The interactions between Hen Harriers and wind turbines

WINDHARRIER

FINAL PROJECT REPORT

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Prepared by:
Dr. Mark Wilson
Mr. Darío Fernández-Bellon
Dr. Sandra Irwin
Prof. John O'Halloran

School of Biological, Earth & Environmental Sciences,
University College Cork,
Ireland.

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Project Team

Prof. John O'Halloran	Principal Investigator
Dr. Mark Wilson	Post-doctoral Researcher
Mr. Darío Fernández-Bellon	Research Support Officer
Dr. Sandra Irwin	Project Manager
Mr. Barry O'Mahony	Senior Research Assistant
Mr. Paul Troake	Research Assistant
Mr. Davey Farrar	Research Assistant
Mr. Davy Watson	Research Assistant
Mr. Tony Nagle	Research Assistant
Ms. Sarah Ingham	Research Assistant

Executive Summary

Ireland is, along with other EU Member States, obliged to decrease its consumption of fossil fuels through increased deployment of renewable energy resources. Wind energy offers an ideal means of meeting this demand and large areas of the Irish uplands have the potential for wind energy development. The continued growth of this sector in Ireland coupled with the fact that much of it is taking place in areas with important bird habitats, has led to a growing demand for information on the impact that this may have on bird communities. Bird species such as Hen Harriers *Circus cyaneus* are particularly vulnerable, as their populations may not have sufficient resilience to withstand additional pressures in upland habitats where they have already experienced considerable environmental and land use changes. Several new wind farm developments have been built and many others recently proposed in areas where Hen Harriers breed.

Hen Harriers are vulnerable across much of their global range and are a rare bird of prey in Ireland, where they breed in upland areas between April and August each year. Their populations are vulnerable to habitat modifications that result from land use change and at present there is concern for their conservation in the face of increasing wind energy development, as the effects of wind turbines on them are, as yet, poorly understood. All EU Member States are responsible, under the EU Birds Directive, to maintain their favourable conservation status and consequently there may be competing demands in the uplands in relation to conservation and energy generation.

The most high profile impact of wind energy development on birds is the potential for direct mortality caused by collisions with wind farm infrastructure. However, there is also significant potential for indirect effects through habitat loss where facilities are built or through displacement of birds from otherwise suitable habitat. Given the importance of developing a renewable energy source, this project set out to provide a comprehensive understanding of the impacts of wind energy developments on Hen Harriers in Ireland. This study focussed on five main areas of Hen Harrier ecology during the breeding season: spatial overlap with wind energy development; prey availability; breeding success; flight behaviour and collision risk; and foraging behaviour.

The primary conflict between wind energy development and Hen Harrier conservation is the large spatial overlap between these competing resources. This study investigated the extent of this overlap and the impact of the wind energy sector on the Irish population of Hen Harriers. Of the 69 survey squares across Ireland where breeding Hen Harriers were recorded in 2010, 28% were seen to coincide with one or more wind energy developments by 2012. A weak negative relationship was identified between wind farm presence and change in the number of breeding Hen Harrier pairs in survey squares between 2000 and 2010. However, the available evidence suggests that this was not a causative relationship but that local factors not included in the current study may have been responsible for the observed changes in Hen Harrier numbers within the survey squares. Furthermore, Hen Harrier population trends were negatively affected by a complex interaction between wind farm developments and the proportion of land between 200m and 400m above sea level. This is the first study of this kind in Ireland and further investigations will be required, when further data become available, to understand more fully the effects involved.

Prey availability is an important factor in mediating the effects of land use change on Hen Harrier populations. Small birds make up a significant proportion of the Hen Harrier diet during the breeding season and so a detailed study of the impacts on wind farms in Ireland on upland breeding bird communities was undertaken. Bird densities were found to be lower at wind farm study sites than at control sites and lower closer to turbines (within 100m) at wind farm study sites than further away. This investigation, the first of its kind, of the role of habitat in the observed findings, revealed that the effect of wind farm development on bird communities is mediated through habitat changes around wind farms. The particular species of bird impacted by wind farm development depends on the existing habitat at the site and the extent of the area affected by modifications related to wind farm construction.

Impacts of wind farms on either prey availability or hunting efficiency may ultimately impact on birds through effects breeding success. Reduced breeding success is of particular concern for bird species with low reproductive rates or those with already vulnerable or declining populations such as Hen Harriers. The breeding performance of Hen Harrier pairs in Ireland was assessed in relation to wind energy development using three measures of breeding performance (nest success, fledged brood size and productivity) and no statistically significant relationships with distance to wind turbines were observed. However, lower nest success rates were recorded within 1km of turbines which, although not statistically significantly different to nest success rates further away from turbines, may be of biological relevance and cannot be ignored. Where nests within 1km of wind turbines were successful, their fledged brood sizes were not different from those nests further away from turbines, meaning that the impact of wind turbines on Hen Harrier breeding success is mediated through nest success and not through impacts on clutch or brood sizes.

The most commonly reported impact of wind turbines on birds is direct mortality associated with collisions. This study set out to gain a comprehensive understanding of Hen Harrier flight behaviour and collision risk at wind farms in Ireland. Birds are at risk of collision with wind turbines only when their flight path overlaps with the rotor blade sweep area of a wind turbine and in the current study, adult Hen Harriers were seen to spend 12% of their flight time at wind farms at turbine rotor sweep height and this did not differ between wind farm and control sites. The amount of time spent flying at this height by newly fledged Hen Harriers close to the nest was negligible (<1%). Using conservative estimates, collision risk analysis revealed that, over the life time of a typical wind farm in Ireland (25 years), the number of Hen Harrier deaths resulting from collisions with wind turbines is estimated to be in the range of 0.8 to 2.5 birds. These findings demonstrate that Hen Harriers are at low risk of collision with wind farm infrastructure as a result of their typically low flight height and known avoidance behaviour.

The impacts of land use change are often mediated through impacts on foraging success and so a detailed investigation of Hen Harrier foraging behaviour at Irish wind farms was undertaken. This is the first study to examine habitat selection by foraging Hen Harriers at operational wind farms. For this purpose novel GPS tags were deployed on adult Hen Harriers. This method of data collection offers a new and highly efficient method of collecting data on habitat use of foraging birds. However, due to the small sample sizes that were achieved in practice due to difficulties in deploying and recovering tags, the majority of data used in the analysis of Hen Harrier foraging use in this study came from traditional vantage point watches. The findings highlight the importance for Hen Harriers of open habitats suitable for foraging and the selection of foraging habitats by Hen Harriers differed between wind farm and control study sites. Although the availability of open and young forested habitats was similar at all study sites, the use of forested areas was lower around wind farms relative to control study sites.

Based on the findings of the current project and a detailed review of current impact assessment methods a range of recommendations for the assessment of the potential impacts of wind energy developments on Hen Harriers are made. Recommendations are made in the areas of assessment design and duration, survey methods and cumulative impact assessment. This work is a significant step in the direction of developing an analytical framework for reviewing wind energy proposals in Ireland and provides a basis not only for evaluating individual projects, but also for comparing projects and for undertaking an assessment of the cumulative effects of wind farm developments and other human activities.

This study concludes that breeding Hen Harriers occupy areas of the landscape which coincide with both existing and potential wind farms in Ireland, and there is some association between wind farm presence and the numbers of Hen Harriers, particularly at altitudes between 200 and 400m, where the majority of Hen Harriers are known to breed. Wind farm presence led to a reduction in the abundance of some bird species which are components of the Hen Harrier diet. The risk of mortality for Hen Harriers through collision with turbines was found to be low at the study sites. In considering each of the elements of this project individually and collectively this study recommends a range of monitoring and assessment practices to help decisions to be made regarding the location of wind farms and, at the same time, maintaining a favourable conservation status of the Hen Harrier. This study makes a significant contribution to the body of knowledge on the interaction between wind farm development and Hen Harriers in Ireland and provides high quality scientific evidence to support the formulation of policy and practice.

Adult male Hen Harrier. Photo by Barry O'Mahony.

1. Introduction

1. 1 Background

This project set out to investigate the interaction between Hen Harriers *Circus cyaneus* and wind turbines in Ireland and was carried out in the context of a national population of Hen Harriers that is small, with some evidence of regional declines over the past decade (Irwin *et al.*, 2011, Ruddock *et al.*, 2012). Hen Harriers are listed on Annex 1 of the EU Birds Directive (2009/147/EC) and are on the Amber list of species of conservation concern in Ireland (Colhoun & 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 this demand 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 (Pearce-Higgins *et al.*, 2009b, Fielding *et al.*, 2011, Ruddock *et al.*, 2012). Until such data are obtained, regulation of wind energy development in Hen Harrier areas must proceed on a precautionary basis. Strict legislation in place to limit the impacts of wind turbines on Hen Harriers, currently also limits the potential for wind energy development (Rourke *et al.*, 2009, Scannell, 2011). This project set out to investigate whether, and to what extent, Hen Harriers are affected by wind turbines in their upland breeding areas in Ireland. The aspects of Hen Harrier ecology considered in this study were breeding biology, flight behaviour, collision risk and avian prey.

1. 2 Hen Harrier biology and ecology

Hen Harriers have a wide distribution and breeding range across the northern hemisphere including Asia, Russia and Northern Europe. Although the Hen Harrier *Circus cyaneus* and the North American Northern Harrier *Circus hudsonius* are now considered to be different species, they were until recently classified as the same species. Despite differences in geographical distribution, both species' ecology is very similar and they are treated as sister species with similar morphology, behaviour and ecological requirements (del Hoyo & Collar, 2014). They are medium sized territorial birds of prey that breed in upland areas in Ireland, typically between 100m and 400m above sea level, and spend the winter more widely distributed at lower altitudes at communal roost sites (Clarke & Watson, 1990, Wilson *et al.*, 2010, Ruddock *et al.*, 2012). They also extend their range by migrating further south during the winter to parts of North Africa, Asia and South America. Adult male and female Hen Harriers differ markedly in both size and colour. Females are brown in colour with a white rump and white bars on their tails and are larger than the grey and white males. The difference in appearance between the sexes is so significant that they were once thought to be separate species. Juvenile Hen Harriers of both sexes have similar colouring to the adult females until they begin to moult into their adult plumage towards the end of their first year.

Adult female Hen Harrier. Photo by Richard Mills.

Young Hen Harrier chicks at a typical nesting site on the ground. Photo by Barry O'Mahony.

Hen Harriers are ground nesting birds that breed in moorland, young conifer plantations and other upland habitats (Wilson *et al.*, 2009, Wilson *et al.*, 2010). In spring Hen Harriers leave their communal winter roost sites and move towards the uplands where pairs establish territories and build nests in open areas. Both males and females are involved in nest building and egg laying takes place between April and May with average brood size of between four and five eggs (Irwin *et al.*, 2008). During incubation the males provide most of the food for the females and subsequently for the juvenile birds (Picozzi, 1980) by foraging over a wide area around the nest (up to at least 11km according to data from GPS tagged birds) (Arroyo *et al.*, 2006, Irwin *et al.*, 2012, Arroyo *et al.*, 2014). Eggs hatch approximately one month after they are laid and the young fledge the nest approximately one month later. Hen Harrier nesting attempts in Ireland have a success rate of over 60%, with roughly one fledged young per breeding pair (Irwin *et al.*, 2011), which is relatively low compared with the productivity of Hen Harrier pairs in Britain (Fielding *et al.*, 2009). Fledging occurs during July and juvenile Hen Harriers subsequently disperse from their natal areas (Irwin *et al.*, 2008). Studies from Scotland and Wales have found that Hen Harrier females breed in their second calendar year, while the typical age of first breeding for males is third calendar year (Etheridge *et al.*, 1997, Whitfield & FIelding, 2009).

Wind energy developments may impact on Hen Harrier populations indirectly through impacts on prey availability related to changes in habitat composition. Hen Harriers forage preferentially over habitats with high prey densities (Cormier, 1989, Madders, 2000, Amar *et al.*, 2007), and the availability of food has been related to changes in Hen Harrier abundance in the context of previous land use change (Amar *et al.*, 2003, Amar & Redpath, 2005, Amar *et al.*, 2008). Their annual breeding success can be affected by availability of food, both before and during the nest period (Amar & Redpath, 2002, Amar *et al.*, 2003). Hen Harriers have a diverse diet, which varies between areas and seasons, and includes a wide range of bird species, small mammals, amphibians and reptiles (Redpath, 1992, Dobson *et al.*, 2009, Irwin *et al.*, 2012). Small passerine birds, particularly Meadow Pipits *Anthus pratensis* and Skylarks *Alauda arvensis*, feature strongly in the diet of Hen Harriers during the breeding season (Picozzi, 1978, Picozzi, 1980, Amar *et al.*, 2003, Wilson-Parr, 2005).

1. 3 The Irish Hen Harrier population

Hen Harrier numbers in Ireland have shown considerable fluctuation over time. They were once widespread across Ireland but by the early 20th century their numbers had been substantially reduced and they were considered by some observers to have been wiped out (Watson, 1977, O'Flynn, 1983, Whilde, 1993). The population in Ireland increased again to an estimated 250-350 breeding pairs by the 1970s (Watson, 1977), but their numbers have once again declined over the past 25 years, as they have across Europe, and they are now a species of conservation concern in Ireland and across Europe. They are an Annex I species on the European Birds Directive (2009/147/EC) and are on the Amber List of the Birds of Conservation Concern in Ireland (Burfield & von Bommel, 2004, OJEU, 2010, Colhoun & Cummins, 2013). This Directive requires that EU member states safeguard Hen Harrier populations, by protecting areas of suitable habitat through designation of Special Protection Areas (SPAs) and taking any other necessary steps to ensure the effective conservation of national populations. There are currently six designated Hen Harrier SPAs in Ireland, including parts of Clare, Cork, Galway, Kerry, Laois, Limerick, Monaghan, Offaly and Tipperary, all holding breeding Hen Harriers (Table 1.1). These areas are comprised principally of heaths and bogs, rough grassland and young conifer plantations, which are all important nesting and foraging habitats for this bird (Redpath *et al.*, 1998, Norriss *et al.*, 2002, Wilson *et al.*, 2009).

Table 1.1: Designated Hen Harrier SPAs in Ireland.

SPA	Counties
Slieve Bloom Mountains	Offaly & Laois
Stack's to Mullaghareirk Mountains, West Limerick Hills & Mount Eagle	Cork, Kerry & Limerick
Mullaghanish to Musheramore Mountains	Cork
Slieve Felim to Silvermine Mountains	Limerick & Tipperary
Slieve Beagh	Monaghan
Slieve Aughty Mountains	Clare & Galway

Since 2000 a nationwide survey of breeding Hen Harriers in Ireland has been undertaken every 5 years which has recorded a small increase in numbers in recent years providing a picture of a relatively stable Hen Harrier population in Ireland (Norriss *et al.*, 2002, Barton *et al.*, 2006, Ruddock *et al.*, 2012). It is important to note that this stability may be the result of increased survey effort in the most recent survey (Ruddock *et al.*, 2012). Significant declines in local Hen Harrier populations have been recorded in a number of areas (Irwin *et al.*, 2011, Ruddock *et al.*, 2012). With a current population estimate of less than 172 breeding pairs, the species remains vulnerable and rare in the Republic of Ireland (Ruddock *et al.*, 2012), where its breeding productivity is lower than in other parts of its range (Irwin *et al.*, 2011).

1. 4 Hen Harrier populations and land use change

The fluctuations in Hen Harrier populations over time in Ireland can be related to human-related pressures, particularly habitat modification and loss (Watson, 1977, O'Flynn, 1983, Amar & Redpath, 2005). Extensive afforestation over the past 60 years has resulted in the loss of large areas of open habitat traditionally used by breeding Hen Harriers (Avery & Leslie, 1990, O'Leary *et al.*, 2000). Hen Harriers have responded to these habitat modifications in Britain and Ireland by nesting in young conifer plantations (Barton *et al.*, 2006, Wilson *et al.*, 2009). Hen Harriers throughout their range are vulnerable to habitat loss, fragmentation and degradation (Bibby & Etheridge, 1993, Redpath *et al.*, 2002b, Hayhow *et al.*, 2013), particularly where these involve changes in agricultural practice (Pain *et al.*, 1997, Millon *et al.*, 2002, Amar *et al.*, 2005) and afforestation (Madders, 2000, Sim *et al.*, 2007). These impacts are mediated by the availability of prey and foraging habitat and of suitable breeding sites (Picozzi, 1980, Sim *et al.*, 2001, Amar *et al.*, 2003, New *et al.*, 2011).

The susceptibility of Hen Harriers to human-induced land use change presents significant challenges for their conservation management, and compliance with legislation, in the context of on-going land use change (Meek *et al.*, 1998, Amar *et al.*, 2003, Amar & Redpath, 2005, Amar *et al.*, 2011, Fielding *et al.*, 2011, New *et al.*, 2011, Hayhow *et al.*, 2013). The most recent development in many Hen Harrier habitats is wind farm development for renewable energy generation (Madders & Whitfield, 2006, Pearce-Higgins *et al.*, 2009b).

