Hen Harrier *Circus cyaneus* population trends in relation to wind farms

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SUMMARY

Capsule The data presented here demonstrate a considerable spatial overlap between wind farms and the breeding distribution of Hen Harriers in Ireland, but evidence for a negative impact of wind farms on their populations is weak.

Aim To assess the extent of the overlap between wind farms and breeding Hen Harriers and to investigate their potential impact on Hen Harrier population trends.

Methods Data on Hen Harrier breeding distribution in 10km x 10km survey squares from national surveys were used in conjunction with information on the location of wind farms to examine whether, and to what extent, changes in Hen Harrier distribution and abundance between 2000 and 2010 were related to wind energy development.

Results Of the sixty nine survey squares holding Hen Harriers during the 2010 breeding season, 28% also held one or more wind farms. Data from 36 of the squares with breeding Hen Harriers during the 2000 survey revealed a marginally non-significant negative relationship between wind farm presence and change in the number of breeding pairs between 2000 and 2010.

Conclusions A considerable overlap exists between Hen Harrier breeding distribution and the location of wind farms in Ireland, particularly in areas between 200m and 400m above sea level. The presence of wind farms is negatively related to Hen Harrier population trends in squares surveyed in 2000 and 2010, but this relationship is not statistically significant, and may not be causal. This is the first study

to assess the influence of wind energy development on Hen Harriers at such a large geographic and population scale.

INTRODUCTION

Hen Harrier *Circus cyaneus* populations are declining across Europe, with some evidence of regional declines over the past decade recorded for the moderately small Irish population (Irwin *et al.* 2011, Ruddock *et al.* 2012, BirdLife International 2015). The species is listed on Annex 1 of the EU Birds Directive (2009/147/EC) and is on the Amber list of species of conservation concern in Ireland (Colhoun and Cummins 2013). Their populations are protected in Ireland through the designation of Special Protection Areas (SPAs) within which the Irish government is required to ensure that the conservation status of Hen Harrier populations is favourable (Wilson *et al.* 2010). In many of the areas where Hen Harriers breed, demands for wind-energy development are high, and these demands must be met in compliance with environmental measures, including those aimed at protecting Hen Harrier populations. In the absence of detailed information about the interactions between breeding Hen Harriers and wind turbines, there are concerns that turbines could impact negatively on this species, either by causing mortality or by reducing the availability or value of areas around them to Hen Harriers (Fielding *et al.* 2011, Pearce-Higgins *et al.* 2009b, Ruddock *et al.* 2012).

In Ireland and Britain, Hen Harriers breed in moorland, young conifer plantations and other upland habitats, typically between 100m and 400m above sea level (Ruddock *et al.* 2012, Watson 1977, Wilson *et al.* 2009). Outside of the breeding season they range more widely across both upland and lowland areas (Clarke and Watson 1990). Hen Harriers were once widespread in Ireland and Britain, but their populations have decreased here, and across Europe, in response to changes in land use and direct persecution (Burfield and von Bommel 2004, Ruddock *et al.* 2012, Sim *et al.* 2007). Hen Harriers are now a species of conservation concern in Ireland (Colhoun and Cummins 2013) where breeding productivity is lower than in other parts of their range (Irwin *et al.* 2011). Current estimates report a breeding population of less than 172 pairs in the Republic of Ireland (Ruddock *et al.* 2012), and a further 59 territorial pairs in Northern Ireland (Hayhow *et al*. 2013).

The susceptibility of this rare bird species to human-induced land use change presents significant challenges for their conservation management, and compliance with legislation, in the context of on-going transformation of upland habitats. Among the land use changes that may affect Hen Harrier populations are agricultural intensification, the establishment, maturation and harvesting of forest plantations, fluctuations in prey populations (i.e. small mammals) and wind farm construction for renewable energy generation (Amar *et al.* 2011, Amar and Redpath 2005, Fielding *et al.* 2011, Madders and Whitfield 2006, New *et al.* 2011, Pearce-Higgins *et al.* 2009a, Redpath *et al.* 2002). In particular, the construction and operation of wind turbines can impact on Hen Harriers, and other birds, in a range of ways (de Lucas *et al.* 2007, Drewitt and Langston 2006, Dai *et al.* 2015).

