How to count a vagabond? – Population estimation in the Corncrake *Crex crex*

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Monitoring rare species often fails to account for imperfect detection. Corncrake occurrence is only indicated by calling males, which are highly mobile within the breeding season, making it difficult to determine actual breeding population sizes.

We conducted nocturnal counts at intervals of approx. 10 days during the breeding season over multiple years. A multi-state occupancy model for open populations was used to estimate numbers of occupied calling sites alongside with immigration and departure probabilities for each interval, while accounting for imperfect detection. A hierarchical formulation of the model enabled us to estimate also the number of occupied calling sites in subareas, where only two surveys per season took place. Thus a cumulative detection probability taking into account inter-seasonal movements could be calculated for the first time for Corncrakes.

Based on an average detection probability of 0.60 (CrI: 0.56-0.65) estimated numbers of males present during the two annual surveys was substantially higher (up to 50 %) than the numbers counted. Numbers of calling males peaked in mid and late May, when also most females started first broods. We found a high degree of turnover in site occupancy. Low detection probability associated with constant departure strongly limited the proportion of birds that can be detected even with frequent counts at 10-day intervals. Because timing of mowing is based on calling site occupancy in the study area, effective protection depends on information on Corncrake occurrence. Repeated nocturnal surveys during May and June are recommended to increase encounter probability for conservation purpose, but reliable population estimates require an analysis with open population models, especially at breeding sites where only few counts are feasible.

Key words: Corncrake *Crex crex*, detection probability, monitoring, multi-state occupancy model, open population

1. Introduction

Effective conservation management depends on reliable information on the abundance of the target species (Yoccoz *et al.* 2001). Many birds are monitored using the number of singing males as a proxy for breeding population size. During such studies it is unlikely that all individuals present were actually encountered and especially in rare species true population size is often underestimated (Yoccoz *et al.* 2001, MacKenzie *et al.* 2009).

Corncrakes *Crex crex* are medium-sized rails that breed in grass meadows. Staying concealed in tall vegetation most of the time, their occurrence can only be acoustically detected (Green *et al.* 1997). Males give loud, disyllabic calls almost continuously during the night to attract females (Schäffer 1995). Corncrakes show a successive polygamous breeding system and brood care is only provided by females. During egg-laying nocturnal calling activity of males is reduced for 7-10 days (Tyler & Green 1996). When females start incubating, males resume calling in the same or in a newly established territory (Schäffer 1999). Males may move long distances to new breeding sites especially after their original home ranges are mown, but also in the absence of mowing (Schäffer 1999, Šklíba & Fuchs 2002). Because Corncrakes are highly mobile within the breeding season, actual population size is difficult to determine and probably underestimated by 20-30 % with a single nocturnal count (Peake & McGregor 2001).

Corncrakes are threatened directly by grassland mowing and indirectly by habitat loss due to land use intensification and suffered severe population declines all over western Europe (Green *et al.* 1997). Monitoring data are important to reveal local changes in population size and to evaluate the effectiveness of conservation measures.

Here we present a staggered arrival site-occupancy model with relaxed closure assumption to estimate breeding population size and derive recommendations to optimize Corncrake census.

2. Methods

The study area comprises about 54 km² of grassland polders in the Lower Oder Valley National Park (53° 03' N, 14° 18' E), and holds the largest Corncrake population in Germany. Floodplain meadows are inundated during winter until early April and vegetation is dominated by reed canary grass *Phalaris arundinacea* and sedges *Carex* spp.. Most meadows are annually mown or grazed.

Timing of Corncrake broods was determined on the basis of nests found during the breeding season (n=5) and chicks observed or captured during mowing (n=47). Chick age was assessed using body mass (GREEN & TYLER 2005) and by comparing feather development with photographs of chicks of known age (D. WEND, unpublished). This was used to calculate the date of the start of egg-laying, assuming an average incubation and egg-laying period of 25 days (GREEN *et al.* 1997).