1. 5 Wind energy in Ireland

Global renewable energy is the fastest growing power source and is expected to become the second most important global electricity resource (after coal) by 2016 (OECD/IEA, 2013). Worldwide, wind energy contributed approximately 4% of the world's energy demand during the first half of 2014 (WWEA, 2014). With a total installed wind capacity of 2,037MW at the end of 2013, Ireland is currently 20th on the list of countries using wind energy. 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 and 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). There are now more than 200 wind farms (1,424 individual turbines) spread across the island of Ireland (IWEA, 2014) including 17 wind farms(246 individual turbines) in areas designated as Hen Harrier SPAs (Table 1.2). Currently there are approximately 2 wind turbines per $10km^2$ of land across Ireland, which is comparable to turbine densities in the UK which are approximately 1.9 turbines per $10km^2$. This figure is just half of the current densities in countries such as Spain and the Netherlands (4.0 and 4.6 turbines per $10km^2$, respectively) and considerably lower than those such as Denmark where there are currently more than 17 wind turbines per $10km^2$ (IWEA, pers. comm.).

Table 1.2: Distribution of wind energy installations in Hen Harrier SPAs in Ireland (IWEA, 2014).

SPA	Active wind farms	Active turbines
S. Blooms	0	None
Stack's	12	152 (+11 in wind farms partly inside SPA)
Mullaghanish	1	6
S. Felim	2	9 (+11 in wind farms partly inside SPA)
S. Beagh	0	None
S. Aughties	2	79

Significant further expansion of this sector is required if Ireland is to reduce its reliance on fossil fuels and meet the ambitious target of generating 16% of energy consumption from renewable sources by 2020 set out by the EU Directive on the promotion of use of energy from renewable sources (Directive 2009/28/EC). These targets must be met in compliance with the EU Birds and Habitats Directives (Directives 2009/147/EC and 92/43/EEC, respectively) which together form the basis for conservation legislation in the EU, and this must be supported by appropriate national policy.

1. 6 Wind energy and birds

Wind energy is commonly recognised as a green power technology that can reduce our dependence on fossil fuels (Leung & Yang, 2012). However, there are some 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 (Tabassum *et al.*, 2014). Many of the early reports of negative impacts of wind turbines on bird species came from areas with very high densities of wind turbines such as the Altamont Pass in California (Thelander & Smallwood, 2007, Smallwood & Thelander, 2008) and Tarifa in southern Spain (de Lucas *et al.*, 2004), where extensive wind energy developments were poorly sited in areas where very high densities of migrating birds were channelled by geography into the wind farm. More recent wind energy developments are typically sited more carefully due to environmental considerations including local bird communities (Bright *et al.*, 2008b). Much of the research on wind turbines and birds focuses on charismatic or endangered species (Gil-Sánchez *et al.*, 2004, de Lucas *et al.*, 2007b, Carrete *et al.*, 2009, Dahl *et al.*, 2012). 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 bird species (Stewart *et al.*, 2005a, Pearce-Higgins *et al.*, 2012, Northrup & Wittemyer, 2013). Impacts appear to be more significant for populations of long-lived, large bird species with low productivity (Drewitt & Langston, 2006, Kikuchi, 2008, Pearce-Higgins *et al.*, 2009b). The potential negative effects of wind turbines on birds include the direct effect of mortality caused by collisions, and indirect effects such as displacement due to disturbance, loss of foraging or nesting habitat, and barrier effects (Drewitt & Langston, 2006, de Lucas *et al.*, 2007b, Stewart *et al.*, 2007, Rourke *et al.*, 2009, Rees, 2012).

1. 6. 1 Wind energy and avian collisions

Bird mortality due to collisions with wind farm infrastructure (including towers, blades and power lines) is one of the main ecological concerns associated with wind energy (Drewitt & Langston, 2008, Marques *et al.*, 2014). Many studies have reported on the direct impact of wind turbines on birds through collision mortality (Chamberlain *et al.*, 2006, Madders & Whitfield, 2006, Band *et al.*, 2007, de Lucas *et al.*, 2008). There is, however, some evidence that birds become habituated to the presence of wind farms (Madsen & Boertmann, 2008, Leung & Yang, 2012, Tabassum *et al.*, 2014) and the numbers of birds reported to be killed by turbines is not higher than deaths from other causes such as predation, poachers, aircraft and collision with structures such as communication towers, power lines and buildings (Erickson *et al.*, 2005, Sovacool, 2013, Tabassum *et al.*, 2014). However, when combined with other factors, these mortalities can impact significantly on some bird populations (Drewitt & Langston, 2006, Sterner *et al.*, 2007, Erickson *et al.*, 2014). The collision risk presented by wind turbines is variable and is the result of complex interactions between bird species characteristics, flight behaviour and abundance, site characteristics (location, habitat and elevation) and wind farm features (turbine type, height and configuration) (Lawrence *et al.*, 2007, Sterner *et al.*, 2007, de Lucas *et al.*, 2008, Kikuchi, 2008, Northrup & Wittemyer, 2013, Marques *et al.*, 2014).

Bird species differ from one another in their susceptibility to collision mortality and birds with long life spans, low natural mortality rates and small geographic ranges are most at risk (Carrete *et al.*, 2009), as are those whose flight heights coincide with the height of wind turbine rotor blade sweep (Johnson *et al.*, 2001). Migratory bird species may have higher collision risk than residents (Drewitt & Langston, 2006, Everaert & Stienen, 2007, Lekuona & Ursúa, 2007, Kikuchi, 2008). There is also some evidence that collision events are correlated with times of poor visibility associated with darkness or poor weather (Kunz *et al.*, 2007, Larsen & Guillemette, 2007, Lawrence *et al.*, 2007). Where low rates of bird collisions with wind farm infrastructure are observed, this may be because wind farms are typically located to avoid areas where bird concentrations are high (Johnson *et al.*, 2000b), or because many bird species show avoidance behaviour of turbines during flight (Chamberlain *et al.*, 2006, Higgins *et al.*, 2007, Larsen & Guillemette, 2007, Garvin *et al.*, 2011). Inappropriately sited wind farm developments may have significant long-term negative impacts on some bird populations including White-tailed Sea Eagles *Haliaeetus albicilla*, Griffon Vultures *Gyps fulvus* and Egyptian Vultures *Neophron percnopterus* as a result of increased mortality, particularly when bird species are long-lived and have low natural mortality rates (Carrete *et al.*, 2009, Dahl *et al.*, 2012, Martínez-Abraín *et al.*, 2012). Furthermore, while current recorded mortality rates may not reach thresholds required to negatively impact at population level for some species, further development in the wind energy sector and the associated rise in turbine numbers may mean that these thresholds are reached in a few years (Bellebaum *et al.*, 2013).

1. 6. 2 Wind energy and avian displacement

In addition to the direct impact of wind turbines on bird species through collision risk, wind energy development may also result in habitat loss either directly, where facilities are built, or indirectly, where birds are displaced from otherwise suitable habitat through behavioural avoidance (Drewitt & Langston, 2006, de Lucas *et al.*, 2007b). Displacement of birds as a result of the presence of wind turbines occurs as a result of behavioural responses that prevent or decrease the use of an area for activities such as nesting and foraging (Madders & Whitfield, 2006, Rees, 2012). A number of studies have reported negative impacts of wind turbine development on Hen Harriers and other raptors through displacement (Leddy *et al.*, 1999, Farfán *et al.*, 2009, Pearce-Higgins *et al.*, 2009b, Garvin *et al.*, 2011, Campedelli *et al.*, 2013). Many other studies however, report that the abundance of birds is not affected by the presence of wind farms (Devereux *et al.*, 2008, Madsen & Boertmann, 2008, Douglas *et al.*, 2011, Minderman *et al.*, 2012, Hale *et al.*, 2014). While some studies conclude that wind farms can have a significant negative impact on bird abundance, variation between wind farms and between bird species can greatly affect the risks involved (Stewart *et al.*, 2007, Stevens *et al.*, 2013). A review of studies examining the effects of wind farm developments on raptor species concluded that the available evidence suggests that displacement effects of wind turbines on raptors are negligible for the most part (Madders & Whitfield, 2006). Where an effect is reported, the extent of avoidance ranges from 100m to 800m from turbines (Leddy *et al.*, 1999, Stewart *et al.*, 2005a, Pearce-Higgins *et al.*, 2009b). While few studies assess disturbance in relation to the life-cycle of a wind farm, both Campedelli *et al.* (2013) and Pearce-Higgins *et al.* (2012) reported that observed negative effects of wind farms on birds occur as a result of disturbance by high levels of activity during the construction phase. Although declines in bird numbers are not reported to persist through the operational phase of the wind farm for the most part in the UK, populations of some species did not recover after the construction phase (Pearce-Higgins *et al.*, 2012).

The reported impacts of wind farms on birds vary considerably between species. Breeding wading birds, which are particularly vulnerable to disturbance, are most often reported to be negatively impacted by the presence of wind farms (Everaert & Stienen, 2007, Stewart *et al.*, 2007, Pearce-Higgins *et al.*, 2012, Rees, 2012). Many studies report no observable effect of wind turbines on habitat use by birds close to wind farms (de Lucas *et al.*, 2005, Farfán *et al.*, 2009, Minderman *et al.*, 2012). Reports of population level effects of wind farms on birds have been confined to some seabirds and raptors (Drewitt & Langston, 2006, de Lucas *et al.*, 2007b, Everaert & Stienen, 2007, Carrete *et al.*, 2009, Dahl *et al.*, 2012, Campedelli *et al.*, 2013), with many studies reporting no detectable population level effects during the operational phase (Douglas *et al.*, 2011, Pearce-Higgins *et al.*, 2012).

1. 6. 3 Wind energy and avian habitat quality

While the direct loss of habitat caused by wind energy development is unlikely to significantly impact bird populations (Percival, 2005, Madders & Whitfield, 2006) the indirect effects of reduced habitat quality relating to reduced prey availability or hunting efficiency, which ultimately impact diet and breeding success, may be significant. Reduced breeding success is of particular concern for bird species with low reproductive rates or those with already vulnerable or declining populations. These effects are rarely reported and are difficult to study because such detailed data are time consuming and often difficult to collect. Furthermore reproductive success is highly variable and is influenced by a number of factors making it difficult to distinguish the effects of individual factors. While it is hypothesised that wind turbines may affect the breeding success of birds that are not displaced from areas close to wind turbines (Drewitt & Langston, 2006), there is little evidence to support this in the literature, with some recent studies reporting no observed effect of wind turbines on nest success (Martínez-Abraín *et al.*, 2012, Hatchett *et al.*, 2013, Northrup & Wittemyer, 2013, Bennett *et al.*, 2014, Gillespie & Dinsmore, 2014).

1. 6. 4 Cumulative impacts of wind energy on birds

Cumulative impacts refer to the additional changes caused by a proposed development in conjunction with other similar developments or as the combined effect of a set of developments taken together over time and across landscapes (SNH, 2012a). While individually a wind farm may have only minor ecological effects, collectively these effects may be significant and potentially greater than the sum of the individual parts (Masden *et al.*, 2010). Assessments of the cumulative impacts of wind energy developments are required under the EU Directive (85/337/EEC). Scientific studies of the cumulative impacts of wind energy on birds are limited (Drewitt & Langston, 2006, Stewart *et al.*, 2007). This is related to the difficulty in assessing cumulative impact and the lack of standard assessment methods and the lack of availability of primary data (Stewart *et al.*, 2007, Masden, 2010, Masden *et al.*, 2010). Cumulative impact assessments consider how bird mortality associated with wind energy development might have an impact at population level and therefore estimates of population sizes are required and not readily obtained for most bird species. Furthermore, assessment depends on the development of reliable predictive population models (Stewart *et al.*, 2007). A number of studies conducted to date have revealed no significant cumulative impact (Young & Erickson, 2003, Fielding *et al.*, 2006, Johnson & Erickson, 2011, Erickson *et al.*, 2014). While a study of Golden Plovers *Pluvialis apricaria* in Scotland by Pearce-Higgins *et al.* (2008) reported the potential for regional impacts of wind energy developments on bird, no cumulative impact at national level was predicted.

1. 7 Wind energy and Hen Harriers

There is considerable spatial overlap between the breeding range of Hen Harriers and the upland areas in which wind farm development has been concentrated in Ireland. This is partly because there are few economically competing land uses in many upland areas, and the potential to disturb large numbers of people is smaller than in other parts of the country. Higher wind resources further increase the attractiveness for wind farms in upland areas in the Hen Harrier's range (Bright *et al.*, 2008a). Although their sensitivity to displacement is considered low-medium (Madders & Whitfield, 2006), because of their distribution in habitats that are optimal for wind energy production, Hen Harriers are considered to be highly sensitive to expanding wind farm developments (Percival, 2003b, Bright *et al.*, 2008a).

The peer-reviewed study by Pearce-Higgins *et al.* (2009b) has had a considerable impact on the assessment of the possible impacts of wind farms on upland birds in Ireland and the UK, including Hen Harriers. Pearce-Higgins *et al.* (2009b) considered in detail nine wind farms (>10 turbines), located within unenclosed upland habitats during the construction and post-construction stages of the wind farm life-cycle. In addition, 'control' areas (1.3-11.4km from the wind farm) were used for comparative purposes. That study found that Hen Harriers avoided flying within 250m of turbines, leading to a 53% reduction within 500m of turbines although the confidence interval for this reduction included 0. Furthermore, a follow-up study revealed that, for the majority of bird species, the negative impact of wind farm development occur during the construction stage and do not persist during the operational stage (Pearce-Higgins *et al.*, 2012). Pearce-Higgins *et al.* (2009b) was a correlative study that considered the effects of turbines on a range of foraging birds, including Hen Harriers. It did not, however, consider potential impacts such as loss of nesting sites, impacts of reduced foraging success on breeding output or the risk of collision by flying birds with turbines.

1. 7. 1 Wind energy and Hen Harrier collisions

Mortality of birds due to collision with wind turbines is commonly reported and since the mid-1980s, many studies have been conducted on avian mortality due to wind turbines (Sterner *et al.*, 2007, Drewitt & Langston, 2008, Bellebaum *et al.*, 2013, Erickson *et al.*, 2014). Direct mortality of Hen Harriers resulting from collision with turbines has been recorded in some studies (Whitfield & Madders, 2006a, Scott & McHaffie, 2008), however reports of Hen Harrier deaths related to the presence of wind farms, in both published and grey literature, are rare. In a comprehensive study of bird mortality at the Buffalo Ridge Wind Farm Area in the United States, Johnson *et al.* (2000a) recorded no Northern Harrier *Circus hudsonius* mortalities over a four year intensive study period, despite their being one of the more abundant bird species in the study area. In a review of literature on Hen Harrier collision mortality at wind farms in North America and Europe, Whitfield & Madders (2006b) concluded that Hen Harriers are less susceptible to collision than other raptors, with negligible numbers of deaths recorded.

Collisions with wind turbines are most likely to occur where birds fly regularly at turbine blade height and do not avoid turbines. Hen Harriers typically fly below the height of wind turbine rotor blade sweep at heights of less than 25m (Smallwood & Thelander, 2004, Drewitt & Langston, 2006, Whitfield & Madders, 2006a). This low flight height coupled with the small-scale avoidance of wind turbines shown by Hen Harriers, suggests that collision risk will be low for this species (Whitfield & Madders, 2006b).

1. 7. 2 Wind energy and Hen Harrier displacement

Displacement of birds from areas immediately adjacent to wind farms may result from the presence of wind turbines, which may impact on either foraging or nesting activities. Much of the data from studies of the displacement effects of wind farms on Hen Harriers exists in the grey literature and is not readily accessed. Furthermore, much of the available work relies on small sample sizes related to the rarity of Hen Harriers in the landscape and of interactions between Hen Harrier and wind energy development. Studies involving intensive monitoring of Hen Harrier populations before and after turbine construction, report a range of responses to these developments including increase (Robson, 2011), stability (Forrest *et al.*, 2011) and temporary decline followed by recovery (McMillan, 2011). Hen Harriers have a low sensitivity to displacement (Whitfield & Madders, 2006b) and most studies do not report avoidance of turbines except on the smallest scale, and all of the above studies report Hen Harriers breeding within a few hundred metres of turbines.