Many studies have reported on the proximal impacts of wind turbines on Hen Harriers and other raptors through collision risk (Band *et al.* 2007, Chamberlain *et al.* 2006, de Lucas *et al.* 2008, Madders and Whitfield 2006, Balotari-Chiebao *et al.* 2016) and displacement during both the construction (Pearce-Higgins *et al.* 2012) and the operational phases (Garvin *et al.* 2011, Madden and Porter 2007, Pearce-Higgins *et al.* 2009a, Douglas *et al.* 2011). However, observed impacts vary widely between different studies and there is a pressing need for more information on the potential ecological effects of wind farms on Hen Harriers (Stewart *et al.* 2007, Wang *et al.* 2015, Tabassum *et al.* 2014). In particular, a better understanding of population-level impacts of wind turbines on birds is crucial to allow planners and policy makers to successfully balance renewable energy targets with effective nature conservation (Hill *et al.* 1997, Tellería 2009a, Beston *et al.* 2016, Morinha *et al.* 2014). Masden (2010) modelled the effects of wind farm developments on future Hen Harrier population trends in Orkney and found that predicted declines in the population were linked to effects of habitat loss and displacement rather than direct mortality. However, to date, no studies have investigated whether observed changes in Hen Harrier populations are related to wind energy development. Information on the response of populations to changes in land use is essential to the conservation biology and management of Hen Harriers, as it is to all vulnerable bird species.

Central to the concern over the impacts of wind energy development on Hen Harriers is the spatial overlap between wind farms and bird conservation interests in upland areas. This is partly because there are few economically competing land uses in many upland areas, and the potential to disturb or inconvenience large numbers of people is lower than in other parts of the country. Greater wind resources further increase the attractiveness of upland areas for wind farm construction (Bright *et al.* 2008a).

After over 20 years of wind energy development there are now 235 wind farms on the island of Ireland including 17 wind farms in areas now designated as Hen Harrier Special Protection Areas (SPAs), with a further 10 wind farms proposed for these areas. Effective and efficient regulation of wind energy development in upland areas in part depends on achieving a comprehensive understanding of the ways in which Hen Harriers respond to these developments. The vast majority of wind farms in Ireland have been developed since the turn of the 21st century, during which time four national surveys of Ireland's Hen Harrier population have been carried out at five year intervals (Barton *et al.* 2006, Norriss *et al.* 2002, Ruddock *et al.* 2012). This provides an excellent opportunity to assess the importance of wind energy development as a factor in Hen Harrier population changes in Ireland.

The aim of this study was to determine whether the breeding Hen Harrier population across Ireland has been affected by wind farm developments in recent years. To date, very little research has been published on effects of wind farms on Hen Harriers on such a large population or geographic scale. In particular, this study focuses on the changes in Ireland's Hen Harrier population between 2000 and 2010 in relation to the construction of wind farm infrastructures during this period.

MATERIALS AND METHODS

In order to evaluate the large-scale effects of wind farms on Hen Harriers, two approaches were taken. The first investigated the overlap between wind farms in Ireland and breeding sites of Hen Harriers. The second part of this study examined whether changes in Hen Harrier population between 2000 and 2010 in Ireland were related to wind energy development during this time. As Hen Harrier distribution is influenced by a range of environmental factors including elevation and habitat (Amar and Redpath 2002, Ruddock *et al.* 2012, Sim *et al.* 2007, Wilson *et al.* 2009), we also investigated the relative importance of these factors in driving Hen Harrier numbers. We used data on Hen Harrier populations from both the 2000 and 2010 National Breeding Hen Harrier Surveys (Norriss *et al.* 2002, Ruddock *et al.* 2012) in combination with information on wind farms available on the Irish Wind Energy Associated (IWEA) website.

Spatial overlap between wind farms and Hen Harriers

The scale used for this study was that of the 10km square. Geographical overlap was determined using ArcGIS 10.0 by overlaying the individual 10km x 10km squares (n=69) which held Hen Harriers during the 2010 National Hen Harrier Survey (Ruddock *et al.* 2012) and the locations of all wind farms across Ireland (as detailed on the Irish Wind Energy Association website (www.iwea.com) at the end of 2012). To determine the elevation overlap between Hen Harrier breeding sites and wind farms, elevations for breeding sites and wind farms were extracted from a digital elevation model of Ireland.

