Reproductive output of Hen Harriers *Circus cyaneus* in relation to wind turbine proximity

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Despite the growing importance of wind energy developments in Ireland, and concerns about its potential ecological impact on birds, there is a notable lack of published scientific information in this area. As a bird of conservation concern, the Hen Harrier *Circus cyaneus* inhabits upland areas with potential for wind energy resources. This study assessed the breeding performance of Hen Harriers across Ireland in relation to wind farm development by analysing the breeding output from 84 nests located at varying distances from wind farms. Three measures of breeding performance were investigated: (a) nest success (the proportion of nests that fledged one or more young), (b) fledged brood size (the average number of fledged chicks per successful nest), and (c) overall productivity of breeding pairs (the average number of fledged chicks across all nesting attempts). No statistically significant relationships were found between these breeding parameters and distance of the nest from the nearest wind turbine. However, lower nest success within 1 km of wind turbines than at greater distances were sufficiently close to statistical significance, and with a sufficiently small sample size, that this difference may be of biological relevance. Nests within 1 km of wind turbines which were successful had similar fledged brood sizes to those of nests at greater distances from turbines. These findings support previous research which highlighted the importance of areas within a 1 km radius of raptor nests. Our results provide the first insight into the potential effects of wind turbines for breeding success of Hen Harriers, which should be taken into consideration in assessments of wind farm impacts on this vulnerable species. Further work is required to quantify (a) direct Hen Harrier mortality through collisions, (b) habitat loss and displacement caused by wind turbines and (c) to continue ongoing monitoring of breeding success in order to confirm whether the effect of wind farm proximity suggested here is consistent. This work will support the development of an integrated management strategy for Hen Harriers in Ireland.

Introduction

The Hen Harrier *Circus cyaneus* is a territorial bird of prey that breeds in upland areas in Ireland. It is an Annex I species on the European Birds Directive 2009/147/EC (OJEU 2010) and is on the Amber List of Birds of Conservation Concern in Ireland (Colhoun & Cummins 2013), where an increase in breeding numbers has been reported in recent years

Plate 66. Female Hen Harrier (Shay Connolly).

(Ruddock *et al.* 2012). However, this increase is possibly an artefact of increased survey effort, and with a population estimate of 128–172 breeding pairs the species remains vulnerable and is rare in the Republic of Ireland (Ruddock *et al.* 2012).

Once common across the Irish uplands, Hen Harrier populations have shown significant fluctuations over time in response to human-related pressures, particularly habitat modification and loss (O'Flynn 1983). Extensive afforestation over the past 60 years has resulted in the loss of large areas of open habitat traditionally used by breeding Hen Harriers (O'Leary *et al.* 2000, Avery & Leslie 2010). This species has responded to these habitat modifications across its range by nesting in young conifer plantations (Norriss *et al.* 2002, Barton *et al.* 2006, Wilson *et al.* 2009). Although this apparent ability to adjust to a changing landscape may allow the species to persist in the short term, research suggests that in some instances these new habitats may prove to be an 'ecological trap' where Hen Harrier productivity is too low to maintain populations in the longer term (Wilson *et al.* 2012). Young conifer plantations provide dense vegetation cover suitable for nesting, but may be associated with higher rates of nest predation or with lower prey availability in areas surrounding the nest, leading to lower breeding output and a mismatch between the species' habitat preferences and the actual value of these habitats (Wilson *et al*. 2012). This complex ecological relationship between Hen Harriers and their surroundings, with continuing changes in availability and suitability of their preferred habitats, is further complicated with the recent expansion of wind energy across many upland areas in Ireland.

