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SHORT REPORT

Activity patterns of breeding Hen Harriers *Circus cyaneus* assessed using nest cameras

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ABSTRACT
Nest camera footage from 13 Hen Harrier *Circus cyaneus* nests was analysed to document patterns of adult attendance, incubation, brooding and prey delivery rates. Nest attendance was high throughout the incubation stage and began to decrease when chicks were five days old. Chick provisioning increased gradually after hatching and peaked when the chicks were five days old. Daily activity rates were highest during the middle of the day, from 08:00 to 19:00 hours.

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Hen Harriers *Circus cyaneus* are listed as an Annex-I species by the European Union Birds Directive (OJEU 2010) and are a species of conservation concern in Ireland and the United Kingdom (Colhoun & Cummins 2013, Eaton *et al.* 2015). The rarity, declining populations and protected status of this species have led to considerable conservation and monitoring efforts, both as part of national population surveys (Hayhow *et al.* 2013, Ruddock *et al.* 2016) and monitoring associated with impact assessment of developments in upland areas. This work is often difficult due to the species' secretive nature and low detection rates, with survey protocols recommending multiple watches of between 2.5 and 6 hours duration throughout the season to confirm the presence of breeding pairs (Hardey *et al.* 2009). Detection of breeding birds and location of nests can be further hindered in certain habitats, such as plantation forest, where birds approaching the nest may remain hidden from view (Hardey *et al.* 2009). A good understanding of the nesting ecology of the species is crucial for effective monitoring and, ultimately, for its conservation. While a considerable amount of research has been published on different aspects of Hen Harrier breeding success in relation to environmental and anthropogenic factors and its consequences on population trends (Etheridge *et al.* 1997, Green & Etheridge 1999, Redpath *et al.* 2002, Amar *et al.* 2008, Irwin *et al.* 2011), publications on the behaviour of nesting birds are limited to work carried out in Scotland by direct observations at nest sites (Balfour & Macdonald 1970, Watson 1977, Picozzi 1978, Dickson 1995, Redpath & Thirgood 1997, Amar *et al.* 2003, Leckie *et al.* 2008).

Remote cameras have been widely used as a tool to monitor different aspects of the ecology of nesting raptors, including diet, nest survival and predation (Smithers *et al.* 2005, Margalida *et al.* 2006, Cox *et al.* 2012). Nest cameras also enable accurate data collection on behavioural patterns of breeding adults which can improve our understanding of nesting ecology and also inform nest finding and population monitoring protocols. Here we present data from nest cameras used at Hen Harrier nests in Ireland, to determine patterns of nest attendance, provisioning rates and activity of breeding birds during different stages of the breeding cycle.

We deployed digital trail cameras, under licence, at Hen Harrier nests in the Ballyhoura Mountains, West Clare and Slieve Aughty Mountains (Counties Cork, Clare and Galway in Ireland) during three consecutive breeding seasons (2008–2010). This resulted in recordings from a total of 13 nests which were analysed to quantify behaviours occurring between 05:00 and 22:00 hours. As Hen Harriers are a ground nesting species, the nestlings start to move away from the immediate nest area (and the coverage of nest cameras) when they are just two weeks old. For this reason, only recordings from 10 days prior to hatching and up to 14 days after hatching of the first chick (hereafter 'hatching') were included in the analyses.

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Nest cameras were activated by motion detection via a passive infra-red sensor. While this technology minimizes the need for regular battery and memory card replacement, it can result in incomplete recordings if certain activities are not detected by the motion sensor. A preliminary assessment of nest camera recordings revealed that gaps of less than 30 minutes in length could be attributed to periods of inactivity with certainty, whereas gaps longer than 30 minutes could reflect periods of inactivity, but could, in a small number of cases include behaviours undetected by the motion sensors. Therefore, we only analysed recordings that included three or more continuous hours of recordings where gaps between sequences were less than 30 minutes long.