Calling male Corncrakes were counted at night throughout the entire study area on two occasions in mid-May and mid-June. Additionally, we conducted nocturnal counts at intervals of approx. 10 days in subareas from early May to late July in two periods (1998-2000 and 2012-2015). All calling locations within a radius of 200 m were attributed to the same individual and considered as one calling site, assuming neighbouring males keep an average distance of 250 m to each other (PEAKE & MCGREGOR 2001). However, sites without calling activity during three subsequent checks (30 days) were considered as deserted and new observations of calling males at the same site after three subsequent checks were treated as a new calling site of a different individual. During the entire study 412 calling sites were recorded. To estimate the true number of occupied calling sites for each 10-day period over a single breeding season, we used a multistate occupancy model for open populations (KENDALL *et al.* 2013). One of the key assumption of the model is that a calling site can be occupied only once during a breeding season. The model estimates the probability that a calling site was occupied during the season (i.e. occupancy) by accounting for imperfect detection. In contrast to traditional occupancy models the open population model relaxes the closure assumption between visits. Within the 10-day intervals, the model allows a Corncrake to colonize a previously unoccupied calling site (i.e. arrival probability) and to desert an occupied calling site (i.e. departure probability). The basic structure of our model for a single season is similar to the occupancy model with relaxed closure assumption developed by KENDALL *et al.* (2013). The differences between years were modelled either as fixed effects (arrival probability) or as random effects (occupancy, departure probability, detection probability). This hierarchical formulation of the model also enabled us to estimate the number of occupied calling sites in subareas, where only two surveys per season took place. The population size was estimated as a derived parameter summing the number of occupied calling site during each 10-days period. Similarly, the cumulative detection probabilities for different numbers of annual counts were calculated as derived parameter by dividing the number of recorded calling sites up to visit j (i.e. the male has arrived, has not departed and was detected) through the total number of occupied calling sites. To estimate model parameters we used a Bayesian approach based on Markov-chain Monte Carlo methods (MCMC; LINK *et al.* 2002). MCMC analyses were conducted using JAGS 3.4.0 (PLUMMER 2003) and were executed in R using the R add-on library *rjags*. We used vague priors for all parameters, and posteriors were based on two parallel chains with 20,000 iterations each, discarding the first 10,000 values and thinning the remainder by using every 10^{th} value. We used the means of the simulated values of the posterior distributions as point estimates of the parameters and 2.5 % and 97.5 % quantiles as estimates of the 95 % Bayesian credible intervals (CrI).

3. Results

Model estimates of males present during the two annual surveys were substantially higher than the numbers counted (Fig. 1). Observed numbers of calling Corncrakes were higher mid-May (mean 105 ± 45 calling males) than mid-June (mean: 61 ± 22 calling males). Average estimates were 172 (± 58) calling males for mid-May and 123 (± 39) calling males for mid-June, respectively, implying that occupied calling sites were underestimated up to 50 %.

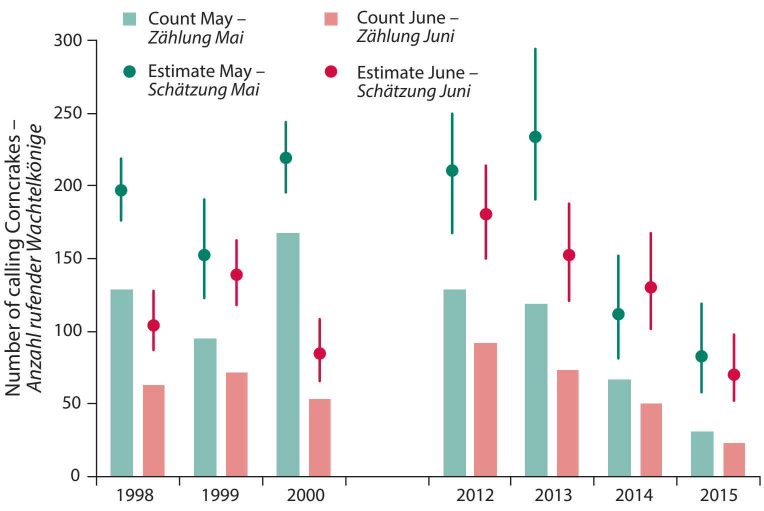

Fig. 1: Number of calling Corncrakes counted mid-May and mid-June and estimates (± 95 % credible intervals) in years with repeated counts (1998-2000, 2012-2015) – *Anzahl rufender Männchen nach Synchronzählung Mitte Mai und Mitte Juni und Schätzungen (± 95 % Vertrauensintervalle) in Jahren mit wiederholten Zählungen (1998-2000, 2012-2015).*