A review of available literature on wind turbine avoidance by Hen Harriers by Madders & Whitfield (2006) concluded that most research shows that the displacement of foraging of raptors in general, and Hen Harriers in particular, is negligible. Madders & Whitfield (2006) found no evidence of complete displacement of Hen Harriers from any wind farm site studies and ranked this species' sensitivity to displacement as low-medium. Most studies included in their review showed no indication of Hen Harrier displacement at wind farm sites across Europe and North America where it has been studied (Johnson *et al.*, 2000b, Bergen, 2001, Kerlinger, 2002, Reichenbach, 2003, Schmidt *et al.*, 2003, Kerlinger *et al.*, 2006). One study reviewed by Madders & Whitfield (2006) did report displacement of foraging Hen Harriers from areas close to wind turbines in the year following construction (Johnson *et al.*, 2000c).

A study published in 2007 provided detailed information on pre- and post-wind farm construction at a wind farm site in Ireland and found no evidence of displacement of Hen Harriers from the area adjacent to the wind farm (Madden & Porter, 2007). That study also reported Hen Harrier foraging within the wind farm site, and on one occasion within 10m of a turbine, subsequent to wind farm construction. Some avoidance of wind turbines was seen in a study by Forrest *et al.* (2011) in north east Scotland. A similar study by Robson (2011) in Argyll in Scotland reported no change in the use of suitable habitat by Hen Harriers following wind farm construction. A study by Pearce-Higgins *et al.* (2009b) assessing the abundance of breeding birds around large (>10 turbines) upland wind farms in Scotland and northern England found evidence for wind turbine avoidance by Hen Harriers to a distance of 250m.

While there is little evidence in the literature of displacement of foraging Hen Harriers from areas close to wind turbines, the information available on the displacement of Hen Harrier nesting attempts associated with the presence of wind turbines is conflicting. This is an impact that is difficult to assess robustly due to the rarity of Hen Harrier nests in the landscape, though it appears that nest site selection is related to habitat availability and the management of habitat close to active wind turbines may be a factor in the continued nesting of Hen Harriers close to active wind turbines. No evidence for displacement of nesting locations was found by a study in Argyll where a habitat enhancement area was created adjacent to a wind farm (Robson, 2011). A study in north east Scotland, where traditional nesting areas were protected as part of a management plan, similarly found no impact on nesting behaviour of Hen Harriers (Forrest *et al.*, 2011). Madders & Whitfield (2006) found just one study that reported displacement of Hen Harrier nesting attempts to a distance of 300m from active wind turbines, but no information is available on whether a habitat management plan was in place in this study.

1. 7. 3 Studying Hen Harrier ecology

Research on endangered bird species, such as the Hen Harrier, is limited by the species' rarity, as they usually occur in low numbers and at low densities. As a result, collecting field data requires considerably more effort than for other more common species making it difficult to obtain large sample sizes. Not only are endangered species difficult to survey because they are hard to find, but the factors that threaten them (such as high frequencies of nest predation or high sensitivity to disturbance) and legislative protection further complicate data collection. Hen Harriers are a rare bird of prey in Ireland with less than 200 pairs distributed across the country (Ruddock *et al.*, 2012) and their interaction with wind farms is uncommon, meaning that negative impacts are infrequent occurrences that are difficult to measure. The challenges of studying Hen Harriers in the Irish landscape are also compounded by those of ecological studies in general, as bird populations fluctuate both seasonally and annually, as well as spatially (Newton, 2010).

Rare species are, however, those for which information on potential threats are most needed, and meaningful conclusions can be drawn when reasonable caution is applied to the interpretation of research findings, even where few data are available (Ellison & Agrawal, 2005). Research conclusions based on ecological data are strengthened when the limitations of the study are well understood. This is because conclusions prematurely drawn on insufficient data can easily be proven wrong, placing all output from such research into doubt. If, on the other hand, conclusions are appropriately presented in the context of a paucity of data, they can provide important support for management decisions and the design and implementation of conservation practices and policies (Scannell, 2011).

1. 8 Aims and Objectives

This study set out to produce scientific data to underpin supportive policies for sustainable development of the wind energy sector. Scientific research is required to identify any impact on Hen Harriers and to inform mitigation measures, as those currently being implemented in many areas are based on anecdotal data or lack adequate data to support the measure (de Lucas *et al.*, 2007b). Although there is little evidence for differences in population trends between operational wind farms and reference sites (Devereux *et al.*, 2008, Pearce-Higgins *et al.*, 2012) the potential threat posed to birds by wind farms cannot be ignored. The reported negative impacts of wind farms (Leddy *et al.*, 1999, Higgins *et al.*, 2007, Pearce-Higgins *et al.*, 2009b), coupled with the proposed increase in this sector over the coming years, means that a cautionary approach to planning should be taken. In this context there is a pressing need for more data in this field (Drewitt & Langston, 2006, Stewart *et al.*, 2007, Bright *et al.*, 2008a, Carrete *et al.*, 2009).

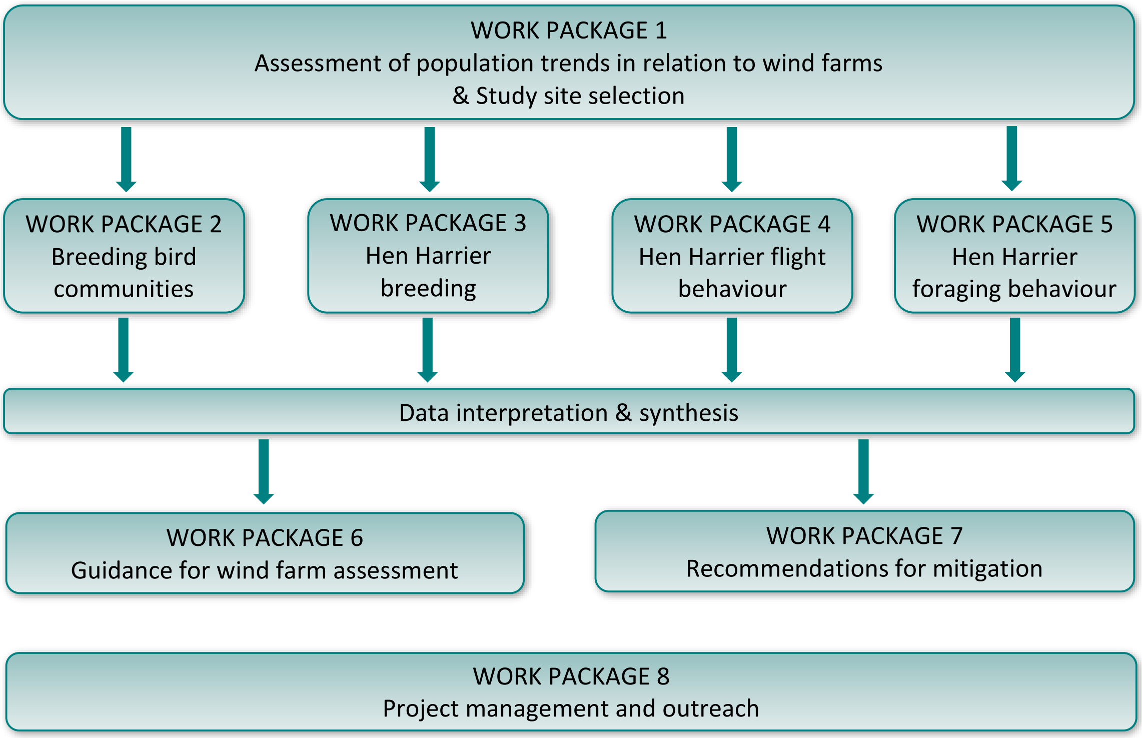
In Ireland, concerns about the effects of wind farms on birds, as well as on other elements of the environment, combined with a lack of robust data have been identified as significant barriers to expansion of the wind energy sector (Rourke *et al.*, 2009, Scannell, 2011). Despite this, relatively few studies have assessed the impacts of wind turbines on birds in Ireland to date (Percival, 2003b, Madden & Porter, 2007) and there is an urgent need to evaluate the potential effects of wind farms on bird populations, particularly Hen Harriers (Irwin *et al.*, 2011, O'Halloran *et al.*, 2012, Ruddock *et al.*, 2012). Effective and efficient regulation of wind energy development in upland areas in part depends on our achieving a good understanding of the ways in which Hen Harriers respond to these developments.

The objectives of this project, as outlined in the project proposal were to:

- Determine the nature and extent of wind energy-related impacts on Hen Harrier foraging.
- Determine whether wind farms appear to be avoided by nesting Hen Harriers, and whether Hen Harrier breeding success is related to proximity to wind farms
- Evaluate the best way to assess the cumulative impact of wind turbines, either within a wind farm site or at the scale of a whole SPA.
- Quantify any direct mortality risks posed by wind turbines for Hen Harriers, especially as related to recently fledged birds.
- Develop appropriate mitigation measures to facilitate future sustainable wind energy development.

1. 9 Project Structure

This study comprised 7 research Work Packages and an eighth Work Package dedicated to project management and outreach, including project communication and dissemination of findings. Each of the four data collection Work Packages (2-4) focussed on one element of Hen Harrier ecology. Data collection was conducted collectively for these work packages at wind farm and control study sites across Ireland. Existing data were added to the data pool where appropriate from previous National Surveys of breeding Hen Harriers and from previous research projects at UCC. Details of the interrelationships between the individual project Work Packages are shown in the PERT chart below.



Work Package 1 provided an assessment of recent Hen Harrier populations trends in relation to wind energy deployment in Ireland using data derived from National Hen Harrier surveys that had been conducted prior to this project in 2000 (Norriss *et al.*, 2002), 2005 (Barton *et al.*, 2006) and 2010 (Ruddock *et al.*, 2012). Information on wind turbine deployment across Ireland was sourced from the web site of the Irish Wind Energy Association (IWEA). The first deliverable (**D1**) of this work Package was a manuscript on the assessment of whether the current level of wind farm development to date has influenced population trends of Hen Harriers in Ireland. The second deliverable was a candidate study site list for the WINDHARRIER project (**D2**).

Work Packages 2, 3, 4 and 5 were all concerned with the collection of primary research data on Hen Harrier ecology. All data were collected during the Hen Harrier breeding seasons (April – August) of 2012 and 2013 under licences issued by National Parks & Wildlife Service.

Work Package 2 provided the third deliverable of this project, which was a final study site list selected from the candidate list produced in Work Package 1 (**D3**). Due to the limited availability of suitable study sites, these lists did not differ as the number of candidate study sites identified in Work Package 1 was smaller than anticipated and all of the identified candidate sites were required for data collection.

Secondly, Work Package 2 provided a comparison of breeding bird communities around wind farms and at control sites without wind turbines. This study aimed to collect data similar to that provided on the distribution of breeding birds around upland wind farms in Scotland reported by (Pearce-Higgins *et al.*, 2009b). A more robust methodology was used in the current project, though Hen Harriers were not included in the analysis as they were not recorded during the surveys undertaken in the current study. The rarity of Hen Harriers in Ireland at present (Ruddock *et al.*, 2012) means that they are not routinely detected in bird surveys such as the one deployed here. Data analysis for this Work Package was confined to those species for which robust data sets were available and was used to produce a manuscript on the avoidance of wind farms by upland bird species in Ireland (**D4**).

Work Package 3 provided a study of the effects of wind farm presence, size and proximity on Hen Harrier breeding parameters. Primary data collected during the WINDHARRIER project was used together with archived data on Hen Harrier breeding held at University College Cork to achieve this objective. The use of archived data served to increase the sample size for this study and maximise the robustness of the data analysis. The first deliverable was an estimate of the effect of wind farms on Hen Harrier breeding biology (**D5**). The second deliverable from this Work Package was a manuscript prepared on this topic (**D5**).

Work Package 4 provided a study of Hen Harrier flight behaviour using primary data collected using both traditional vantage point watches and novel GPS tags. The deliverable from this Work Package was an assessment of collision risk posed by wind farms to adult and juvenile Hen Harriers breeding in or fledged from the immediately surrounding landscape (**D6**).

Work Package 5 provided an assessment of the influence of wind farm presence, size and proximity on the foraging flight behaviour of Hen Harriers based on data collected from adult and juvenile Hen Harriers at wind farm and control study sites (**D7**).

Work Packages 6 and 7 combined reviews of published and grey literature and existing best practice with the findings of earlier project Work Packages to provide guidelines for wind farm assessments and recommendations for mitigation. Work Package 6 provided guidelines for the assessment of Hen Harriers for wind farm development (**D8**) and Work Package 7 provided recommendations for mitigation of potential impacts on Hen Harriers arising from wind farm developments (**D9**).

Work Package 8 was concerned with project management and outreach, including project communication and dissemination of findings. Under this Work Package, a project steering committee was convened including researchers from University College Cork (UCC), representatives of the Irish Wind Energy Association (IWEA), a representative of National Parks & Wildlife Service (NPWS) and an independent ornithological expert Alan Fielding. This group was responsible for the scientific content and direction of the WINDHARRIER project. The deliverable of this work package was that all project technical project and financial repost would be delivered on time (**D10**).

Work Package 1a

2. Assessment of population trends in relation to wind farms

Central to the conflict between wind energy development and bird conservation is the amount of spatial overlap between these competing demands. In this context many of the areas suitable for wind energy development in Ireland are found in important Hen Harrier habitats. This study set out to assess the extent of this overlap and to investigate the potential impact of the wind energy sector on the Irish population of Hen Harriers. Data on Hen Harrier distribution from national surveys of Hen Harrier populations by National Parks and Wildlife Service were used in conjunction with information on the distribution of wind farms from the website of the Irish Wind Energy Association. We examined whether, and to what extent, changes in Hen Harrier distribution between 2000 and 2010 are related to variation associated with wind farms, location, elevation and forest cover. Twenty eight per cent of the sixty nine 10km x 10km survey squares holding Hen Harriers during the 2010 breeding season were found to coincide with one or more wind farm developments. Thirty six of these squares were used in the subsequent analysis of Hen Harrier population trends in relation to wind energy development. A weak negative relationship 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 available evidence suggests that this was not a causative relationship and that external factors not under investigation in this study may have been responsible for the observed effect.

2. 1 Introduction

The aim of this Work Package was to determine whether breeding Hen Harrier populations across Ireland have been affected by wind farm developments in recent years. To date very little research of this type has appeared in the peer-reviewed scientific literature though much exists in the form of unpublished reports and other grey literature. In particular, this Work Package 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.

In Ireland and Britain Hen Harriers breed in moorland, young conifer plantations and other upland habitats, typically between 100m and 400m above sea level (Watson, 1977, Wilson *et al.*, 2009, Ruddock *et al.*, 2012). Outside of the breeding season they range much more widely across both upland and lowland areas (Clarke & Watson, 1990). These birds of prey were once widespread in Ireland and Britain, but their populations have decreased here, and across Europe, in response to land use change and persecution (Burfield & von Bommel, 2004, Sim *et al.*, 2007, Ruddock *et al.*, 2012). Hen Harriers are now a species of conservation concern in Ireland (Colhoun & Cummins, 2013) where their 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 63 territorial pairs in Northern Ireland (Sim *et al.*, 2007). Hen Harriers are considered vulnerable throughout their European range (Burfield & von Bommel, 2004) and are protected under Annex 1 of the European Birds Directive (2009/147/EC). This Directive requires that EU member states safeguard Hen Harrier populations, by protecting areas of suitable habitat through designation of Special Protection Areas (SPAs) and taking any other necessary steps to ensure the effective conservation of national populations.

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 land use change in the uplands. Among the types of land uses that may affect Hen Harrier populations are intensification of agricultural and grazing practices, forestry, control of prey populations (i.e. small mammals) and wind farm development for renewable energy generation (Redpath *et al.*, 2002a, Amar & Redpath, 2005, Madders & Whitfield, 2006, Pearce-Higgins *et al.*, 2009a, Amar *et al.*, 2011, Fielding *et al.*, 2011, New *et al.*, 2011). In particular, the construction and operation of wind turbines can impact on Hen Harriers, and other birds, in a range of ways (Drewitt & Langston, 2006, de Lucas *et al.*, 2007b).

Many studies have reported on the proximal impacts of wind turbines on Hen Harriers and other raptors through collision risk (Chamberlain *et al.*, 2006, Madders & Whitfield, 2006, Band *et al.*, 2007, de Lucas *et al.*, 2008) and displacement during construction (Pearce-Higgins *et al.*, 2012) and operation (Madden & Porter, 2007, Pearce-Higgins *et al.*, 2009a, Garvin *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 (Stewart *et al.*, 2007). 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). Masden (2010) modelled the effects of wind farm developments on future Hen Harrier population trends in Orkney. She found that resulting 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 past changes in Hen Harrier populations are related to wind farm developments. Information on the response of populations to habitat change is essential to the conservation biology and management of Hen Harriers.

There is considerable spatial overlap between the breeding range of Hen Harriers in Ireland and the upland areas in which onshore wind farm development has been concentrated in this country. 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 smaller than in other parts of the country. Higher wind resources further increase the attractiveness of wind farm developments in upland areas (Bright *et al.*, 2008a).