Renewable energy is a growing component of Ireland's energy supply and wind power in particular is central to the Irish Government's energy production strategy (DCENR 2012). This sector has developed rapidly in recent years with the construction of over 200 onshore wind farms (more than 1,600 individual turbines) across the island of Ireland (IWEA 2014). The contribution of wind energy to the total energy consumption in Ireland increased from 1% in 2000 to 15% in 2012 (Howley *et al.* 2014). Wind energy is commonly recognised as a 'green' power technology that can reduce our dependence on fossil fuels (Leung & Yang 2012). However, there are growing concerns that it may carry an ecological cost, particularly for birds, and there is a pressing need for information on the ecological impacts of wind farms (Drewitt & Langston 2006, De Lucas *et al.* 2007, Stewart *et al.* 2007, Rourke *et al.* 2009). In Ireland, concerns about the effects of wind farms on birds, as well as on other taxa and on the abiotic environment, combined with a lack of robust data have been identified as significant barriers to on-going wind energy development (Rourke *et al.* 2009, Scannell 2011). Despite this, relatively few studies to date have assessed the impacts of wind farms on birds in Ireland (Percival 2003, Madden & Porter 2007). There is an urgent need to evaluate the potential effects of wind farms on bird populations, particularly Hen Harriers (Irwin *et al.* 2011, Ruddock *et al.* 2012), in order to inform conservation and mitigation measures.

The impacts of wind turbines on birds are not yet fully understood, but it is clear that there is considerable variation across regions and between species (Pearce-Higgins *et al.* 2012, Northrup & Wittemyer 2013, May *et al.* 2015). The potential negative effects of wind turbines on birds include direct mortality caused by collision with turbine blades, and indirect effects such as displacement due to disturbance, loss of foraging or nesting habitat, and barrier effects (Stewart *et al.* 2007, Campedelli *et al.* 2014). Impacts appear to be more significant for populations of long-lived, large bird species with low productivity, particularly rare birds of conservation importance (Drewitt & Langston 2006, Pearce-Higgins *et al.* 2009a). Due to their distribution in habitats that are optimal for wind energy production, Hen Harriers are considered to be highly sensitive to wind farm developments (McCluskie 2015, McGuinness *et al.* 2015). Foraging Hen Harriers have been shown to avoid wind farm infrastructures with displacements of up to 0.5 km from turbines reported (Madders & Whitfield 2006, Pearce–Higgins *et al.* 2009b, Garvin *et al.* 2011). However, wind turbines are reported not to cause displacement of Hen Harrier nests (Madden & Porter 2007, Robson 2011). Similarly, wind turbines are reported not to influence the location of Montagu's Harrier *Circus pygargus* nests (Hernández-Pliego *et al*. 2015). Although Hen Harrier ecology and behaviour makes for a low level of collision risk, direct mortality resulting from collision with turbines has been recorded in some studies (Whitfield & Madders 2006, Fennelly 2015, McCluskie 2015). While individual effects of wind farms may have only minor ecological effects on a bird species, collectively, a number of effects may be significant and potentially greater than the sum of the individual effects (Masden 2010). Although these impacts have the potential to affect breeding output of some bird species (Martínez-Abraín *et al.* 2012, Northrup & Wittemyer 2013), no work has been published to date, in Ireland or elsewhere, on the effects of wind farm developments on Hen Harrier breeding productivity. Here we study the breeding performance of Hen Harriers in relation to wind farms at sites across Ireland. By analysing data from Hen Harrier territories, located at a range of distances from active wind farms, we aim to (i) assess whether nests located in proximity to wind turbines suffer reduced productivity and, if so, (ii) determine the maximum distance from turbines at which this effect is significant. To our knowledge, this is the first study to assess the effects of wind farms on the breeding performance of Hen Harriers.

Methods

Data were collected each year between 2007 and 2013 during the Hen Harrier breeding season (April-August) at a selection of sites across the species' Irish range (counties Kerry, Limerick, Tipperary, Clare, Galway, Tyrone and Roscommon). During this period, vantage point watches overlooking areas of suitable habitat were carried out to locate active territories by recording Hen Harrier courtship and territorial behaviours. Further observations of birds engaging in nest building, prey delivery and other nest-associated behaviours were used to identify nest locations. Nests were then regularly monitored by remote observation until the conclusion of the breeding season in order to determine breeding outcome and check for fledged young. All fieldwork was carried out under licence issued by National Parks and Wildlife Service (NPWS).