The proportion of time spent by female Hen Harriers in attendance (on the nest or next to the nest) and time spent actively incubating or brooding (sitting on or covering eggs or chicks) across the day was systematically extracted from the nest camera recordings. Female Hen Harriers are responsible for incubation, brooding and feeding the young, with only anecdotal evidence of the male's involvement in these behaviours (Watson 1977). Female Hen Harriers typically feed away from the nest before the eggs hatch (Hardey *et al.* 2009), so the timing of prey deliveries to the nest was recorded only after hatching of the first egg. Diurnal patterns and variation in nest attendance, incubation or brooding, and prey deliveries across the nesting period were recorded according to the time of day (05:00–22:00 hours) and stage of the nest in relation to the hatching of the first egg (from day −10 before hatching to day +14).

The selection criteria used to exclude non-continuous recordings resulted in a total of 878 hours of recordings analysed from the 13 Hen Harrier nests; all nests were active for the period analysed from day −10 to day 14. Gaps in recordings which resulted in exclusion from analyses can be attributed to the low sensitivity of motion sensor technology currently available in trail cameras. While these criteria ensured the quality of the recordings analysed and provided representative coverage across different times of day and nesting stages, it suggests that nest monitoring of open habitat, ground nesting species would be optimized with continuous recording cameras.

Nest attendance was very high, with adult female Hen Harriers remaining in attendance at the nest for at least 90% of the time between 05:00 and 22:00 hours up until seven days after hatching. Attendance progressively decreased thereafter until day 14 after hatching, by which time females were only spending approximately half of their time at the nest (Figure 1 and Table S1 in online supplementary material). Incubation and brooding behaviours followed a similar pattern to nest attendance, with females spending more than 75% of the time incubating or brooding until day 5 after hatching. Brooding then decreased gradually to 22% by day 14 after hatching (Figure 1 and Table S1 in online supplementary material). Coinciding with decreases in brooding and attendance, the nestlings started to move away from the immediate nest cup into the

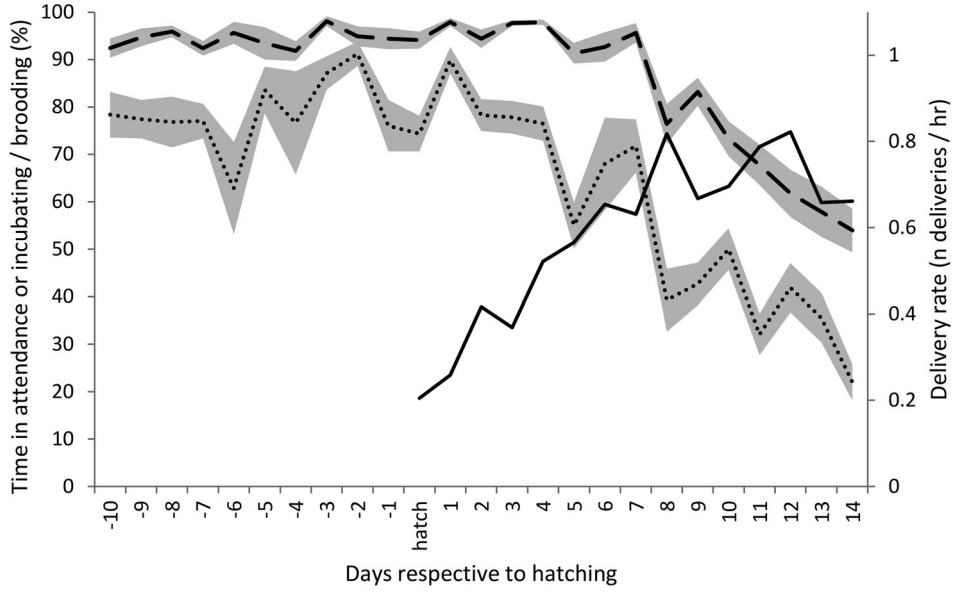

Figure 1. Mean daily rates of total time spent by adult Hen Harriers at the nest (attendance; dashed line), portion of time spent actively incubating or brooding (dotted line) and rates of prey deliveries to nests (continuous black line). Rates are presented by day relative to hatching of the first chick, shaded areas represent ±se.