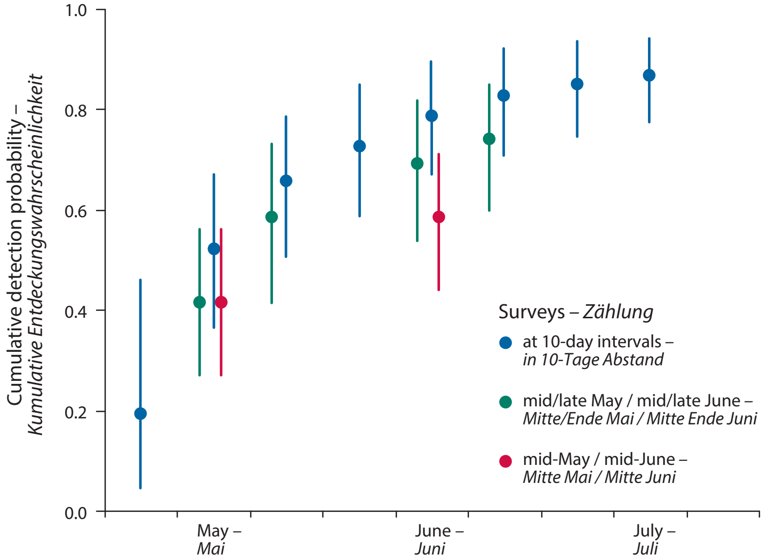

Fig. 2: Cumulative detection probability (± 95 % credible intervals) of calling Corncrakes during the breeding season shown for different census efforts; estimates include estimated arrival and departure probabilities between each survey interval – *Kumulative Entdeckungswahrscheinlichkeit (± 95 % Vertrauensintervall) von rufenden Wachtelkönigen während der Brutsaison, gezeigt für unterschiedlichen Zählaufwand; Schätzungen beinhalten die geschätzte Zu- und Abwanderungsrate zwischen jeder Zählung.*

Detection probability was on average 0.60 (95 % CrI: 0.56-0.65) during single counts. When two counts per season are performed in mid-May and mid-June, a cumulative detection of only 0.58 (95 % CrI: 0.44-0.71) of the birds present during the breeding season was reached. Two additional counts in late May and late June would increase the total encounter probability to 0.74 (95 % CrI: 0.60-0.85). With eight counts at 10-day intervals cumulative detection probability was 0.86 (95 % CrI: 0.78-0.94) by the end of the study period (Fig. 2).

We observed continuous arrival (median: 0.08 per 10-day interval) and departure (median: 0.20 per 10-day interval) throughout the breeding season. As a result of the seasonal pattern in arrival and departure, occupancy of calling sites peaked in mid and late May. The majority of first broods were also initiated in the second half of May (Fig. 3). Calling activity of males gradually ceased during July.