The distance to the nearest wind turbine was calculated for all nests in order to analyse the effect of wind farms on breeding Hen Harriers using ArcMap 10.2 (ESRI). Previous research has indicated that avoidance of wind farms by breeding Hen Harriers may occur within 1 km of turbines (Pearce–Higgins *et al.* 2009b) and that foraging behaviour of breeding pairs can be influenced by habitat changes at varying distances of 1, 2 and 3 km from the nest (Arroyo *et al.* 2009). To allow for detection of different processes occurring at these scales, nests were grouped according to their distance to the nearest turbine into the following distance bands: 0–1 km, 1–2 km, 2–3 km and >3 km.

Three measures of breeding performance were calculated for each distance band: (a) nest success (the proportion of nests that fledged one or more young); (b) fledged brood size (the average number of fledged chicks per successful nest); and (c) overall productivity of breeding pairs (the average number of fledged chicks across all nesting attempts. Differences in measures of breeding performance between the different distance bands were analysed using fixed-effect one-way ANOVAs and one-tailed T-tests following examination of the distributions of data to ensure that assumptions of normality and homogeneity of variance were met. Minitab was used for all statistical analyses.

Results

Between 2007 and 2013 a total of 84 Hen Harrier territories across Ireland were monitored, and their breeding outcome determined. Linear distances from these nests to the nearest wind turbine ranged from 0.4 km to 7.0 km. Nest success for all territories monitored was 53.6%, with 45 successful and 39 failed nests. The mean fledged brood size was 2.4 (±0.1 se) chicks per successful nest and mean nest productivity was 1.3 (±0.2 se) chicks per nesting attempt.

When grouped according to distance from the nearest turbine, nest success was lowest (33.3%) at nests located in the 0–1 km band (n = 9). Nest success was 60.0% in both the 1–2 km (n = 20) and 2–3 km (n = 20) bands, and 51.4% for nests located at more than 3 km from wind turbines (n = 35) (Figure 1). However, differences between the four distance bands were not statistically significant ($F_{3,80}$ = 0.72, P = 0.542). When the success of nests in the 0–1 km band (nest success = 33.3%) was compared with the success of all nests more than 1 km from wind turbines (nest success = 56.0%), the difference approached statistical significance (one-tailed T-value = 1.29, df = 82, P = 0.10).

Plate 67. Male Hen Harrier (Andy Hay, rspb-images.com)

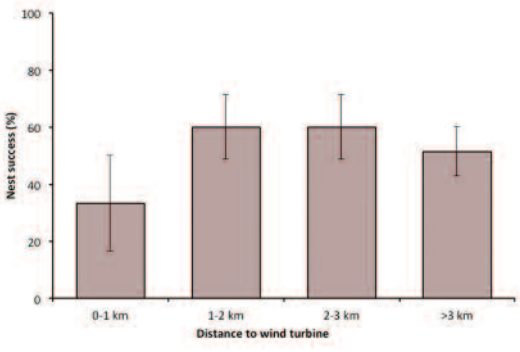

Figure 1. Mean Hen Harrier nest success rates (± se) from 2007 to 2013 across Ireland, classified by the distance of nests to the nearest wind turbine. Nest success is defined as the proportion of nests that fledged one or more young. Numbers of nests in each distance band are shown within each bar.

There was no significant difference in fledged brood size between distance bands, which ranged from 2.33 to 2.58 chicks per successful nest ($F_{3,80} = 0.26$, P = 0.853) (Figure 2). Productivity was lowest for nests closest to wind turbines (0–1 km, 0.78 chicks per nesting attempt) but not statistically different from those nests in the other bands (1.55, 1.35 and 1.23 chicks per nesting attempt at 1–2 km, 2–3 km and >3 km respectively) (F-value = 0.68, df = 3, P = 0.566).