After more than 20 years of wind farm development in Ireland there are now more than 200 wind farms spread across the country, comprising 1,424 turbines in total. This includes 17 wind farms in areas now designated as Hen Harrier Special Protection Areas (SPAs) and a further 10 planned for these areas. Effective and efficient regulation of wind energy development in upland areas in part depends on our 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 installed since the turn of the 21st century, during which time three national surveys of Ireland's Hen Harrier population have been carried out at five year intervals (Norriss *et al.*, 2002, Barton *et al.*, 2006, Ruddock *et al.*, 2012). These provide a unique opportunity to assess the importance of wind energy development as a factor in Hen Harrier population change in Ireland.

In order to produce a large-scale evaluation of the effects of wind farms on Hen Harriers this study was undertaken in two sections. The first part aimed to investigate the overlap between wind farms in Ireland and breeding sites of Hen Harriers. The distribution of wind farms in Ireland was recorded from the web site of the Irish Wind Energy Association (www.iwea.com) at the end of 2012 and the distribution of Hen Harriers in Ireland was recorded from the 2010 National Hen Harrier Survey (Ruddock *et al.*, 2012). The second part of this study examined whether changes in Ireland's Hen Harrier population between 2000 and 2010 were related to wind turbine development during this time. As Hen Harrier distribution is influenced by a range of environmental factors including elevation and habitat (Amar & Redpath, 2002, Sim *et al.*, 2007, Wilson *et al.*, 2009, Ruddock *et al.*, 2012), we also investigated their relative importance 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 farm developments recorded from the Irish Wind Energy Associated website. Initially this work package aimed to include data from the North of Ireland in these analyses. However, it was not possible to acquire this data in a format appropriate for use in the current project and consequently results refer only to the Republic of Ireland.

2. 2 Materials and methods

2. 2. 1 Study area selection and Hen Harrier data

The scale used for this study was that of the 10km square. The individual 10km x 10km squares (n=69) which held Hen Harriers during the 2010 National Hen Harrier Survey (Ruddock *et al.*, 2012) were used in the first part of this study to investigate the overlap between wind farms and Hen Harrier breeding sites.

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 during the 10 year interval between the two surveys. Data analysis for this second part of the study on the relationship between Hen Harrier population trends and wind farm development in Ireland was restricted to squares where Hen Harrier breeding pairs were confirmed during the 2000 National Hen Harrier Survey in order to ensure that, in all squares considered, survey effort in 2000 was at least of a high enough standard to identify breeding pairs. This approach also ensures a minimum standard of survey effort among squares visited in 2010, as survey effort in 2010 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. Although these constraints reduce the sample size they ensure that the data are of the highest possible quality, methodologically comparable and that the resulting analysis is robust. This resulted in a total of 36 squares being included in this part of the analysis (Fig. 2.1).

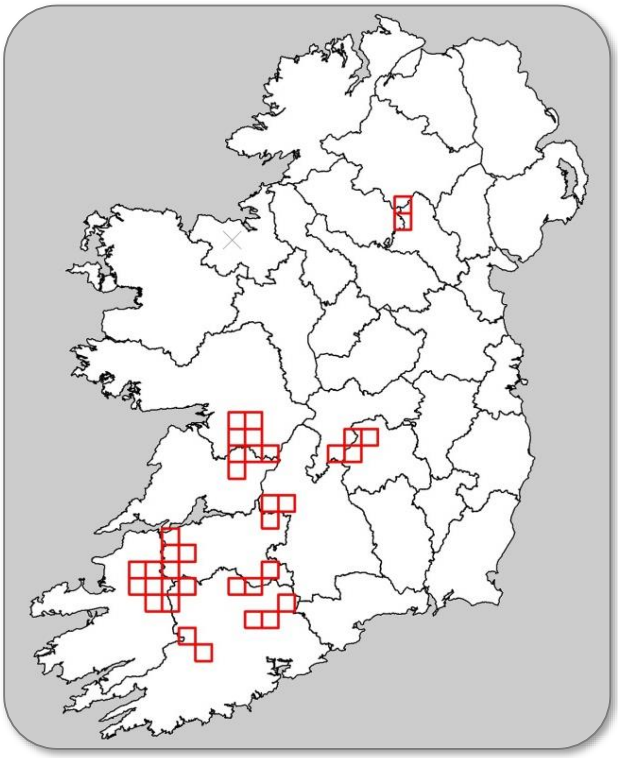


Figure 2.1: The 36 10km squares included in this study (red boxes).

2. 2. 2 Wind turbines

In the first part of this study the locations of all wind turbines across Ireland, as detailed on the Irish Wind Energy Association website at the end of 2012 were used. In the second part of this study the locations of all wind turbines constructed between the periods 2000 and 2010 in the 36 study squares were identified from aerial photos, and plotted in the Geographic Information System (GIS) programme ArcGIS 10.0. This was used to calculate the number of turbines built in each square between 2000 and 2010.

2. 2. 3 Forest cover

Total forest cover in the study squares up to 2010 was estimated from combined forest cover recorded in 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 in 2010, the changes in closed canopy forest and in pre-thicket forest cover between 2000 and 2010 were calculated. The following categories of forest plantation were provisionally classified as pre-thicket habitat:

1. First rotation plantations up to and including fifteen years of age.
2. Second rotation plantations between three and fifteen years after planting.
3. 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 FIPS 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, all data on forested areas were verified visually using aerial photographs from 2000, 2005 and 2012.

2. 2. 4 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 200 and 400m, as seen in Table 2.1.

Table 2.1: Numbers and densities of confirmed breeding Hen Harrier pairs in 2010 in the 10km squares used in this study, in each of 3 elevation categories. Data are taken from Ruddock et al. (2011).

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

2. 2. 5 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 turbine development was tested using general linear models (GLMs). Because changes in the number of breeding Hen Harriers were normally distributed, Gaussian GLMs were used. Turbine 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 either turbine numbers or changes in numbers of Hen Harrier pairs were spatially auto correlated.

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 which turbine-related variable would be best to include in the models. In addition to turbines, the starting model included three grouping variables (grouping squares broadly according to hill ranges, longitude and latitude), three variables relating to the proportion of land area within three elevation categories, the area of felled forest in 2000, the total area of forest in 2010, and the change between 2000 and 2010 in the area of closed canopy forest and pre-thicket forest. Variables which provide a more detailed characterisation of the topographical environment (such as terrain ruggedness and slope) were also included. Finally the importance of neighbouring areas on the changes detected in Hen Harrier numbers was investigated by considering the percentage of suitable Hen Harrier habitat and land at optimal elevations in surrounding areas, as well as degree of isolation of areas analysed with regards to these factors).

As well as these variables, the starting model also included interaction terms between these variables and turbine presence. Each of these interaction terms were 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.

2. 3 Results

2. 3. 1 Spatial overlap between wind energy development 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. 2.2. 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 farm developments. The yellow squares indicated the presence of wind farms as listed on the IWEA website prior to the end of 2012 and the green squares indicate Hen Harrier areas where no wind energy development had taken place by the end of 2012.

The observed overlap in spatial distribution of Hen Harriers and wind farm developments was not limited to a two dimensional surface distribution, but also occurs when elevation is examined (Fig. 2.3). 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.

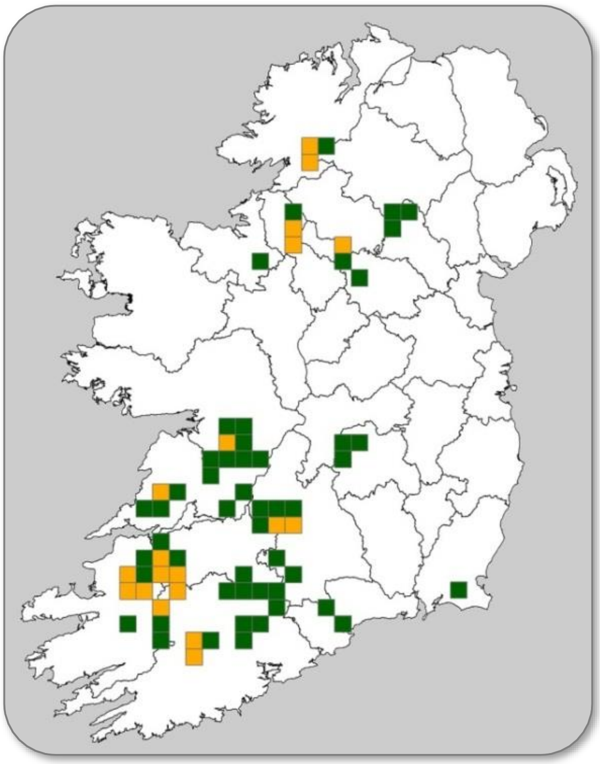


Figure 2.2: Distribution of Hen Harriers at a 10km square scale in the Republic of Ireland as recorded during the 2010 National Survey. Hen Harriers were recorded in all coloured squares. Yellow squares had wind farm development as of 2012 (n = 19) and green squares did not (n = 50).

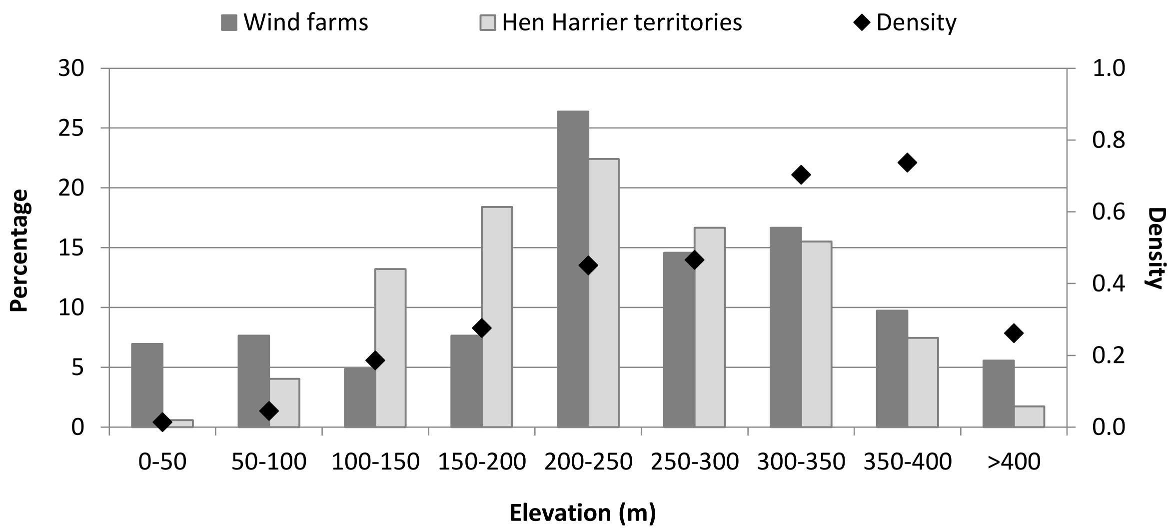


Figure 2.3: Frequency of occurrence (%) of wind farms and Hen Harrier territories (2010 breeding season) across the island of Ireland at a range of elevations and corresponding Hen Harrier densities.

2. 3. 2 Hen Harrier population trends and wind energy development

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 farm development, the number of turbines built was not related to the change in number of breeding Hen Harriers (Fig. 2.4).

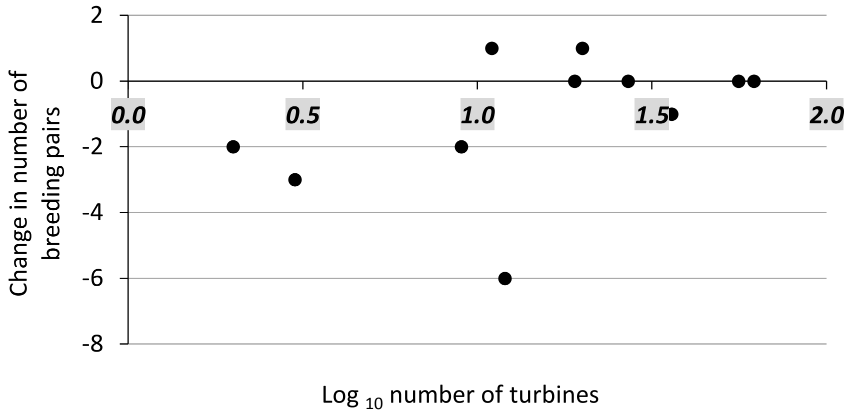


Figure 2.4: Change in number of breeding Hen Harriers between 2000 and 2010 plotted against the number of wind turbines built, in the eleven squares that experienced turbine development during this period. This relationship is not statistically significant (Pearson's r = 0.41, n = 12, P = 0.18).

However, comparing squares with and without turbine development, there appeared to be a weak negative relationship between turbine development and change in breeding Hen Harrier numbers (Fig. 2.5), although this relationship was a marginally non-significant negative relationship (t=1.82, d.f. = 34, P = 0.077). Presence of turbines was therefore selected as the most appropriate variable for inclusion in general linear models. 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.

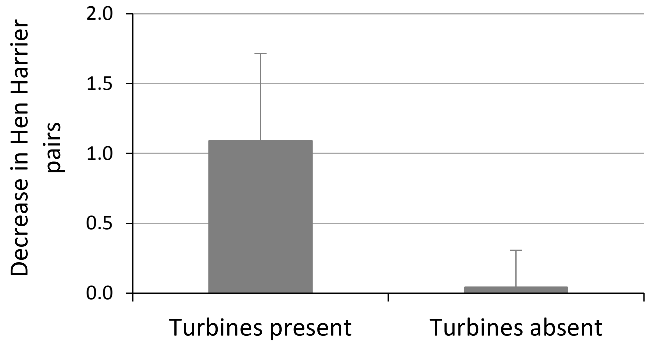


Figure 2.5: Change in number of breeding Hen Harriers between 2000 and 2010, in the 11 squares that experienced wind turbine development during this period and the 25 squares where no turbines were built. On average, Hen Harriers declined by over 1 pair per square more in squares with turbines than in squares with no turbines, but this difference was not statistically significant (t = 1.82, d.f. = 34, P = 0.077).

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 2.2). The apparent effects (“Estimate”) 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 2.2). This means 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 (Fig. 2.6).

Table 2.2: 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

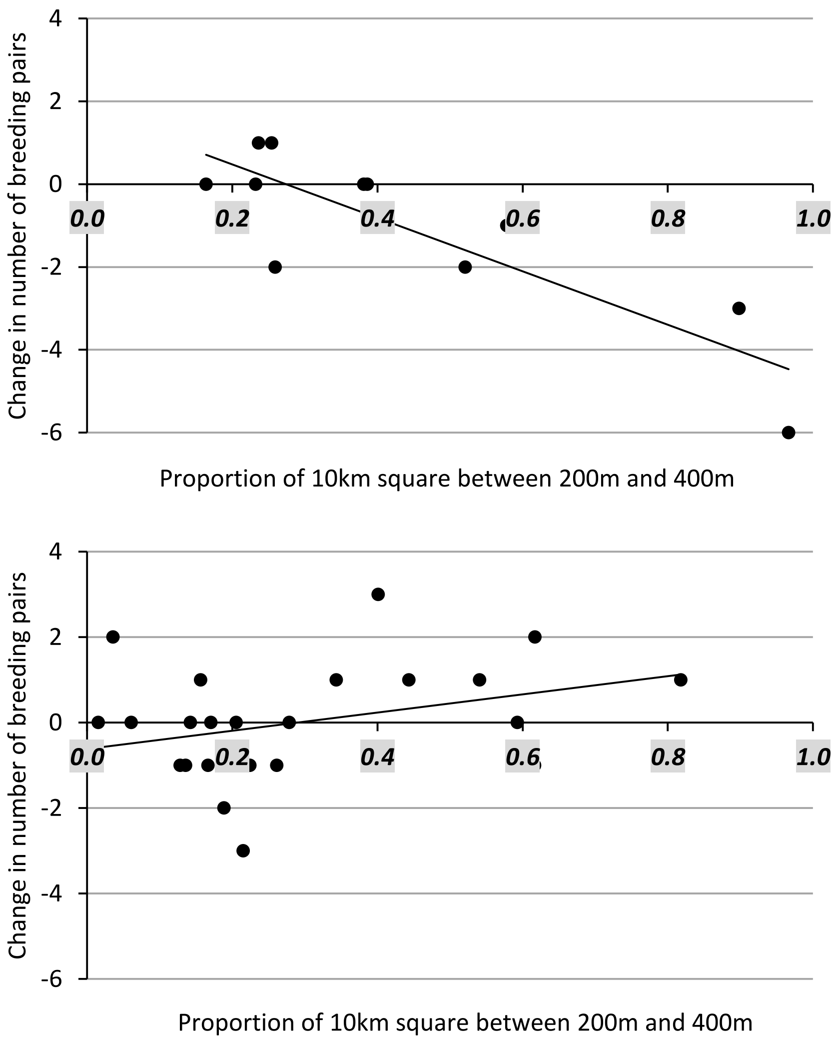


Figure 2.6: The relationship between change in the number of Hen Harriers between 2000 and 2010 and the proportion of land between 200m and 400m in 12 squares where wind turbines were built during this period (above) and in 25 squares where there was no wind energy development during this time (below). See Table 2.2 for full details of the model output.