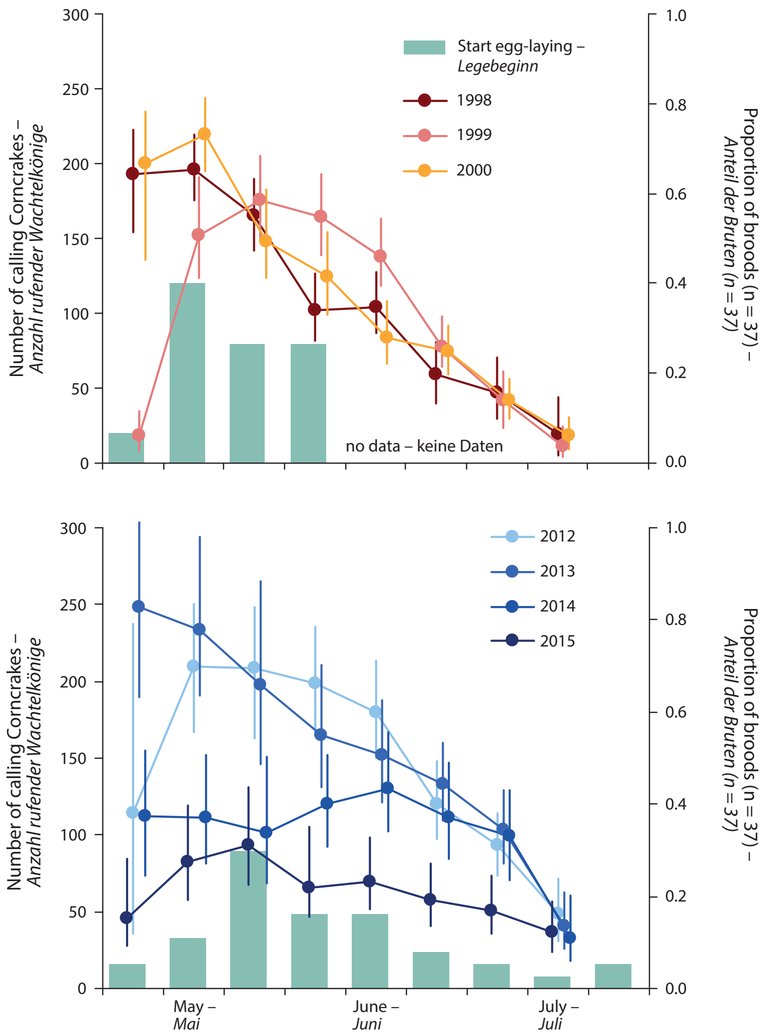

Fig. 3: Estimates (± 95 % credible intervals) of the number of calling Corncrakes during the breeding period and seasonal progress of brood initiation – *Schätzung (± 95 % Vertrauensintervalle) der Anzahl rufender Wachtelkönige und Anteil der begonnenen Bruten im saisonalen Verlauf.*

4. Discussion

Open population occupancy models applied to repeated counts are a powerful tool for inference on population size when dealing with mobile species. Corncrakes are known for distinct inter-seasonal movements (Schäffer 1999, Mikkelsen *et al.* 2013). Spontaneous departure regularly occurred during the breeding season and mowing presumably increased male dispersal, which was also confirmed for radio-tracked males in the same study area and period (Bellebaum *et al.* 2016). Because males often disperse over long distances (>100 km) to new calling sites during the breeding season, male Corncrakes may use a system of early and late breeding sites across large parts of the continent (Koffijberg *et al.* 2016).

Our model revealed that even in a species which is easily detectable by its distinctive calling behaviour, a large portion of occupied sites is missed with a single or few nocturnal counts. We found a high degree of turnover in local site occupancy, which further reduced cumulative detection probability. Numbers of Corncrakes present were underestimated by up to 50 % with a single count, which is considerably higher than former assumptions of 20-30 % underestimation from studies of radio-tracked males in Scotland (Stowe & Hudson 1988, Tyler & Green 1996, Peake & McGregor 2001). Peake & McGregor (2001) showed that individual males call less frequently than formerly assumed and found a similar detection probability of 0.66 with a single count. When paired, male Corncrakes reduce or quit nocturnal call activity (Tyler & Green 1996). A lower song output during pair bonds associated with lower encounter probability was also observed for passerine species (Gibbs & Wenny 1993, Amrhein *et al.* 2007). In Nightingales *Luscinia megarhynchos* 66 % (Amrhein *et al.* 2007), in Kentucky Warblers *Oporornis formosus* 65 % and in Ovenbirds *Seiurus aurocapillus* only 50 % (Gibbs & Wenny 1993) of paired males present were detected during common surveys. Similarly, the reduction of nocturnal call activity of males accompanying females could also explain low detection probability of individuals in Corncrakes during single visits.

Broods started later than mid-June were probably second clutches because chicks from first broods were already independent by that time. Corncrakes usually produce two broods per season (Green *et al.* 1997, Schäffer 1999). Unlike these studies we found no distinct peak of second broods, but broods were initiated throughout the breeding season until late July. A second peak may still exist, because in our study most broods were detected during mowing, and few meadows were mown in late July and August so late hatched chicks could fledge unnoticed.