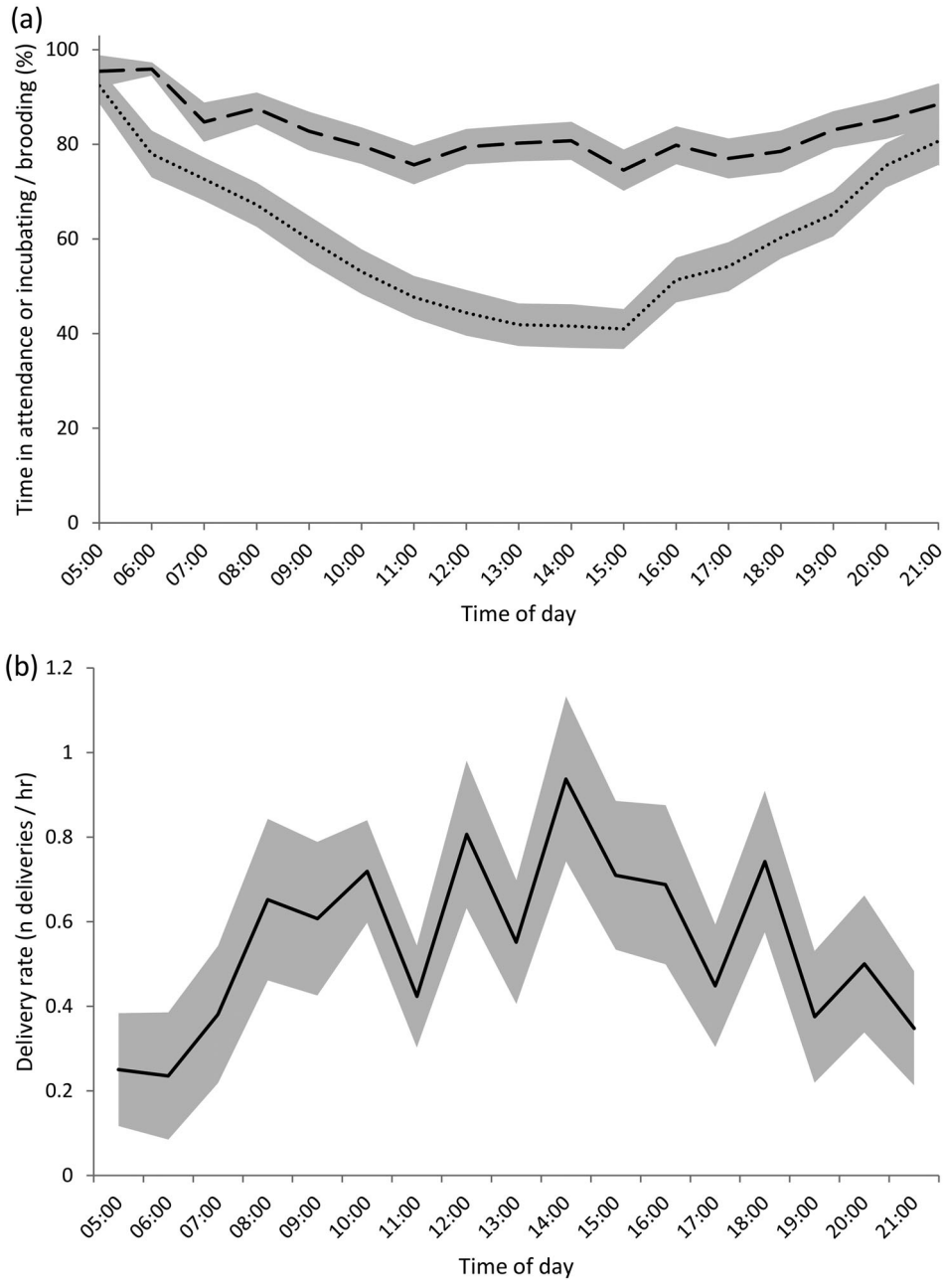

Figure 2. Mean hourly rates of (a) total time spent by adult Hen Harriers at the nest (attendance; dashed line), portion of time spent actively incubating or brooding (dotted line) and (b) rates of prey deliveries to nests (continuous black line). Shaded areas represent ±se.