2. 4 Discussion

2. 4. 1 Spatial overlap between wind energy development and Hen Harriers

One of the bird species for which potential impacts of wind energy development in Ireland have been of greatest concern is the Hen Harrier. This concern is related to the rarity of Hen Harriers in Ireland and throughout their range, the legal protection afforded to this species by the Birds Directive (2009/147/EC) and the considerable spatial overlap between the range of this species and the upland areas in which onshore wind farm development 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, but upland areas are also home to some important bird populations, not least of which is 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 28% of 10km x 10km squares in the Irish uplands occupied by breeding Hen Harriers have experienced the installation of wind farms since 2000, while 72% have not been impacted by wind energy developments. In a similar study of Hen Harrier sensitivity to wind farms in Scotland the species was found to be highly sensitive to wind energy development as more than 10% high sensitivity buffered areas of territories were located within 2km of proposed or existing wind farms (Bright *et al.*, 2008a). There it was identified as just one of three bird species of 16 included in the study, that were highly sensitive to wind energy development (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). 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 show important variations across a species' range, as is the case of White-tailed Sea Eagles *Haliaeetus albicilla*, for which small overlaps were reported in Scotland (Bright *et al.*, 2008a) while wind farm developments in Norway have been built in areas with high densities of breeding pairs (Dahl *et al.*, 2012). Although spatial overlap is not always associated with negative impacts on birds (Fielding *et al.*, 2006), studies of this kind, although rare, are important to determine whether wind energy development is likely to conflict with bird conservation. Careful planning is required to minimise any potential impact and the findings of this work package 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 observed overlap in spatial distribution of Hen Harriers and wind farms is expected to increase as Ireland's wind energy sector continues to grow to meet the Irish Government's energy production strategy (DCENR, 2012).

Further analyses revealed that the observed overlap is not limited to a two dimensional surface distribution, but also occurs in relation to elevation. Sixty seven per cent of Irish wind farms are located between 200m and 400m above sea level, an elevation band where up to 62% of all Hen Harrier territories are also found. Maximum Hen Harrier breeding densities also occur at these elevations, with an average of 4.2 pairs per 100km^2 (Irwin *et al.*, 2012, Ruddock *et al.*, 2012).

2. 4. 2 Hen Harrier population trends and wind energy development

Hen Harrier populations have fluctuated significantly throughout their range over the past century and data on recent population trends indicates stability over the last decade (Watson, 1977, O'Flynn, 1983, Norriss *et al.*, 2002, Barton *et al.*, 2006, Ruddock *et al.*, 2012). The availability of data on Hen Harrier populations from the 2000, 2005 and 2010 National Surveys affords us the opportunity to investigate the relationship between the deployment of wind energy facilities and changes in Hen Harrier breeding numbers. It is important to bear in mind that any 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 possible mechanisms that may impact on breeding Hen Harrier numbers.

Although not statistically significant, a weak negative relationship 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 General Linear Model suggest that this relationship is also likely to be influenced by the effects of 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 related to availability of suitable forest habitats and possibly also to availability of habitat at appropriate elevations. Having taken these variables into account, the main effect of wind turbine presence in the model is a slightly positive one. However, this is countered by the strongly negative 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 medium elevations in areas suitable for turbines are intrinsically less well suited to Hen Harriers. The data show that many turbines have been built in this altitude range and it is possible that any negative interaction between Hen Harriers and turbines is greatest at this height, as it is the band of altitude most frequently occupied by breeding Hen Harriers (unpublished data). 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 direct 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 energy developments (Percival, 2003b, Madders & 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 & Madders, 2005). Factors not investigated in this analysis that could also impact on changes in Hen Harrier populations include the availability of open habitats, changes in both the availability and quality of such habitats during the study period, disturbance by human activities and changes in populations of predators and prey.

Despite the large volume of work reported on the impacts of wind energy development on birds, long-term studies of bird populations in relation to wind farms are scarce. The current study provides valuable insight into the factors regulating Hen Harriers at a population scale. While this approach serves to underline the importance of certain on-going environmental changes in upland habitats (i.e. changes in pre-thicket cover), 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. In the case of Hen Harriers in the Irish context, 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. While this study provides information on how wind farm developments fit into this complex scenario, further research will be necessary for a full understanding of the factors regulating Hen Harrier populations in Ireland.

Work Package 1b
3. Study Site Selection

The aim of the second part of Work Package 1 was to produce a list of candidate study sites where primary data would be collected during the WINDHARRIER project towards Work Packages 2-5.

3. 1 Methods

Data on wind farm locations were collated from information supplied by the Irish Wind Energy Association (IWEA) and supplemented by information sourced using the internet on locations of existing wind farms. These two datasets were cross-referenced with one another and interrogated to identify areas where wind farms were situated near locations where Hen Harriers had been known to breed (Fig. 3.1). A shortlist of wind farms was drawn up that comprised all wind farms within 2km of any confirmed Hen Harrier breeding locations as identified during the 2005 and 2010 National Hen Harrier Surveys. From this shortlist, candidate study sites were selected on the basis of their comprising more than four turbines. Sites were selected from all available sites using the selection criteria described below.

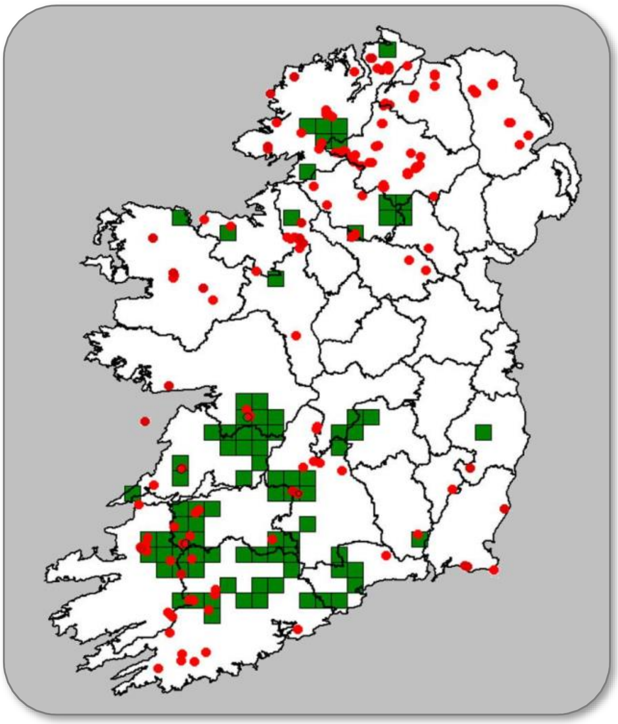


Figure 3.1: Hen Harrier breeding activity in 2000 and 2005 (green squares) and Wind Farm locations (red dots).

Site selection criteria for Wind Farm sites:

- Presence of wind turbines
- Presence of suitable nesting and/or foraging habitat for Hen Harriers in the area occupied by the turbines
- Evidence of Hen Harrier breeding, preferably within 2km of the site in 2012
- Evidence that Hen Harriers have bred within 3km of the site (using information from the 2005 and 2010 national Hen Harrier surveys)

- A minimum number of 4 turbines
- More than 2km from any other study site
- A selection of linear and clustered arrays
- Target modern turbines of similar designs

Site selection criteria for Control areas:

- Absence of wind turbines
- Closely matched to Wind Farm sites in terms of habitat composition
- Presence of suitable habitat for Hen Harriers
- Evidence of Hen Harrier breeding, preferably within 2km of the site in 2012
- Evidence that Hen Harriers have bred within 3km of the site (using information from the 2005 and 2010 national Hen Harrier surveys)
- Closely matched to Wind Farm sites in terms of size (size to be measured using a buffer of 500m around turbines and control sites to be a minimum of percentage of area of active wind farm sites)

3. 2 Study Sites

Appropriate sites for the collection of data required for the WINDHARRIER project were limited across Ireland. Twelve wind farms study sites were selected and permission to access sites for the purposes of data collection was secured where required. Local access was required for the collection of data for Work Package 2, but site access was not required for other aspects of data collection. Twelve control sites, matched to these wind farms sites in all respects, except the presence of turbines, were also selected (Fig. 3.2). Fieldwork was undertaken at these sites between April and August each year to collect data for the WINDHARRIER project. Data were collected selectively across the available wind farm and control study sites and further detail on sites used is provided in individual Work Packages sections of this report.

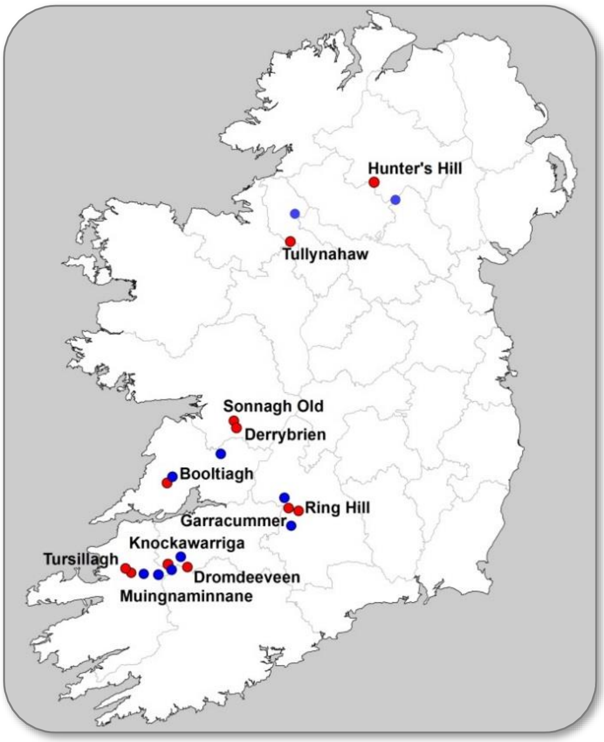


Figure 3.2: Study sites selected for the WINDHARRIER research project. Red dots represent wind farm study sites and blue dots represent control study sites. NOTE Two study sites were located within the wind farm at Derrybrien.

Work Package 2

4. Breeding bird communities in and around wind farms

Bird communities in areas occupied by people have been shaped by changes in land use as bird populations respond to modifications in either the availability or the suitability of their habitat. Among the most recent of these changes is the development of wind turbines for the conversion of wind energy into electricity. The influence of this land use change is concentrated in habitats with high wind energy potential such as upland habitats. Many studies of birds in relation to wind energy developments have focussed on direct mortality of birds, but the importance of indirect effects such as displacement and habitat loss is being increasingly recognised. This study focussed on the effects of wind energy development on upland bird communities in Ireland, using a control gradient design to assess the likelihood of impacts at different spatial scale. Bird densities were lower at wind farm sites than at control sites and lower closer to wind turbines than further away at wind farm sites. For forest bird species in particular, densities were significantly lower within 100m of wind turbines, but not thereafter. This study demonstrates that the observed effect is very localised and mediated through modifications to habitats caused by wind energy development, which led to a reduction of forest habitats and a corresponding decrease in the densities of bird species associated with these habitats.

4. 1 Introduction

The aim of this Work Package was to assess the effect of onshore wind farms on the distribution and behaviour of breeding birds, a dominant component of the Hen Harrier's diet, at wind farm and control sites. The ecology, distribution and abundance of birds are sensitive to environmental conditions (Koskimies, 1989, Furness & Greenwood, 1993, Kent *et al.*, 2014) and changes in land use are widely recognised as an important factor influencing bird population trends (Gaston *et al.*, 2003, Fuller, 2012, Kampichler *et al.*, 2012). Around the world, terrestrial bird communities have been shaped by habitat modification resulting from human activities such as afforestation, deforestation, cultivation and changes in management intensity of agricultural land, and urban and industrial development (Gaston *et al.*, 2003, Sweeney *et al.*, 2010, Fuller, 2012, Scridel, 2014). Due to increasing demands for food, fibre, water and energy these land use changes are likely to remain an important influence on bird populations into the future (Jetz *et al.*, 2007, Eglington & Pearce-Higgins, 2012, Pearce-Higgins *et al.*, 2012).

The shift from traditional to renewable energy sources has become an important factor driving changes in land use of natural and semi-natural habitats in recent decades (Fthenakis & Kim, 2009). Efforts to reduce the negative environmental impacts of traditional energy sources (Anon, 2007b) have led to a rapid growth of the renewable energy sector, particularly regarding the generation of electricity from wind energy. Use of wind energy reduces human reliance on electricity generation from fossil fuels and can reduce the atmospheric pollution associated with meeting global energy demands. Although widely perceived as one of the cleanest and most affordable energy sources, the on-going increase in wind energy developments has led to an awareness of its potential associated environmental impacts (Leung & Yang, 2012, Tabassum *et al.*, 2014). Large scale deployment of wind energy installations can result in habitat loss and degradation, and turbine blades can sometimes kill birds and bats (Kuvlesky *et al.*, 2007, Northrup & Wittemyer, 2013).

The continued growth in wind energy development, and the fact that much of this is focussed in areas with important bird habitats, has led to a growing demand for information on the potential impact that this may have on bird communities. The most commonly reported negative impact on birds is direct mortality caused by collisions with turbine blades (de Lucas *et al.*, 2008, Kikuchi, 2008, Erickson *et al.*, 2014, Marques *et al.*, 2014). Wind farms can also cause displacement of bird species, either through loss of habitat or through the avoidance of otherwise suitable habitat due to the presence of turbines (Drewitt & Langston, 2006, Pearce-Higgins *et al.*, 2009b, Douglas *et al.*, 2011). Some studies have reported reduced breeding densities of waders and raptors close to wind farms (Farfán *et al.*, 2009, Garvin *et al.*, 2011, Pearce-Higgins *et al.*, 2012, Campedelli *et al.*, 2013) while research on corvids, gamebirds and passerines has found little or no negative effects of wind turbines on bird abundance (Devereux *et al.*, 2008, Farfán *et al.*, 2009, Douglas *et al.*, 2011, Minderman *et al.*, 2012, Hale *et al.*, 2014). Reviews of available evidence on the displacement effect of wind farms on birds indicates that the existence and extent of impacts varies considerably across species, habitats, seasons and geographic regions (Leddy *et al.*, 1999, Drewitt & Langston, 2006, Stewart *et al.*, 2007, Farfán *et al.*, 2009, Pearce-Higgins *et al.*, 2009b).

Common and widespread bird species may not be subject to species specific conservation legislation, but are nevertheless of considerable ecological importance, fulfilling key ecosystem roles as predators, prey and seed dispersers, and all bird species are protected by the EU Birds Directive (2009/147/EC) (Sekercioglu, 2006). Research on wind farm impacts to date has tended to focus on charismatic, rare or endangered bird species with low abundances (Drewitt & Langston, 2006, de Lucas *et al.*, 2007a). While the displacement of specific species can ultimately result in a shift in the structure of avian communities (Tabassum *et al.*, 2014) there has been little attempt to address the potential impact on bird communities as a whole. Furthermore there has been a lack of studies which take account of the interdependent effects of habitat and wind turbine presence or which address ecosystem level impacts of wind energy development. Understanding whether, and to what extent, wind turbines affect bird communities as a whole is an essential step towards developing a comprehensive understanding of the effects of wind energy development at a broader ecosystem scale.

Small bird species make up a significant component of the diet of Hen Harriers and impacts of wind energy development on breeding birds may have knock-on effects on Hen Harriers whose populations are reliant on the availability of suitable prey. Studies on the impact of previous land use change on Hen Harriers has highlighted the reduction in prey availability as an important factor in mediating observed impacts (Amar *et al.*, 2003). Higher numbers of Hen Harriers are associated with greater availability of suitable prey items during the breeding season (Hagen, 1969, Redpath *et al.*, 2002b, Baines & Richardson, 2013) and Hen Harriers forage preferentially over habitats with high frequencies of suitable prey (Madders, 2010).

The Hen Harrier diet varies across seasons and geographic regions and is comprised predominantly of small rodents and passerine birds (Picozzi, 1980, Baines & Richardson, 2013). Hen Harriers prey on a very wide range of bird species such as Meadow Pipits *Anthus pratensis* and Skylarks *Alauda arvensis* (Dobson *et al.*, 2009). In the UK Meadow Pipits *Anthus pratensis* and field voles *Microtus arvensis* are important prey items for Hen Harriers (Amar *et al.*, 2003, Baines & Richardson, 2013). In Ireland small mammals, birds, amphibians and reptiles are all included in the diet of Hen Harriers during the breeding season. Land management which affects the availability of prey may ultimately impact on Hen Harrier numbers. A very clear example of this comes from work on Scottish Grouse moors where the increase in prey items brought about by the management of heather moorlands for Grouse populations has been seen to lead to increases in Hen Harrier abundance (Redpath *et al.*, 2002a, Baines & Richardson, 2013). There, research has shown that habitat management may be a useful tool in minimising the conflict between Grouse moors and Hen Harrier conservation. The appropriate management of separate areas of habitat could be used to effectively segregate Grouse (in areas of high heather cover) from Hen Harriers (in areas of heather/grass mosaics). A similar approach may be useful in reducing the conflict between Hen Harrier conservation and the placement of wind farms, by guiding the siting of wind farms in areas that have the lowest quality habitat for foraging Hen Harriers.