Hen Harrier population trends and wind energy development

Study area selection and Hen Harrier data

The numbers of confirmed pairs of breeding Hen Harriers from the National Surveys carried out in 2000 and 2010 (Norriss *et al.* 2002, Ruddock *et al.* 2012) were used to calculate the change in number of breeding pairs per 10 km square during the 10 year interval between the two surveys. Data analysis for this second part of the study was restricted to squares where Hen Harrier breeding pairs were confirmed during the 2000 National Hen Harrier Survey. As survey effort varied considerably between squares surveyed in 2000 (Ruddock *et al.* 2012), this approach made it possible to ensure that survey effort was sufficient to detect breeding pairs in all squares considered. This approach also ensures a minimum standard of data from 2010, as survey effort was less variable among squares where Hen Harriers had been previously recorded (Ruddock *et al.* 2012). To further ensure consistency of survey effort in the 2010 survey, we restricted our data analysis to squares that received three or more visits during the 2010 survey. This selection of survey squares ensures that the data we used were of the highest available quality, and that the resulting analysis would be robust. This resulted in a total of 36 squares being included in this part of the analysis (Fig. 1).

Wind turbines

The locations of all individual wind turbines constructed between the periods 2000 and 2010 in the 36 survey squares selected were identified from aerial photos, and plotted in ArcGIS 10.0. This was used to calculate the number of turbines constructed in each square between 2000 and 2010.

Forest cover

Total forest cover in the study squares up to 2010 was estimated from the 2007 Forest Service's Forest Inventory and Planning System (FIPS) and the inventory for the Coillte database. As well as total area of forest planted up to and including 2010, the changes in closed canopy forest and in pre-thicket forest cover between 2000 and 2010 were also calculated. The following categories of forest plantation were classified as pre-thicket habitat:

- First rotation plantations up to and including fifteen years of age.

- Second rotation plantations between three and fifteen years after planting.
- Forests classified in the Coillte database as "Under-developed", "Dead" and "Burned".

Private forests planted prior to 1998 often do not have a planting year recorded in the FIPS database, and even forests for which planting year is known can vary substantially in the rate at which they develop. Also, felling and replanting is typically not recorded in FIPS and there can be a considerable lag between these activities taking place and their being recorded in the Coillte database. In order to correct errors in forest classification arising from such discrepancies, data relating to all forested areas were verified visually using aerial photographs from 2000, 2005 and 2012.

Geographical position and elevation

The northing and easting of the centre of each 10km square were used to represent the geographical position of the square. A digital elevation model covering the island of Ireland was used to classify areas into three broad categories of elevation: 0 – 100m, 100 – 200m and 200 – 400m. Hen Harrier densities vary greatly between these elevation categories, being concentrated between 200m and 400m (Table 1).

Data analysis

Statistical analyses were carried out in R 2.13.1 statistical software package. Within the 36 10km squares included in this analysis, the relationship between Hen Harrier breeding population change and wind farms was tested using general linear models (GLMs). Because changes in the number of breeding Hen Harriers were normally distributed, Gaussian GLMs were used. Wind farm development within the 10km squares was represented by two variables, the first being the number of turbines built in each square and the second being a binary variable that classified squares as either 'turbines present' or 'turbines absent'. Moran's I (in R package `ape`) was used to test whether turbine numbers or changes in numbers of Hen Harrier pairs were spatially autocorrelated.

Prior to running the GLMs, the relationship between the two turbine-related variables and the change in number of breeding Hen Harriers between 2000 and 2010 were examined, in order to determine whether turbine number or presence would be best to include in the models. In addition to turbines, the initial model included: three grouping variables (categorising squares according to geographical area, longitude and latitude); three continuous variables relating to the proportion of land area within three elevation categories; two variables providing a more detailed characterisation of the topographical environment (slope and terrain ruggedness, defined as the standard deviation of elevation within the square, see White (2006)); the area of felled forest in 2000; the total area of forest in 2010; the change between 2000 and 2010 in the area of closed canopy forest and pre-thicket forest; and the suitability of surrounding areas outside the square measured as the percentage of land at optimal Hen Harrier breeding elevations.

As well as these variables, the starting model also included interaction terms between these variables and turbine presence. Each of these interaction terms was tested prior to model selection in reduced models that included only the interaction term and the two component variables. Only interaction terms that were retained (according to AICc) in these reduced models were included in the 'full' model from which model selection proceeded.