surrounding vegetation more frequently. Across the day, female attendance was most frequent early and late in the day, with lowest nest attendance rates recorded during the middle of the day (Figure 2).

A total of 417 prey deliveries were recorded in this study across the 13 nest sites. Prey delivery rates increased gradually after hatching for the first five days. After day 5, delivery rates remained above 0.5 deliveries per hour (ranging from 0.52 to 0.82 deliveries per hour) (Figure 1 and Table S1 in online supplementary material). Deliveries were recorded throughout the day (earliest 05:59, latest 21:41) but rates were generally low before 08:00 and after 19:00, with rates ranging from 0.42 to 0.94 deliveries per hour during the middle of the day (Figure 2 and Table S2 in online supplementary material). It was not possible to discern which of the adults was responsible for hunting, as food passes occurred away from the nest and out of sight of the cameras. However, from day 4 after hatching onwards, males were recorded delivering prey items directly to the nest, never staying there for more than a few seconds. From day 7 after hatching,

these deliveries sometimes took the form of 'prey drops', where the male overflew the nest and dropped the prey item into the nest without landing. Prey drops accounted for 9.5% of deliveries recorded from day 7 after hatching.

The timing of some of the behaviours reported here differs from previous observations at Hen Harrier nests in other regions. We found decreased female attendance as early as seven days after hatching, a pattern usually associated with increased female foraging (Hardey *et al.* 2009). While our data cannot be used to determine foraging behaviour by the female, it suggests that the decrease in attendance can occur earlier than previously reported (Leckie *et al.* 2008, Hardey *et al.* 2009). Daily activity patterns recorded in the current study also deviate from the early morning and late afternoon peaks in activity reported in other parts of the species' range (Watson 1977, Hardey *et al.* 2009). Our findings suggest low levels of activity in the early morning and late evening with higher, but still variable, rates of activity between 08:00 and 19:00. Overall delivery rates recorded in our study were also lower than those reported for nestling periods by other authors who recorded 0.67–1.23 deliveries per hour (Balfour & Macdonald 1970, Watson 1977, Picozzi 1978, Dickson 1995, Redpath & Thirgood 1997). This difference may be due to the fact that our study only covered the initial stages of chick development, when feeding requirements of the young are lower (Dickson 1995).

Our results provide new insights into the nesting ecology and behaviours of this threatened species which would require very intensive efforts to assess by traditional fieldwork methods. We highlight temporal variations in attendance behaviours and provisioning rates which can inform conservation management strategies of the species and have implications for survey and monitoring protocols (e.g. potential for disturbance during times of high attendance, timing nest visits to coincide with low attendance periods or optimizing survey times to coincide with activity peaks). These findings also have implications for survey and monitoring protocols. Important increases in activity were recorded at Hen Harrier nests from five days after hatching onwards, suggesting a potential increase in detectability of breeding pairs and nests at this stage. On the other hand, 'prey drops' by male birds, a behaviour which might hinder detection of breeding pairs and location of nests by reducing the occurrence of more obvious food passes, was found to make up nearly 10% of deliveries after day 7. Finally, periods of maximum activity were recorded in the central part of the day, as opposed to early morning and late afternoon activity peaks reported for other parts of the species' range and recommended as optimal times for vantage point watches. Further work will be necessary to determine whether these variations in attendance and provisioning rates are specific to the Irish population or add to the variability between nesting pairs recorded elsewhere and whether they relate to nest success or predation.

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