Because of large numbers of calling males and mowing is needed to maintain high habitat quality, a variable proportion of meadows occupied by Corncrakes is still mowed during the breeding season in the study area. To avoid destruction of nests and broods, additional counts are needed to identify more occupied fields. When newly arrived males are able to attract a female quickly they will only call for a few days (Tyler & Green 1996). Hence, with infrequent counts especially sites with broods may be overlooked (McGregor *et al.* 2000). While repeated nocturnal counts during May and June can be recommended to increase encounter of Corncrake occurrence for conservation purposes, they will still underestimate total population size. With both low detection probability and constant arrival and departure, even counting at 10-day intervals will require analysis with open population models. This becomes increasingly important when only few counts per season are conducted.

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5. Zusammenfassung

Arbeiter, S., T. Roth, A. Helmecke, H.-J. Haferland & J. Bellebaum 2017: Wie zählt man einen Vagabunden? – Bestandsschätzung beim Wachtelkönig *Crex crex*. Vogelwelt 137: 75–79.

Die Bestandserfassung von seltenen Arten berücksichtigt oft nicht deren mangelhafte Entdeckungswahrscheinlichkeit. Wachtelkönige können nur anhand der Rufaktivität von Männchen nachgewiesen werden. Aufgrund deren hohen Mobilität während der Brutzeit ist eine Schätzung des tatsächlichen Bestands erschwert. Wir haben in mehreren Jahren rufende Männchen im Abstand von ca. 10 Tagen gezählt. Ein „multi-state occupancy"-Modell für offene Populationen wurde verwendet, um die Anzahl von besetzten Rufplätzen sowie Zu- und Abwanderungswahrscheinlichkeiten und die Entdeckungswahrscheinlichkeit für jedes Zählintervall zu schätzen. Die hierarchische Formulierung des Modells ermöglichte es uns auch die Anzahl der besetzten Rufplätze in Teilgebieten zu schätzen, in denen nur zwei Zählungen pro Saison durchgeführt wurden. So konnte zum ersten Mal eine kumulative Entdeckungswahrscheinlichkeit unter Berücksichtigung von Abwanderungen innerhalb der Brutsaison für Wachtelkönige berechnet werden.

Ausgehend von der ermittelten Entdeckungswahrscheinlichkeit von 0,60 (CrI: 0,56-0,65), lag die geschätzte Anzahl der Rufer während der beiden jährlichen Synchronzählungen deutlich höher (bis zu 50 %) als die Zählung. Die Besiedlung

von Rufplätzen erreichte ihren Höchststand Mitte und Ende Mai. Zu diesem Zeitpunkt wurde auch die Mehrzahl der ersten Gelege begonnen. Wir stellten über die gesamte Brutsaison einen hohen Grad an Zu- und Abwanderung von Männchen fest. Die geringe Entdeckungswahrscheinlichkeit zusammen mit kontinuierlich stattfindender Abwanderung begrenzte den Anteil der entdeckten Vögel auch bei häufig stattfindenden Zählungen deutlich. Während mit zwei Zählungen Mitte Mai und Mitte Juni nur 0,58 (95 % CrI: 0,44-0,71) aller anwesenden Vögel entdeckt wurden, wurde mit acht Zählungen im 10-Tage Abstand eine gesamte Entdeckungswahrscheinlichkeit von 0,86 (95 % CrI: 0,78-0,94) bis zum Ende der Brutsaison erreicht. Da der Zeitpunkt der Landnutzung im Untersuchungsgebiet anhand von besiedelten Flächen bestimmt wird, sind Informationen über Wachtelkönigvorkommen entscheidend für einen wirksamen Schutz. Wiederholte nächtliche Zählungen während Mai und Juni sind zu empfehlen, um die Entdeckungswahrscheinlichkeit von besiedelten Flächen zu erhöhen, aber für eine verlässliche Schätzung des lokalen Brutbestands sind „Site occupancy"-Modelle für offene Populationen erforderlich, besonders in Brutgebieten wo nur wenige Zählungen durchgeführt werden.

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