RESULTS

Spatial overlap between wind farms and Hen Harriers

The 69 10km x 10km squares with confirmed breeding Hen Harriers in the Republic of Ireland in 2010 are shown in Fig. 1. Of a total of 69 squares found to be holding Hen Harriers during the 2010 breeding season, 28% of these (n = 19) also held one or more wind farms.

The observed overlap in spatial distribution of Hen Harriers and wind farms was not limited to a two dimensional surface distribution, but is also related to elevation (Fig. 2). Sixty seven per cent of Irish wind farms were located between 200m and 400m above sea level, an elevation band where up to 62% of all Hen Harrier territories were also found. Maximum Hen Harrier breeding densities also occurred at these elevations, with an average of 4.2 Hen Harrier pairs per 100km^2.

Hen Harrier population trends and wind farms

In the 36 Hen Harrier squares where sufficiently robust data were available for analysis there was no evidence of spatial autocorrelation in either changes in the number of breeding pairs between 2000 and 2010 (Moran's I observed = -0.019, expected = -0.029, s.d. = 0.041, P = 0.82), or in the number of turbines built during this time (Moran's I observed = -0.005, expected = -0.029, s.d. = 0.039, P = 0.47). Analysis of turbine development in isolation from other sources of environmental variation indicated that, in squares with wind farms, the number of turbines built was not related to the change in number of breeding Hen Harriers (Fig. 3).

However, comparing squares with and without turbines, there appears to be a negative relationship between turbine development and change in breeding Hen Harrier numbers (Fig. 4), although this relationship is marginally non-significant (t=1.82, d.f. = 34, P = 0.077). Presence of turbines was therefore selected as the most appropriate variable for inclusion in GLMs. As well as all variables described in the methods, first-order interactions between turbine presence and each of five other variables were also included in the starting model on which selection was carried out. These five variables were: the proportion of the squares within each of three elevation categories (<100m; 100m – 200m; and 200m – 400m), change in proportional cover of closed canopy forest and change in proportional cover of pre-thicket forest.

The best model as selected by AICc included the proportion of land between 200m and 400m, the presence of wind turbines within the square, the change in cover of pre-thicket forest, and the interaction between land between 200m and 400m and the presence of wind turbines (Table 2). The apparent effects of wind farm presence, pre-thicket cover and land between 200m and 400m in the final model were all positive. However, the interaction between presence of wind farms and proportion of land between 200m and 400m was negative (Table 2). This suggests that, although in squares without wind farms the relationship between Hen Harrier change and proportion of land in this elevation category was weakly positive, in squares with wind farms it was strongly negative (see Fig. 5).

DISCUSSION

Spatial overlap between wind farms and Hen Harriers

One of the bird species for which potential impacts of wind farms have been of greatest concern is the Hen Harrier. This concern is related to the rarity of Hen Harriers in Ireland and other parts of their range, the legal protection afforded to this species by the Birds Directive (2009/147/EC) and the spatial overlap between the range of this species and the upland areas in which onshore wind farm construction has been concentrated (Bright *et al.* 2008a). Wind farms are most commonly built in upland areas because of strong wind currents and low human population densities. However, upland areas are also home to some important bird populations, including those of the Hen Harrier, which is most abundant in Ireland at elevations between 200m and 400m (Ruddock *et al.* 2012).

The results of this study show that, since 2000, wind farms have been built in 28% of 10km x 10km squares in the Irish uplands which were occupied by breeding Hen Harriers. In a study of sensitivity of 16 bird species to wind farm construction in Scotland, Hen Harriers were found to be one of only three species whose populations were likely to be negatively impacted by wind farms. This was, in large part, due to a high overlap between Hen Harrier territories and areas within 2km of proposed or existing wind farms (Bright *et al.* 2008a).

Such high levels of overlap are not uncommon for raptor species where breeding ranges can be occupied by wind farms. Considerable overlap is reported for Egyptian vultures *Neophron percnopterus* in Spain, where 33% of all territories were located within 15km of wind turbines (Carrete *et al.* 2009). Also in Spain, 30% of squares occupied by Griffon Vultures *Gyps fulvus* were located within 10km of wind turbines (Tellería 2009b). In the Balkans most operational wind turbines are operating within the highest conservation prioritisation zones for vulture conservation (Vasilakis *et al.* 2016). By contrast the overlap of wind energy development with other bird species such as Common Scoters *Melanitta nigra* is very low or negligible (Bright *et al.* 2008b). However, it must be noted that the degree of overlap may vary substantially across a species' range. This is the case for White-tailed Sea Eagles *Haliaeetus albicilla* in Europe. In parts of this species range, such as Norway, wind farms have been built in areas with high breeding densities (Dahl *et al*. 2012). In contrast, the current distribution of White-tailed Eagles in Scotland overlaps minimally with wind farms (Bright *et al*. 2008a) though, given this species' recent rate of population growth in Scotland (Challis *et al*. 2015; Roos *et al*. 2015), this overlap may increase in the future.