Here we study the effects of wind farm developments on upland breeding bird communities by assessing species composition and abundance. To overcome the methodological weakness common to wind farm studies highlighted by Stewart *et al.* (2007), we used a control-impact gradient design. This methodological approach allows us to (i) compare areas under wind farm development and control areas of similar environmental characteristics (control-impact study); (ii) avoid confounding temporal effects associated with Before-After Control Impact designs Strickland *et al.* (2007); (iii) maximise our ability to detect displacement gradients, where the extent of the impact is a function of the distance from wind turbines (Anon, 2007b). This represents the first comprehensive study of wind farm impacts on upland bird communities incorporating consideration of habitat characteristics in the analysis rather than simply using bird densities as a proxy measure of bird habitat.

4. 2 Methods

4. 2. 1 Bird survey design

Bird species composition and densities were assessed at twelve wind farm study sites during the 2012 and 2013 bird breeding seasons. To maximise the detection of potential effects of wind farms on bird populations, we selected large wind farms holding at least 8 turbines (range of 8 to 35) of modern and similar design. A total of 27 survey points were selected at each wind farm, in increasing distance bands from wind turbines (nine survey points within 100m of turbines, six at 100-400m, six at 400-700m, and six at 700-1000m). To avoid any confounding effects of multiple turbines or of other wind farm infrastructures, points further than 100m from individual turbines were selected only outside of the minimum polygon containing all turbines (Fig. 4.1). This design allowed us to evaluate (i) differences between bird densities at wind farm and control sites and (ii) variations in densities at increasing distances from turbines while controlling for confounding environmental factors.

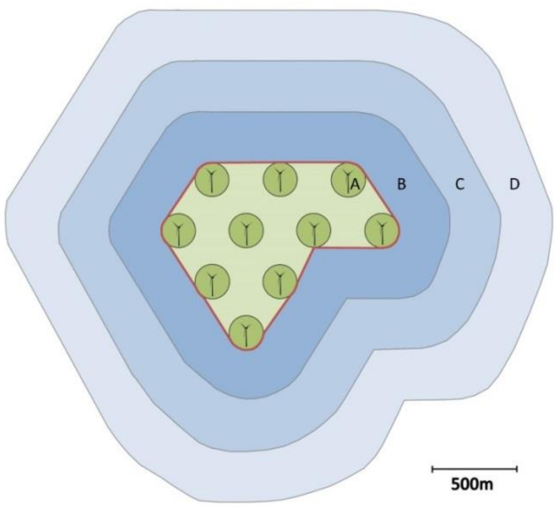


Figure 4.1: Illustration of the distribution of distance bands used in this study at a hypothetical wind farm. A = <100m from wind turbines and within wind farm, B = 100-400m from turbines, C = 400-700m from turbines and D = 700-1000m from turbines.

For each wind farm, a control site was selected within 12km in an area of similar habitat composition and topography with no wind farm development. For every wind farm survey point, a matching control survey point was selected in the corresponding control site. To assess the potential effects of wind farms and their associated infrastructures (tracks, buildings, etc.), control survey points were selected such that their habitat composition was similar to that of the corresponding wind farm point prior to wind farm construction. This was done with the aid of aerial photographs taken prior to wind farm construction. To control for elevation effects on bird densities, control survey points were also selected to match the altitude of their wind farm counterpart.

Breeding birds were surveyed using point count methodology as described in Bibby *et al.* (2000). Point counts were conducted on days without persistent rain or strong wind (less than Beaufort 4) during the breeding season (April to June), from one hour after dawn until noon. Each point count lasted five minutes, during which time all birds detected by sight or sound within a 100m radius were recorded and their distance from the observer noted. The time between point count pairs (wind farm and control site points) was minimised to reduce variability due to weather or time of season. Habitats within a 100m radius of each point were categorised as pre-thicket forest, closed canopy, clear fell, improved grassland, rough grassland, scrub, peatland, or human-altered habitats (i.e. bare ground, tracks, buildings). Percentage cover of each habitat was recorded on site with the aid of aerial photographs. Point count elevation and distance to nearest wind turbine were calculated using ArcGIS 10 software (Environmental Science Research Institute). Bird counts were converted to densities using Distance Software (Thomas *et al.*, 2010) to correct for differences in detectability at different distances from the observer and in different habitats. Densities were calculated for individual species and for all bird species combined. To detect potential specific effects on birds associated with certain habitats, densities were also calculated for forest and open country species (forest species: Great tit *Parus major*, Blue tit *Cyanistes caeruleus*, Long-tailed tit *Aegythalos caudatus*, Chaffinch *Fringilla coelebs*, Bullfinch *Pyrrhula pyrrhula*, Siskin *Carduelis spinus* and Treecreeper *Certhia familiaris*; open country species: Meadow Pipit *Anthus pratensis*, Skylark *Alauda arvensis*, Whetear *Oenanthe oenanthe*, Snipe *Gallinago gallinago*, Red Grouse *Lagopus lagopus* and Curlew *Numenius arquata*). To detect any potential effects of turbine noise (e.g. reducing fieldworkers' ability to hear and detect singing birds or causing behavioural changes resulting in lower singing rates), we calculated the proportion of birds which were recorded as calling or singing (number of birds calling or singing / total number of birds).

4. 2. 2 Data analysis

To assess how the different factors measured affected bird densities we used generalised linear models (GLMs). GLM response variables were bird densities (overall densities, species specific densities, open country and forest species densities). Explanatory variables included site (wind farm or control), distance to nearest turbine (in metres), the interaction between the previous two variables (as distance to turbine was only expected to be relevant at wind farm sites), percentage cover of each habitat type (pre-thicket forest, closed canopy, clear fell, improved grassland, rough grassland, scrub, peatland, or other), and point count elevation (in metres). Models were fitted using backward stepwise procedure where non-significant variables ($P > 0.05$) were removed (Pearce & Ferrier 2000). Akaike's Information Criterion (AIC) were calculated for all models (Burnham & Anderson 2002).

To evaluate differences between wind farm and control sites at a finer scale, we used Wilcoxon signed-rank tests to compare bird densities (birds / Ha), proportions of birds vocalising, point count habitat composition and point count elevation. All statistical analyses were performed with R 3.1.1 (www.r-project.org).

4. 3 Results

A total of 49 bird species were recorded during point count surveys in this study (Table 4.1). The results of the GLM analyses indicated a significant negative relationship between wind energy development and bird densities at the study sites (Table 4.2). The significant positive relationship between distance to turbine and bird density suggests that bird abundance was greater further from wind turbines. Elevation had a negative effect on bird densities (lower bird abundances were recorded at higher elevations) and several habitat types (clear fell, grassland, peatland and pre-thicket) also had a significant effect on bird densities.

Table 4.1: Bird species recorded during point count surveys of breeding birds in this study.

Common name	Scientific name	Common name	Scientific name
Blackbird	*Turdus merula*	Meadow Pipit	*Anthus pratensis*
Blackcap	*Sylvia atricapilla*	Pheasant	*Phasianus colchicus*
Bullfinch	*Pyrrhula pyrrhula*	Pied Wagtail	*Motacilla alba*
Blue Tit	*Cyanistes caeruleus*	Robin	*Erithacus rubecula*
Chiffchaff	*Phylloscopus collybita*	Reed Bunting	*Emberiza schoeniclus*
Chaffinch	*Fringilla coelebs*	Red Grouse	*Lagopus lagopus scotica*
Cuckoo	*Cuculus canorus*	Raven	*Corvus corax*
Coal Tit	*Periparus ater*	Rook	*Corvus frugilegus*
Curlew	*Numenius arquata*	Skylark	*Alauda arvensis*
Dunnock	*Prunella modularis*	Stonechat	*Saxicola torquatus*
Goldcrest	*Regulus regulus*	Spotted Flycatcher	*Muscicapa striata*
Grasshopper Warbler	*Locustella naevia*	Starling	*Sturnus vulgaris*
Goldfinch	*Carduelis carduelis*	Siskin	*Carduelis spinus*
Great Tit	*Parus major*	Swallow	*Hirundo rustica*
Hooded Crow	*Corvus cornix*	Snipe	*Gallinago gallinago*
House Sparrow	*Passer domesticus*	Song Thrush	*Turdus philomelos*
Jay	*Garrulus glandarius*	Sedge Warbler	*Acrocephalus schoenobaenus*
Jackdaw	*Corvus monedula*	Teal	*Anas crecca*
Kestrel	*Falco tinnunculus*	Treecreeper	*Certhia familiaris*
Linnet	*Carduelis cannabina*	Wheatear	*Oenanthe oenanthe*
Lesser Redpoll	*Carduelis cabaret*	Whitethroat	*Sylvia communis*
Long-tailed Tit	*Aegithalos caudatus*	Woodpigeon	*Columba palumbus*
Mistle Thrush	*Turdus viscivorus*	Wren	*Troglodytes troglodytes*
Mallard	*Anas platyrhynchos*	Willow Warbler	*Phylloscopus trochilus*
Magpie	*Pica pica*		

Overall bird densities were lower at wind farm than at control sites ($z = 11670.5$, $P = 0.002$), with survey points within 100m of turbines showing the greatest differences ($z = 1043.5$, $P < 0.001$) (Fig. 4.2). When grouped by their habitat associations, forest bird species were found at lower densities at wind farm sites than at control sites, though this difference was not statistically significant ($z = 5605.5$, $P = 0.097$). A significant difference was found between bird densities within 100m of wind turbines and at control points without wind turbines ($z = 553.5$, $P = 0.009$, Fig. 4.3). Open country bird species were found at lower densities at wind farm sites across all distance bands ($z = 2910.0$, $P = 0.008$, Fig. 4.4). The proportion of birds vocalising (calling or singing) were significantly lower at wind farm point counts within 100m of turbines than at matched control points ($z = 1234.0$, $P = 0.038$, Fig. 4.5).

Table 4.2: Parameter values of the best performing model predicting Hen Harrier density as a function of site, turbine proximity, habitat composition and altitude.

	Estimate	t value	P value
Intercept	6.3129	12.0	<0.001
Site (wind farm)	-0.7586	-2.8	0.005
Distance to turbine	-0.0009	2.3	0.021
Clear fell	-0.0270	-5.4	<0.001
Grassland	-0.0252	-7.3	<0.001
Peatland	-0.0387	-13.4	<0.001
Pre-thicket	-0.0189	-5.2	<0.001
Elevation	-0.0043	-3.1	0.002
Site (wind farm) * Distance to turbine	0.0009	1.7	0.081

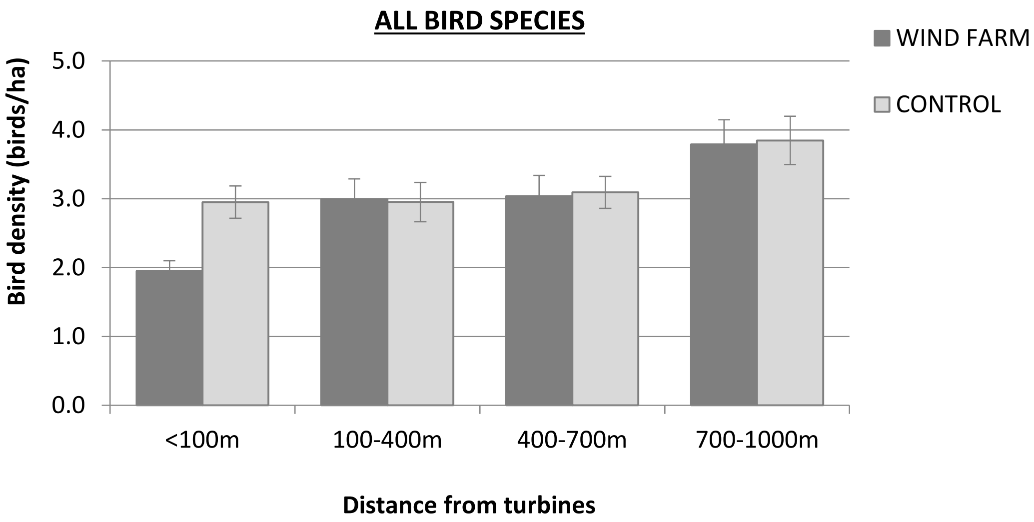


Figure 4.2: Mean (±SE) bird densities at increasing distances from wind turbines.

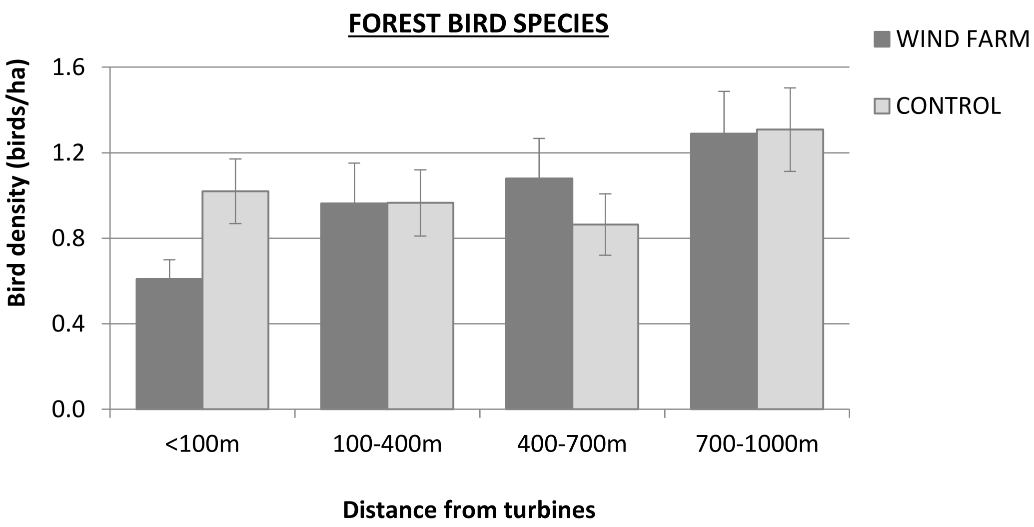


Figure 4.3: Mean (±SE) densities of forest birds at increasing distances from wind turbines.

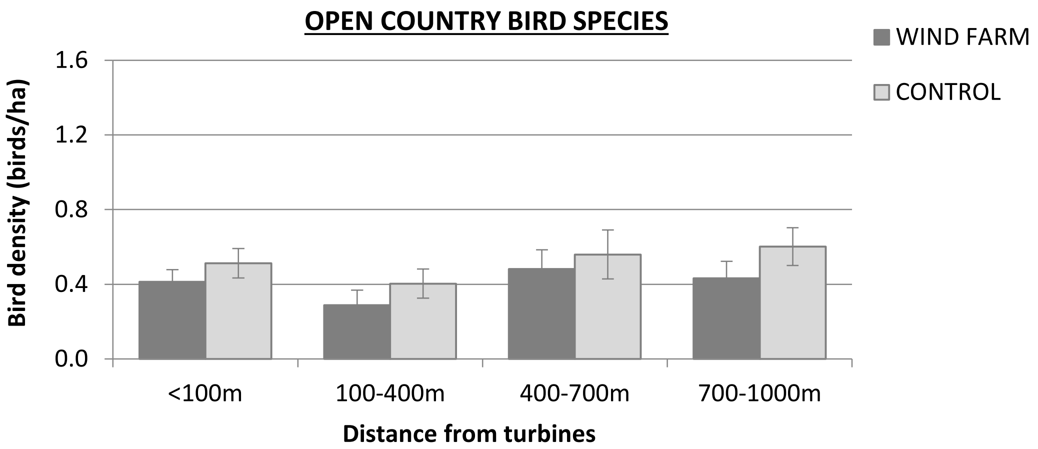


Figure 4.4: Mean (±SE) densities of open country birds at increasing distances from wind turbines.