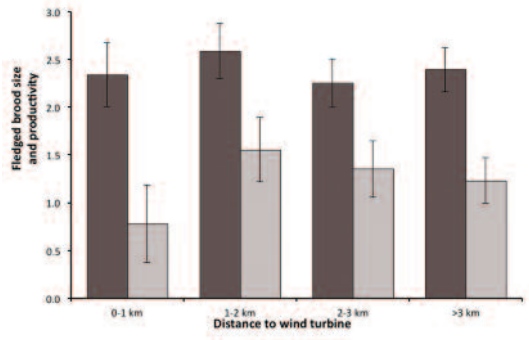

Figure 2. Mean Hen Harrier fledged brood size (dark bars; the average number of fledged chicks per successful nest) and productivity (light bars; the average number of fledged chicks across all recorded nesting attempts) (± se) from 2007 to 2013 across Ireland, classified by the distance of nests to the nearest wind turbine. Numbers of nests in each distance band are shown in Figure 1.

Discussion

We found no significant differences between three measures of breeding output from Hen Harrier nests located at different distances from wind turbines. However, non-statistically significant lower nest success rates and productivity were observed within 1 km of active wind turbines. Due to limited availability of data, a consequence of the species' rarity and restrictions on research activities, it is not possible to investigate differences in breeding success at a finer scale. Of the nine nests monitored in the 0–1km band during this study, 33.3% were successful, while nest success in all other distance bands was 56.0% (n = 75). Hen Harrier nest success rates vary considerably throughout their range, and are influenced by many external factors, though they are typically similar or greater than the rates observed in this study for nests located more than 1 km from turbines (Baines & Richardson 2013, McMillan 2014). Relationships between the presence of wind turbines and the breeding success of local bird populations have been the subject of few investigations to date. From the available literature on this topic it appears that such relationships are species and/ or area specific (Dahl *et al.* 2012, Martínez-Abraín *et al.* 2012, Hatchett *et al.* 2013). Even where impacts on reproductive success are reported, these do not necessarily translate into negative population level effects (Martínez-Abraín *et al.* 2012). However, impacts which of themselves do not impact significantly on a bird species may, when combined with other effects, lead to cumulative negative impacts (Masden 2010, Schaub 2012).

No trend in fledged brood size with increasing distance from wind farms was observed, suggesting that any potential impact of wind turbines on Hen Harrier breeding output is mediated through nest success rather than clutch or brood sizes. The apparent lower productivity (average number of fledglings per nesting attempt) close to turbines in this study, although not statistically significant, may be the result of failed nesting attempts (66.7%), rather than reduced performance of those nests producing fledglings. A similar phenomenon has been reported for a wind farm in Norway in an area occupied by breeding White-tailed Eagles *Haliaeetus albicilla,* where reduced breeding success within 0.5 km of wind turbines was the result of abandonment of territories rather than a reduction in fledged brood size at nests close to turbines (Dahl *et al*. 2012). Although the impacts of wind farms on breeding productivity are recognised as being a crucial determinant of a population level impact (Drewitt & Langston 2006), the scientific literature currently available relates only to impacts on abundance and distribution, while the current study is the first of its kind on the effects on breeding output. Human activities (such as recreation, forestry operations and wind farm development) have been reported to impact on Hen Harriers at distances ranging between 0.5 km and 1 km (Ruddock & Whitfield 2007), while reduced densities of Hen Harriers have sometimes been reported within 0.5 km of active wind turbines (Pearce-Higgins *et al.* 2009b). Research on the spatial ecology of Hen Harriers has shown that foraging females spend most of their time within 1 km of the nest, while males hunt mostly within 2 km of the nest (Arroyo *et al*. 2009, Irwin *et al.* 2012). Therefore, landscape and habitat changes within 1 km of the nest may influence the foraging behaviour of both male and female Hen Harriers, while changes up to 2 km from the nest are more likely to affect males only (Arroyo *et al.* 2014). In the context of the current study this suggests that, if wind farm presence does have an effect on breeding Hen Harriers, this is most likely to affect nests located within 1 km of wind farms, where the overlap between turbines (and associated infrastructure) are the areas used for foraging by breeding birds.