Further analyses revealed that this spatial overlap also occurs in relation to elevation. Although only 10% of land in Ireland is located between 200m and 400m above sea level, these areas hold 62% of Hen Harrier territories and 67% of Irish wind farms. Hen Harrier breeding densities are also highest at these elevations, with an average of 4.2 pairs per 100km^2 (Ruddock *et al.* 2012). These results highlight how the areas which are suitable for Hen Harriers are also important for wind farms and the need for a better understanding of the potential impacts of these developments. Although spatial overlap is not always associated with negative impacts on birds (Fielding *et al.* 2006, Hernández-Pliego *et al.* 2015), where it does occur it affords a valuable opportunity to determine whether, and to what extent, wind energy development is likely to conflict with bird conservation. Careful planning is required to minimise potential for negative impacts of development on conservation objectives (Balotari-Chiebao *et al.* 2016, Vasilakis *et al.* 2016). The findings of this study will be useful in providing guidance for future wind energy development in the identification of areas where development is least likely to conflict with Hen Harrier conservation. This is particularly important as the overlap in spatial distribution of Hen Harriers and wind farms is expected to increase as the wind energy sector continues to grow throughout the Hen Harrier's range to meet energy demands.

Hen Harrier population trends and wind farms

Hen Harrier populations have fluctuated significantly throughout their range over the past century. Recent population trends suggest that the breeding population in Ireland has been relatively stable over the last decade, with regional declines recorded in some areas (Barton *et al.* 2006, Norriss *et al.* 2002, O'Flynn 1983, Ruddock *et al.* 2012, Watson 1977). The availability of data on Hen Harrier populations from the 2000 and 2010 National Surveys affords us the opportunity to investigate whether, at the local scale of 10km, the deployment of wind energy facilities has been related to changes in Hen Harrier breeding numbers. It is important to bear in mind that the relationships identified in this study may not be causal. The environmental variables used to model changes in Hen Harrier breeding numbers were not experimentally manipulated and are related to a large number of other variables whose influence was not directly accounted for in this study. However, in the absence of widely available before and after control impact studies, the relationships revealed by this modelling method afford us a means of identifying factors that may impact on breeding Hen Harrier numbers, and potential mechanisms for these impacts.

A negative relationship, approaching statistical significance, was identified between wind farm presence and change in the number of breeding pairs of Hen Harriers during the period from 2000 to 2010. However, the results of the GLM suggest that this relationship is also likely to be influenced by other factors. The positive effects on Hen Harrier breeding numbers of changes in pre-thicket forest cover and land between 200m and 400m suggest that changes in Hen Harrier populations in the decade between 2000 and 2010 were also related to availability of suitable forest habitats and possibly also to availability of habitat at appropriate elevations. Having taken these variables into account, the effect in the model of wind turbine presence on breeding Hen Harrier numbers is positive. However, this is countered by the highly significant negative effect of the interaction between turbine presence and land area observed between 200m and 400m, for which there are a number of possible reasons. Firstly, it is possible that areas suitable for turbines at medium elevations are intrinsically less well suited to Hen Harriers than other areas at similar altitude. Much wind energy development has taken place between 200m and 400m and it is possible that any negative interaction between Hen Harriers and turbines was greatest at this elevation, as it is also the band of altitude that has most frequently been occupied by breeding Hen Harriers across much of Ireland (Ruddock *et al.* 2012). However, in squares with wind farms, turbine numbers were not negatively related to breeding trends, suggesting that the negative interaction between turbine presence and mid-range elevations is not directly caused by impacts of turbines such as collision mortality (Masden 2010). It may, however, be caused by other impacts of wind farm development, such as disturbance during prospection and surveys for new wind farms (Madders and Whitfield 2006) or displacement due to habitat modification during construction activities (Masden 2010, Pearce-Higgins *et al.* 2012). It is also possible that, in areas where there is more land suitable for wind turbine development, Hen Harriers have been at higher risk of persecution (Whitfield and Madders 2005). Factors not investigated in this analysis that could also impact on changes in Hen Harrier populations include changes in the availability and quality of open habitats during the study period, disturbance by human activities, changes in the intensity of farming practices, changes in forest plantations or changes in populations of predators and prey.