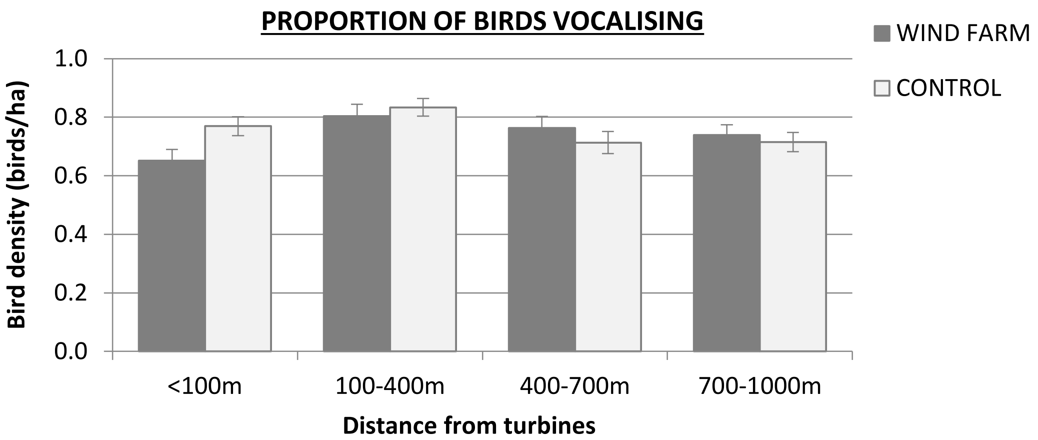


Figure 4.5: Mean (±SE) proportion of birds vocalising (calling or singing) at wind farm and control study sites at increasing distances from wind turbines.

Comparison of the environmental characteristics at point count locations revealed that wind farm and control points were correctly matched for elevation during the site selection process, as there were no differences between the two groups in any of the four distance bands ($z = 16949.5$, $P = 0.270$). However, points located further from turbines were at lower elevations than those close to wind farms (Fig. 4.6).

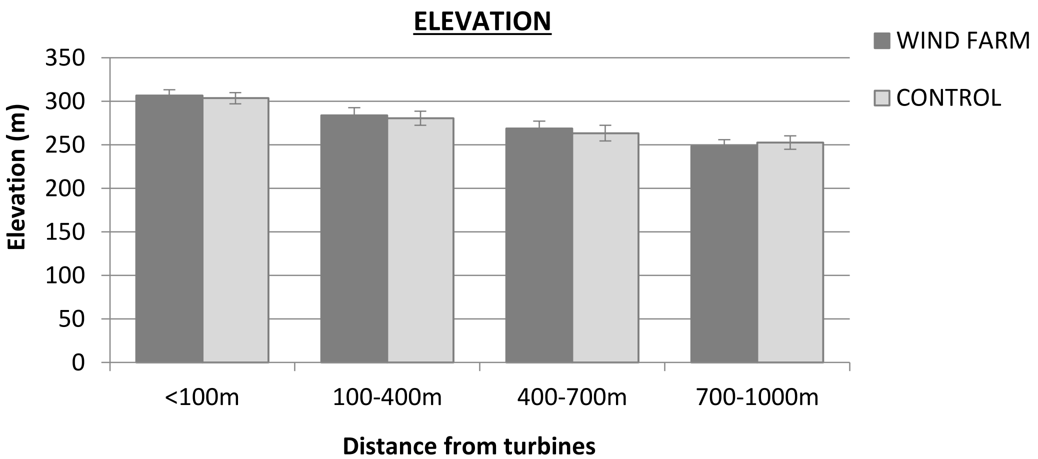


Figure 4.6: Mean (±SE) elevation of point count locations at wind farm and control study sites at increasing distances from wind turbines.

Comparison of habitat composition at wind farm and control sites revealed significant differences for three of the habitat types: human-altered habitats, clear fell and closed canopy. Human-altered habitats occurred more frequently at wind farm sites ($z = 4126.0$, $P < 0.001$), with differences observable up to 700m from turbines (Fig. 4.7). Likewise, clear felled areas occurred more frequently at wind farm sites ($z = 492.0$, $P = 0.039$), with differences evident up to 900m from turbines (Fig. 4.8). Closed canopy areas were less abundant at wind farm sites at points within 100m of turbines than at corresponding points without wind turbines ($z = 636.5$, $P = 0.020$, Fig. 4.9).

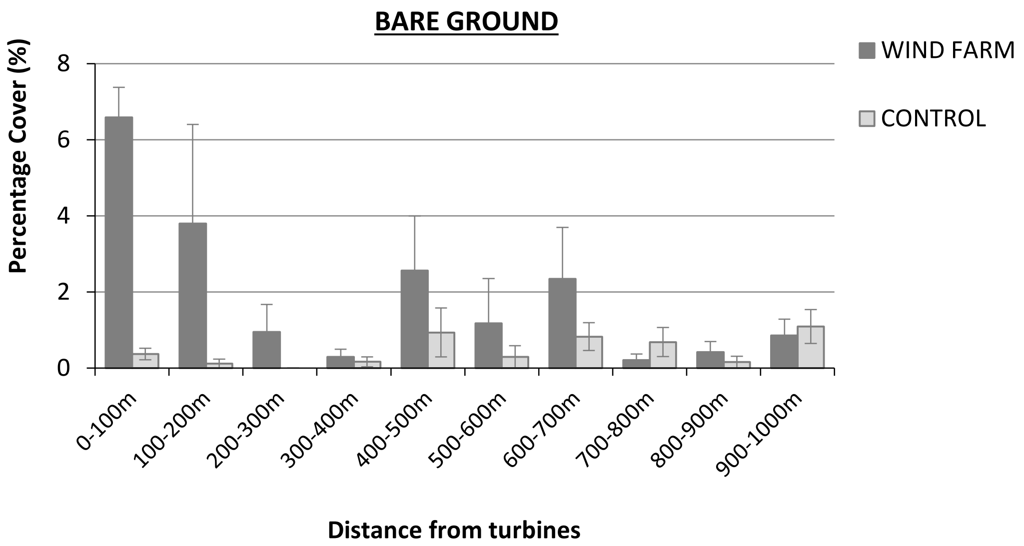


Figure 4.7: Mean (±SE) proportion of bare ground at increasing distances from wind farm and control site point count locations.

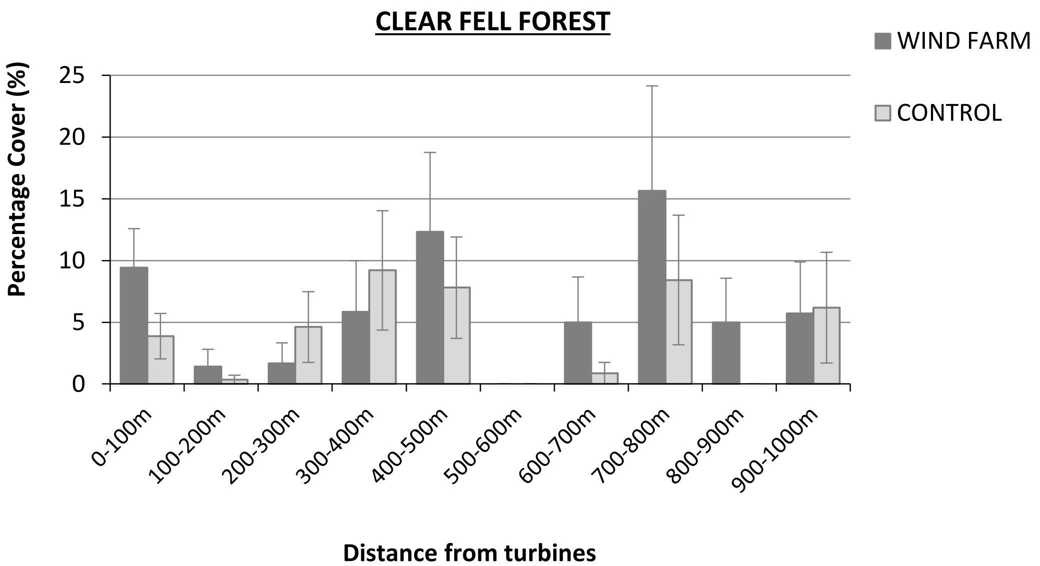


Figure 4.8: Mean (±SE) proportion of clear fell forest at increasing distances from wind farm and control site point count locations.

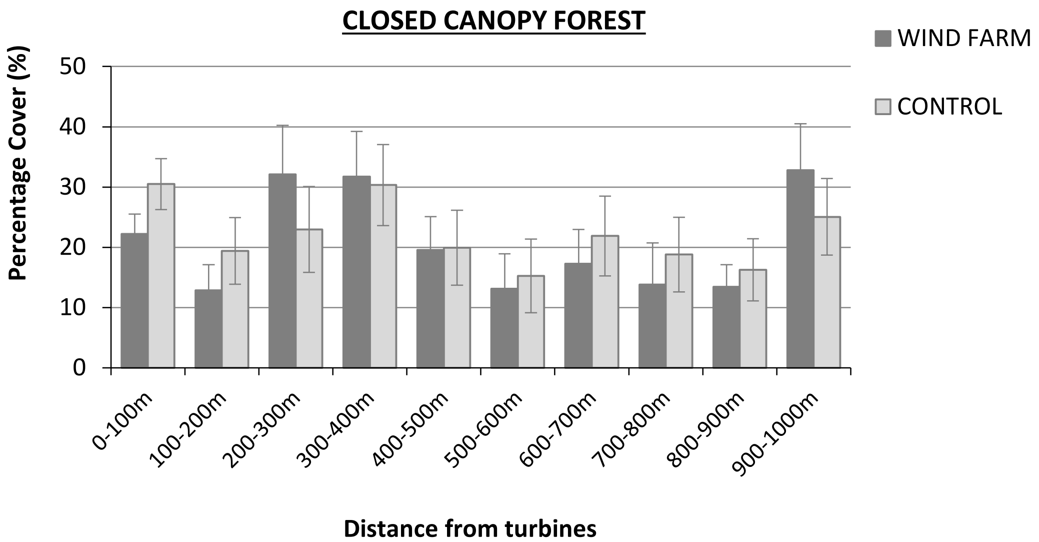


Figure 4.9: Mean (±SE) proportion of closed canopy forest at increasing distances from wind farm and control site point count locations.

4. 4 Discussion

The results of this study indicate that bird densities were lower at wind farm sites than at control sites and lower closer to wind turbines than further away at wind farm sites. For forest bird species densities were significantly lower within 100m of wind turbines. We also found differences in habitat composition between wind farm and control points, but only for certain habitat types. Wind farm sites had less closed canopy cover and larger areas of clear fell and bare ground. These differences were less pronounced with increasing distance from turbines, suggesting a link with wind farm developments. Of the bird species recorded in the present study, just four were reported by Pearce-Higgins *et al.* (2009b) to have reduced breeding densities within 500m of wind farms. These were Curlew *Numenius arquata*, Meadow Pipit *Anthus pratensis*, Snipe *Gallinago gallinago*, Wheatear *Oenanthe oenanthe*. Of these, only Snipe and Curlew densities were reported to remain lower during the operational stage of the wind farm life-cycle (Pearce-Higgins *et al.*, 2012).

Bird density is typically used as a proxy for habitat suitability in studies of wind farm effects (Pearce-Higgins *et al.*, 2009b, Douglas *et al.*, 2011), but this is the first detailed study of habitat composition as it relates to wind energy development and bird density across multiple wind farms over a large geographic area. Wind farm construction activities are often associated with changes in habitat required to accommodate wind turbines and other wind farm infrastructure (tracks, buildings, etc.). Ground clearing and clear felling of forestry are often undertaken to make space for wind farm infrastructures or to maximize wind load factor at sites requiring keyhole arrays (Waldron *et al.*, 2009, Nayak *et al.*, 2010, Pearce-Higgins *et al.*, 2012, Anon, 2013a). Our results suggest that the recorded differences in habitat composition may be a consequence of these practices, which result in a reduction of closed canopy forestry and an increase of clear-felled areas and bare ground close to wind farms. These changes in land use and habitat covers can result in the reduction in forest bird species densities recorded in our study. The extent and intensity of these changes in bird density can be expected to depend on the total area and the habitat types affected by these transformations in land use.

Densities of open country bird species were also found to be lower at wind farm sites, but these differences were independent of distance to wind turbines. Therefore, lower densities may be due to larger scale effects of wind farms. However, as wind turbine effects are expected to follow a gradient from higher to lower impact with increasing distance from turbines (Anon, 2007b), it is likely that other factors may be responsible for the observed differences. These differences could also be the result of differences at a landscape scale, such as differences in habitat management (e.g. grazing intensities, predator control) between wind farm and control sites. Alternatively, the preferential siting of wind farms in afforested upland areas may result in differences in habitat cover at a landscape scale between wind farm and control sites, in turn affecting bird densities (Lachance *et al.*, 2005). However, further evidence will be necessary to discount the possibility of wind farm effects at a landscape scale.

In this study the proportion of calling birds recorded was lower at wind farm sites than at corresponding control sites, but only within 100m of turbines. These differences are probably a result of several factors. Firstly, forest bird species, which rely heavily on acoustic communication, were found to be at lower densities in this distance band in wind farms. Secondly, the changes in habitat recorded close to turbines would result in increased visibility at point counts, increasing the proportion of visual sightings. Finally, turbine noise can be expected to affect fieldworkers' ability to detect singing birds, thus contributing to these results.

Previous studies of wind farm impacts on bird species have shown a broad range of impacts, from increases in species such as Red Grouse *Lagopus lagopus*, that are associated with roads and tracks (Douglas et al. 2011), to no impact on other species (Farfán *et al.*, 2009, Hale *et al.*, 2014) to decreases in the abundance of species sensitive to the presence of wind farm infrastructure (Leddy *et al.*, 1999, Stewart *et al.*, 2005b). Where reduced bird abundance has been reported at wind farms this effect has been confined to an area very close to the wind turbines and has not extended into the wider landscape (Leddy *et al.*, 1999, Pearce-Higgins *et al.*, 2009b). However, these studies are typically confined to a small number of locations or bird species, often with limited sample sizes, and efforts to assess impacts on multiple bird species across multiple sites have been undertaken using meta-analysis or review (Stewart *et al.*, 2005b, Drewitt & Langston, 2006, Madders & Whitfield, 2006, Dahl *et al.*, 2012). This is the first study to examine bird communities across a range of wind farm sites. This approach is important as the effects of land-use change largely occur at bird community level. Shifts in breeding bird community composition occur in response to land-use change as the relative numbers of individual bird species fluctuate (Boren *et al.*, 1999, Sweeney *et al.*, 2010, Kampichler *et al.*, 2012).

Our study highlights the effects of changes in land use on bird communities as a result of wind farm construction. In our study, wind farm developments resulted in a reduction of forest habitats with a corresponding decrease in densities of species associated to these habitats in the areas affected by land use changes. Further research will be required to fully understand the nature of densities of open country species recorded by our study.

Work Package 3
5. Hen Harrier breeding parameters

Despite the growing importance of the wind energy industry in Ireland and concerns over the ecological impact on birds in particular there is a notable lack of published scientific information in this area. As upland birds of conservation concern that inhabit areas which are particularly attractive for wind farms, Hen Harriers are of particular interest in this context. Here we assess Hen Harrier breeding performance across Ireland in relation to wind farm development by analysing the breeding output of 84 nests located at varying distances from wind farms. Three measures of breeding performance were investigated: nest success, fledged brood size and productivity. No statistically significant relationships were found between these breeding parameters and distance to the nearest wind turbine. However, lower nest success rates were observed within 1km of wind turbines which, although not significantly different to those at greater distances, may be of biological relevance. Where nests within 1km of wind turbines were successful their fledged brood sizes were not different from nests at greater distances from turbines. These findings coincide with previous research in highlighting the importance of areas within a 1km radius of raptor nests. Our results provide information on the consequences of wind turbines for breeding success of Hen Harriers, which is an essential component in the assessment of wind farm impacts on this vulnerable species. Further work is required to quantify (a) direct Hen Harrier mortality through collisions and (b) habitat loss and displacement caused by wind turbines, to support the development of an integrated management strategy for Hen Harriers in Ireland.

5. 1 Introduction

The aim of this Work Package was to identify any relationship between proximity to wind farms and breeding outcome of Hen Harrier nests using data collected at Hen Harrier nests in wind farm and control sites. Hen Harriers *Circus cyaneus* are territorial birds of prey that breed 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 the Birds of Conservation Concern in Ireland (Colhoun & Cummins, 2013) where an increase in breeding numbers has been recorded in recent years (Norriss *et al.*, 2002, Barton *et al.*, 2006, Ruddock *et al.*, 2012). However, this increase is possibly an artefact of increased survey effort (Ruddock et al. 2012) 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 suffered significant fluctuations over time in response to human-related pressures, particularly habitat modification and loss (Watson, 1977, 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 (Avery & Leslie, 1990, O'Leary *et al.*, 2000). The species has responded to these habitat modifications across its range by nesting in young conifer plantations (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, in some instances, prove to be an 'ecological trap' where Hen Harrier productivity is too low to maintain populations in the longer term. Hen Harrier breeding success has, however, been reported to decrease with increasing cover of conifer plantations (Cormier, 1989). 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 changing habitat is currently facing a new challenge with the recent increase in wind energy development across upland areas.