Nest success, productivity and fledged brood size observed in the current study are consistent with those reported for Hen Harriers in other parts of the species' distri-

Plate 68. Female Hen Harrier (Neill O'Reilly)

bution range (Fielding *et al.* 2011, McMillan 2014). However, considerable variation has been reported in the breeding output of Hen Harrier populations in Scotland (Etheridge *et al*. 1997, Amar *et al.* 2008, Baines *et al.* 2008), England (Natural England 2008), and Ireland (Irwin *et al.* 2011). As a result, establishing clear cause-and-effect relationships regarding Hen Harrier population parameters presents a considerable challenge. In Ireland, geographic variation in breeding output (Irwin e*t al.* 2011) and on-going regional declines (Ruddock *et al.* 2012) may hinder attempts to understand the effects of single variables such as wind farm developments. A further constraint in research on rare species, and raptors in particular, which occur at low densities is that the required sample sizes are often difficult to achieve (Morrison 1988). Although ecological research benefits from studying abundant species or frequent events to understand natural processes, rare species are often of higher ecological, conservation, management and policy interest. This is particularly true of the interaction between Hen Harriers and existing and planned wind farms in the Irish landscape. As the study of such interactions will typically be based on small sample sizes, the use of a standard set of statistical tools may be difficult or inappropriate, making statistical analyses difficult to obtain where they are most needed (Ellison & Agrawal 2005). Despite using the largest existing data set on breeding Hen Harriers in Ireland, the sample size available for some distance bands in this study was notably small, calling for precautionary interpretation of results. This is of particular importance when interpreting observed differences which, although not statistically significant, may be biologically meaningful (Martínez-Abraín 2008).

Over most of terrestrial Ireland, wind farms tend to be situated at higher elevations than the majority of the surrounding land. This means that their placement is non-random with respect to other land uses and habitat types that have been associated with Hen Harrier distribution, breeding activity and nest success. These include commercial forestry (Madders 2003, Wilson *et al.* 2012), heather-dominated habitats (Arroyo *et al.* 2009, Redpath *et al.* 1998) and intensive farmland (Arroyo *et al.* 2009, Wilson *et al.* 2009). It is possible,

therefore, that any observed relationships between wind farm proximity and Hen Harrier breeding success, such as those discussed here, may be wholly or partly due to the influence of landscape elements which may be linked to wind farm developments (e.g. changes in land use associated with wind farm construction (Nayak *et al.* 2010) or to other unrelated practices (e.g. agricultural intensification, afforestation or peat extraction) (O'Leary *et al.* 2000, Amar & Redpath 2005).

The information presented here relates to established active wind turbines, and it should be noted that the impacts of wind farm construction on breeding Hen Harriers may be of a substantially different nature. Research on other bird species indicates that the construction phase is probably the most critical aspect of wind farm development, and that effects on bird populations reported at operational wind farms may in fact be the result of declines occurring during the construction period (Douglas *et al.* 2011, Pearce-Higgins *et al.* 2012). Little information is available on the effects of wind farm construction activities on breeding Hen Harriers, although disruption at distances of up to 1 km has been reported (Ruddock & Whitfield 2007). The Bird Sensitivity Mapping tool recently developed by BirdWatch Ireland, provides detailed guidance on conservation and an indication of the areas where Hen Harriers are most sensitive to wind energy development (McGuinness *et al.* 2015).

Implications for conservation

Although no statistically significant impact of wind turbines on Hen Harrier breeding performance was detected in the current study, a pattern of reduced nest success and productivity was observed within a 1 km radius of wind turbines. Careful location of wind farms and turbines could mitigate potential negative effects (De Lucas *et al.* 2007), and the findings of this study suggest that the location of Hen Harrier breeding sites should be taken into account at the planning stage of wind farms.

Notwithstanding the limitations discussed above, this study draws upon the most extensive data set available on breeding Hen Harriers in Ireland and improves our understanding of the effects that wind energy development may have on breeding Hen Harriers. However, further work is needed to confirm the extent of these effects. Other lines of research necessary to gain a comprehensive understanding of the overall effects of wind farms on Hen Harriers include studies on the impacts of wind farm construction activities, potential displacement of foraging and nesting Hen Harriers by wind turbines, effects of wind farm developments on Hen Harrier prey availability and abundance, risks of direct mortality by collision with wind turbines, relationships between Hen Harrier breeding success and other potentially confounding landscape variables, and analysis of the effects of wind farm developments at a meta-population scale.

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