Despite the large volume of work reporting on the impacts of wind farms on birds, published studies relating changes in bird populations to wind energy development are scarce. Furthermore, much of the work that has been undertaken on the impacts of wind farms remains unpublished and therefore difficult to access. The current study provides a valuable insight into the factors influencing Hen Harrier population trends. While this approach serves to underline the importance of on-going environmental changes in upland habitats, it also reveals the complexity of factors affecting Hen Harrier population trends. Species with reduced population numbers are particularly vulnerable to the cumulative effects of factors which, in isolation, may not pose a threat at a population scale (Beston *et al.* 2016). In the case of Hen Harriers in Ireland, the species is subject to direct persecution, transformation of breeding habitats, encroachment by increased developments in upland areas and, in some areas, increased levels of predation (Barton *et al.* 2006, Ruddock *et al.* 2012, Wilson *et al.* 2012).

There are substantial political and economic pressures on regulators to allow wind energy developments to proceed in upland areas, many of which are important for Hen Harriers. This study sheds some light on how recent changes in Hen Harrier populations are related to this type of development, as well to other aspects of geography and land use. However, further research is urgently needed to improve our understanding of the individual and cumulative impacts of wind energy on Hen Harrier populations, in order to ensure that regulation of land use for Hen Harrier conservation is effective, but not excessively restrictive.

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TABLES

Table 1. Numbers and densities of confirmed breeding Hen Harrier pairs in 2010 in the 10km x 10km squares used in this study, in each of 3 elevation categories. Data are taken from Ruddock *et al.* (2012).

Elevation	Pairs	Density (100km^{-2})	Area (km^2)
0 – 100m	5	0.25	20.0
100 – 200m	42	1.90	22.3
200 – 400m	80	4.24	18.8
>400m	1	0.66	1.5

Table 2. Output summary for the final model describing change in number of breeding pairs of Hen Harriers in 36 10km squares as a function of altitudinal and land use related variables pertaining to these squares. The summary comprises estimates and standard errors for parameters retained in the model, with t-values and P-values for each. Forward and backward model selection proceeded from a fully specified model (see text for details) according to AICc score. AICc of null model = 141.35; AICc of final model = 123.20; AICc of next best model (as final model but including felling area in 2000) = 124.13.

	Estimate	SE	t	P value
Intercept	-0.66	0.38	-1.72	0.096
200-400m	3.48	1.29	2.71	0.011
Wind farms	2.26	0.74	3.07	0.0045
Pre-thicket change	19.13	7.97	2.40	0.023
200-400m*Wind farms	-7.67	1.70	-4.51	<0.0001

LEGENDS TO FIGURES

Figure 1. Spatial overlap between the distribution of Hen Harriers at a 10km square scale in the Republic of Ireland as recorded during the 2010 National Survey and wind farms. Hen Harriers were recorded in all grey squares. Light grey squares had wind farm development as of 2012 (n = 19) and dark grey squares did not (n = 50).

Figure 2. Frequency of occurrence (%) of wind farms and Hen Harrier territories (2010 breeding season) in 10km squares, and average Hen Harrier breeding densities in these squares, within different ranges of elevation.

Figure 3. Change in number of breeding Hen Harriers between 2000 and 2010 plotted against the number of wind turbines built, in the eleven squares that experienced turbine development during this period. This relationship was not statistically significant (Pearson's $r = 0.41$, $n = 12$, $P = 0.18$).

Figure 4. Change in number of breeding Hen Harriers between 2000 and 2010, in the 11 squares that experienced wind turbine development during this period and the 25 squares where no turbines were built. On average, Hen Harriers declined by over 1 pair per square more in squares with turbines than in squares with no turbines, but this difference was marginally non-significant ($t = 1.82$, d.f. = 34, $P = 0.077$).

Figure 5. The relationship between change in the number of Hen Harrier pairs between 2000 and 2010 and the proportion of land between 200m and 400m in 12 squares where wind turbines were built during this period (above) and in 25 squares where there was no wind energy development during this time (below). See Table 2 for full details of the model output.