon fraction was extracted in R, while hour and Julian date (days since 01/01) were retrieved from file time stamps. Covariates are on different scale. \* 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 per site. Corncrakes were acoustically active (i.e., >1h/night) in 70 (58%) out of 121 nights. The top-ranked model (AICc = 138.5) included cloud cover, wind speed and moon fraction as covariates (no interaction). This model reported a probability (back-transformed from the logit scale) of detecting a corncrake on a single visit at an occupied site of 0.636 (SE = 0.079), 95% confidence interval [0.596, 0.679]. Corncrake detectability was negatively affected by cloud cover (P=0.009; Table 4) and wind speed (P<0.001; Table 4), while moon fraction had a positive effect (P=0.004; Table 4).

*Table 4. Results of the occupancy model with the lowest AICc (formula = ~temp + wdsp + cloud \* fraction ~ 1). SE = standard error; z = z-score for difference in standard deviations from the mean and relative P value. Estimates are in the logit scale.*

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

# 4. Discussion

Corncrake surveys present some challenges due to the elusive 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 the influence of weather, moon and temporal factors on the corncrake calling activity. Moreover, we investigated how the same factors affect the male detectability. Ultimately, we drew conclusions on the best conditions to survey this species.

## 4.1 Calling activity

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

Temperature has a significant effect on the attenuation of sound, as sound absorption (inverse of propagation) is higher at the increasing temperatures (Harris, 1966). From our analysis, corncrakes dropped significantly the calling activity until 12 °C, remaining stable at the increasing temperatures. Interestingly, the experimental work carried out by Harris (1966) highlighted that low-frequency sounds at medium-high humidity (70-90%) were strongly absorbed until around 10 °C, when propagation was constantly low. 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. A similar 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 propagation, temperature has correlated effects with both (Yip et al., 2017).

Wind had a 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 Digby et al. (2014) and Yip et al. (2017). However, this was likely an issue with strong gust above 40 km/h, while we found a decrease in calling activity already at 20 km/h. Alternatively, wind attenuates calling more effectively in open habitat (Priyadarshani et al., 2018), especially for low-frequency calling species, as is the corncrake. Thus, males may save up energy and avoid calling at nights with high wind intensity, as the signal may not be carried effectively.

Our results indicated 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, as a nocturnal calling and ground-dwelling species, corncrakes do not use visual clues, and moonlight may have as species-specific effect. For instance, another ground-nesting species, the common poorwill (*Phalaenoptilus nuttallii*) increases the calling activity during bright 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, as males carry on their courtship calling while being able to spot aerial (e.g., owls) or ground (e.g., foxes) predators more easily. Although caution should be taken, as corncrakes are not aerial feeders, such as the caprimulgids, and other undiscovered mechanisms may explain the relationship with moonlight.

The majority of the calling activity was concentrated between 2200-0500 hrs with very few individuals continuing up to 0700 hrs, when the consecutive calling ceased. Same pattern was corroborated by a corncrake study in the United Kingdom (Stowe & Hudson, 1988). Here, we provided the detailed diel calling pattern of the corncrake using a non-invasive technique, which limited the influence on the individuals that were not caught or tagged.

Tyler and Green (1996) found a larger calling incidence in June than in May and suggested that most males in May are coupled before resuming the calling for the second brood at the end of June. We observed a similar pattern, with our calling peak in the first week of June and as the season progressed, males decreased their calling activity, likely because 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 that was not observed. Results did not change even when the number of basis dimensions (k) that control the smooth wiggliness was increased for the Julian date. Perhaps, males resumed the calling for the second attempt, but with a lower calling activity than earlier in the season.

## 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), while 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 per night. 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 on large scale for long-term at breeding sites (calling and not calling) to retrieve accurate occupancy and detectability figures.

Wind speed had the strongest effect in decreasing the probability of detecting a corncrake, supporting findings from other works (Digby et al., 2014; Todd et al., 2018; Yip et al., 2017). As discussed above (4.1), rather than a masking effect on the recordings, corncrakes may reduce the calling due to the sound attenuation effect of wind. Cloud cover and moon fraction had negative and positive significant relationships with probability to detect a corncrake, respectively. Although the interaction between the two was not significant, detectability increased at night with clear skies and bright moon illumination.

Together with former studies (Thomas et al., 2020; Wilson & Watts, 2006) that found significant associations between environmental variables and bird detectability, we found that the likelihood of detecting a corncrake could be increased by changing the survey protocol. Instead of incrementing the number of visits during a breeding season (Tyler & Green, 1996), conservationists could optimise their efforts by focussing on night with specific conditions. We suggest checking the weather of the night visit and favour cool nights (<15 °C), with low wind speed (<20km/h) and with clear sky and possibly high moon illumination. Although, we understand that a combination of these conditions is unlikely, having a few will still enhance the chances of hearing a corncrake. Peak calling season was at the end of May with the best temporal window between 0100-0200hrs when survey should focus.

# Conclusions

Little is known about the influence of environmental and temporal variables on the calling activity of corncrakes. Surveys rely on males as a proxy for population abundance. Hence, understanding the influence of such variables could make surveys more efficient and, in turn, estimates more accurate. We found a negative influence of temperature and wind speed, while brighter nights (clear sky and high moon illumination) made corncrake more chatty. By analysing the same variables from a detectability point of view we found that wind decreased detectability, while corncrakes during brighter nights were more detectable. Here, we added a new piece of knowledge to the breeding ecology of a nationally endangered ground-nesting species. Unfortunately, female numbers cannot be inferred as seldom calling. If enough data are gathered, however, it would be interesting to know whether environmental or temporal factors play a role in triggering such behaviour. We hope our study encourages other scientists to carry out acoustic deployments to shed light on other elusive and inconspicuous ground-nesting species. Essential biological traits could be uncovered, improving survey efforts and address conservation strategies.

# Author contributions (CRediT)

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

# Data Availability

The R code and the associated dataset 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.

# Funding sources

This work was supported through the EU grant LIFE18 NAT/IE/000090 LIFE Atlantic Crex.

# Acknowledgements

We are grateful to all the field workers and officers who helped report the calling corncrake locations. We thank the farmers for access to their land and for their dedication to preserve the corncrakes in Ireland.

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