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 wind farms (1,424 individual turbines) to date (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.*, 2007b, Stewart *et al.*, 2007, Rourke *et al.*, 2009). In Ireland, concerns about the effects of wind farms on birds, as well as on other elements of the 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 have assessed the impacts of wind farms on birds in Ireland to date (Percival, 2003b, Madden & Porter, 2007) and there is a significant gap in our knowledge of the effects of wind farms on bird populations, particularly Hen Harriers (Irwin *et al.*, 2011, O'Halloran *et al.*, 2012, Ruddock *et al.*, 2012).

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 bird species (Stewart *et al.*, 2007, Pearce-Higgins *et al.*, 2012, Northrup & Wittemyer, 2013). The potential negative effects of wind turbines on birds include the direct effect of collision mortality, and the indirect effects such as displacement due to disturbance, loss of foraging or nesting habitat (Drewitt & Langston, 2006, de Lucas *et al.*, 2007b, Stewart *et al.*, 2007). 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, Kikuchi, 2008, Pearce-Higgins *et al.*, 2009b).

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 (Percival, 2003b, Fernández-Bellon unpublished data, Bright *et al.*, 2008a). Direct mortality of Hen Harriers resulting from collision with turbines has been recorded in some studies (Whitfield & Madders, 2006a). Foraging Hen Harriers have also been shown to avoid wind farm infrastructures, with displacements of foraging up to 0.5km from turbines reported (Madders & Whitfield, 2006, Whitfield & Madders, 2006a, Pearce-Higgins *et al.*, 2009b, Garvin *et al.*, 2011). Wind turbines, however, are reported not to cause displacement of Hen Harrier nests (Madden & Porter, 2007, Robson, 2011). While it is hypothesised that wind turbines may affect the breeding success of birds that are not displaced from areas close to wind turbines, there is little evidence to support this in the literature, with some recent studies reporting no observed effect of wind turbines on nest success (Martínez-Abraín *et al.*, 2012, Hatchett *et al.*, 2013, Northrup & Wittemyer, 2013, Bennett *et al.*, 2014, Gillespie & Dinsmore, 2014). No work has been published to date, in Ireland or elsewhere, on the effects of wind farm developments on Hen Harrier breeding success.

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 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.

5. 2 Methods

Data were collected 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). Fieldwork was carried out under licence issued by NPWS (National Parks & Wildlife Service). During this period, vantage point watches overlooking areas of suitable habitat were carried out to locate active territories by noting 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.

To analyse the effect of wind farms on breeding Hen Harriers, the distance to the nearest wind turbine was calculated for all nests using ArcMap 10.2. Previous research has indicated that avoidance of wind farms by breeding Hen Harriers may occur within 1km of turbines (Pearce-Higgins *et al.*, 2009b) and that foraging behaviour of breeding pairs can be influenced by habitat changes at distances up to 3km from the nest (Amar *et al.*, 2004, 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: 0-1km, 1-2km, 2-3km, >3km.

Three measures of breeding performance were calculated for each distance band from wind turbines. Nest success was calculated as the proportion of nests that successfully fledged one or more juvenile Hen Harrier. Fledged brood size was calculated as the average number of fledged chicks per successful nest and productivity was calculated as the average number of fledged chicks across all nests. Differences in measures of breeding performance between the different distance bands were analysed using fixed-effect one-way ANOVAs and one-tailed T-tests. Minitab was used for all statistical analyses.

Hen Harrier chick and eggs. Photo by Barry O'Mahony.

5. 3 Results

Between 2007 and 2013, a large number of Hen Harrier territories were monitored across Ireland and a total of 84 with known outcomes were included in this study. Linear distances from these nests to the nearest wind turbine ranged from 0.4km to 7.0km. Nest success was 53.6%, with 45 successful and 39 failed nests in total. The mean productivity of Hen Harrier nests in this study was 1.3 chicks per nesting attempt and the mean fledged brood size was 2.4 chicks per successful nest.

When grouped according to distance from the nearest turbine, mean nest success was lowest at nests located in the 0-1km band (33.3%, n= 9). Nest success was 60.0% in both the 1-2km (n = 20) and 2-3km (n = 20) bands and 51.4% for nests located at more than 3km from wind turbines (n = 35, Fig. 5.1). However, there was no significant difference in nest success among the four distance bands ($F_{3,80}$ = 0.72, P = 0.542). When the success of nests in the 0-1km band (nest success = 33.3%) was compared with the success of all nests more than 1km from wind turbines (nest success = 56.0%), differences approached statistical significance (one-tailed T-value = 1.29, df = 82, P = 0.101).

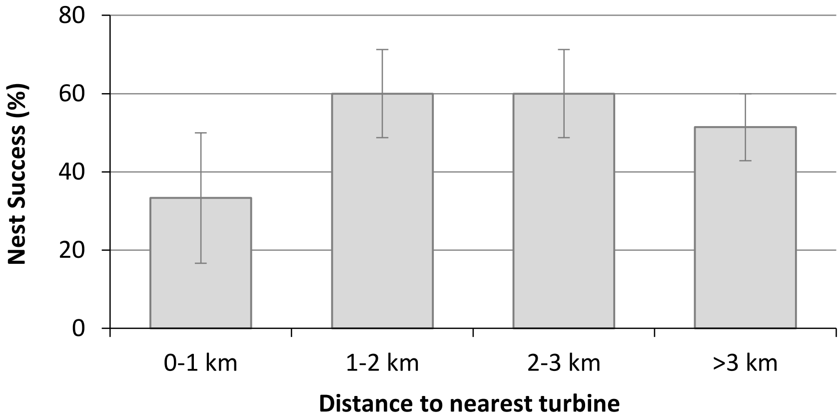


Figure 5.1: Hen Harrier nest success rates from 2007 to 2013 across Ireland, classified by their distances to the nearest wind turbine.

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; Fig. 5.2). Productivity was lowest for nests closest to wind turbines (0-1km, 0.78 chicks per nesting attempt) but not statistically different from productivities of nests in the other bands (1.55, 1.35 and 1.23 chicks per nesting attempt at 1-2km, 2-3km and > 3km respectively) (F-value = 0.68, df = 3, P = 0.566).

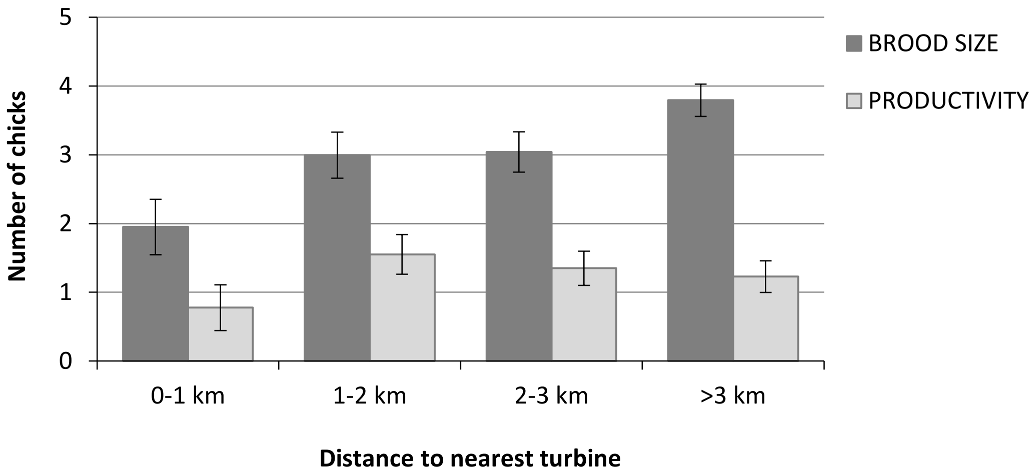


Figure 5.2: Hen Harrier fledged brood size (number of chicks per successful nest, dark bars) and productivity (number of chicks per breeding attempt, light bars) from 2007 to 2013 across Ireland, classified by the distance of nests to the nearest wind turbine.

5. 4 Discussion

Our results show that there are no significant differences between the breeding outputs of Hen Harrier nests located at different distances from wind turbines. However, non-statistically significant lower nest success rates and productivity were observed within 1km of active wind turbines. Due to the limited availability of data related to the rarity of Hen Harriers, and restrictions on research activities, it was not possible to investigate differences in breeding success at a finer scale. Of the 9 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 closer to the rate observed in the latter category in this study, or higher (Green & Etheridge, 1999, Millon *et al.*, 2002, McMillan, 2011, Baines & Richardson, 2013).

The relationship between the presence of wind turbines and the breeding success of local birds has not been the subject of investigation to date. From the available literature on this topic it appears that this relationship is species and/or area specific, though no data are available for raptors (Dahl *et al.*, 2012, Martínez-Abraín *et al.*, 2012, Hatchett *et al.*, 2013, Bennett *et al.*, 2014). Many of these studies report no negative impact of wind farms on breeding success of birds (Dahl *et al.*, 2012, Hatchett *et al.*, 2013, Gillespie & Dinsmore, 2014). Even where impacts on reproductive success of passerine birds have been reported these have not translated into negative population level effects (Martínez-Abraín *et al.*, 2012).

No trend was observed in fledged brood size with increasing distance from wind farms in this study, suggesting that any potential impact of wind turbines on Hen Harrier breeding output is mediated through nest success rather than clutch or brood sizes. Therefore, the apparent lower productivity close to turbines in this study, although not statistically significant, may have been the result of abandoned nesting attempts, rather than reduced performance of those nests producing juveniles. A similar phenomenon has been reported for a wind farm constructed in Norway in an area occupied by breeding White-tailed Eagles, where reduced breeding success within 0.5km of wind turbines was the result of abandonment of territories rather than reduced fledged brood sizes 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 have been reported to impact on Hen Harriers at distances ranging between 0.5km and 1km (Ruddock & Whitfield, 2007), while reduced densities of Hen Harriers have sometimes been reported within 0.5km 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 1km of the nest, while males hunt mostly within 2km of the nest (Arroyo *et al.*, 2009, Irwin *et al.*, 2012, Arroyo *et al.*, 2014). Therefore landscape and habitat changes within 1km of the nest may impact on both male and female foraging, while changes up to 2km 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 1km of wind farms, where turbines are likely to overlap with the foraging areas of both males and females.

Nest success, productivity and fledged brood sizes observed in the current study are in line with those reported for Hen Harriers in other parts of the species' distribution (Amar *et al.*, 2008, Baines *et al.*, 2008, England, 2008, Fielding *et al.*, 2011, McMillan, 2011). 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, geographical variations in breeding output (Irwin *et al.*, 2011) in combination with on-going regional declines (Ruddock *et al.*, 2012) may act as confounding factors when attempting to understand the effects of single variables such as wind farm developments. A further constraint in research on rare species that occur at low densities, and raptors in particular, is that the required sample sizes are often difficult to achieve (Morrison, 1988). Although ecological research benefits from studying abundant species or events to understand natural processes, rare species are often of ecological, management and policy interest. This is particularly true of the interaction between Hen Harriers and wind farms in the Irish landscape. Because the study of such rare events typically involves small sample sizes, the standard set of statistical tools are difficult or inappropriate to use, 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 (Yoccoz, 1991, Martínez-Abraín, 2008). Where small sample sizes are encountered in ecological research lack of significant is as likely to reflect lack of statistical power as it is lack of an effect (Stewart *et al.*, 2007).

The information presented here is relevant to the location of active wind turbines, and it must be taken into account that the impacts of construction activities of these or other wind farm infrastructures during the Hen Harrier breeding season (April – August) may be of an entirely different nature. Research on other bird species indicates that the construction phase is likely to be the most critical aspect of wind farm development, and that observed 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 1km has been reported (Ruddock & Whitfield, 2007).

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

Despite the limitations discussed above, this study calls upon the most extensive data set available on Hen Harrier breeding output in Ireland and represents an important step forward in the knowledge of the interactions between wind farms and Hen Harriers. However, continued work is recommended to further advance our understanding whether, and to what extent, wind turbines affect nesting Hen Harriers. 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 and analysis of the effects of wind farm developments at a meta-population scale.

Work Package 4
6. Hen Harrier flight behaviour

The highest profile risk to birds posed by wind turbines is the potential for individuals to be killed as a result of direct collision with wind turbines. Previous research has shown that Hen Harriers are at low risk of collision with wind farm infrastructure, however a detailed understanding of their flight behaviour in relation to wind energy developments is required to inform appropriate policy and practice. The aim of this study was to investigate the flight activity of adult and juvenile Hen Harriers at wind farms, particularly in relation to the time spent flying at turbine blade height. The second aim was to undertake collision risk modelling to determine the risk of collision for Hen Harriers at wind farms in Ireland. Data were collected using vantage point watches at wind farm and control study sites. No differences in flight heights were found between wind farm and control sites. Hen Harriers at wind farms spent 12% of their flight time within wind turbine rotor sweep height, while the amount of time spent flying at this height by juvenile Hen Harriers was negligible. Over the life time of a wind farm (25 years) the number of Hen harrier deaths resulting from collisions is estimated to be in the range 0.8 to 2.5. This estimate of collision risk is likely to overestimate the probability of collision as it is based on the assumption that flights would continue at collision height if any part of the flight was at rotor height. This finding support reports in the literature that collision mortality for Hen Harriers at wind farms is low.

6. 1 Introduction

The potential effects of wind farms on birds include direct mortality from collisions with wind farm infrastructure, disturbance and displacement effects (Drewitt & Langston, 2006). The mortality risk posed to bird species in general, and raptors in particular, is one of the main environmental concerns associated with wind energy developments (Drewitt & Langston, 2006, Band *et al.*, 2007, Bevanger *et al.*, 2008, Drewitt & Langston, 2008). Migratory species sometimes have higher collision risks than resident species (Drewitt & Langston, 2006, Lekuona & Ursúa, 2007), although wind farms located in areas of high breeding density can cause increased mortality in breeding birds (Bevanger *et al.*, 2008, Nygård *et al.*, 2010). Despite the widely cited risk of mortality to birds from wind turbines, in a study done for the National Wind Coordinating Committee in the United States, Erickson *et al.* (2001) found that wind turbine related avian bird mortality comprised between just 0.01% to 0.02% of the annual avian collision mortality, including collisions with buildings, communication towers and power lines, in the United States. Furthermore Sovacool (2009) estimate that while wind farms in the United States were responsible for approximate 7,000 bird deaths, fossil- fuelled power plants were responsible for the deaths of more than 14 million birds.

Bird species differ in their susceptibility to collision mortality and birds whose flight heights coincide with the height of wind turbine rotor blade sweep are most at risk (Carrete *et al.*, 2009, Furness *et al.*, 2013). Birds are at risk of collision with wind turbines only when their flight path overlaps with the rotor blade sweep area of a wind turbine. The wind turbine sweep area is the area swept by the blades of the wind turbine when they rotate and is sometimes also referred to as the capture area (Fig. 6.1). Both the collision risk for birds and the power output of a wind turbine are directly related to the sweep area of its blades (Krijgsveld *et al.*, 2009, Anon, 2011).

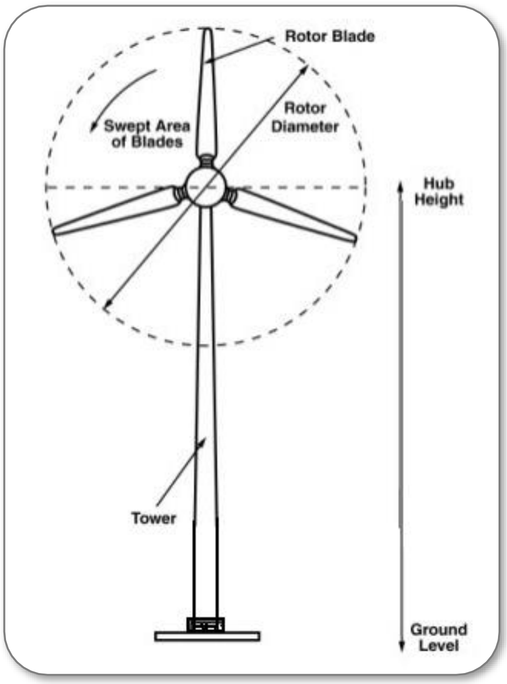


Figure 6.1: Wind turbine characteristics, showing rotor sweep area (after Anon, 2011)

Bird collision risk results from complex interactions between species specific factors such as morphology and behaviour, site-specific factors such as landscape and weather, and wind farm-specific factors such as turbine type and configuration (Drewitt & Langston, 2008, Krijgsveld *et al.*, 2009, Marques *et al.*, 2014). Species-specific flight behaviour is implicit in collision risk and the time spent flying at turbine rotor sweep height is a key factor in assessing collision risk (de Lucas *et al.*, 2008, Smallwood & Thelander, 2008). Previous studies report low flight heights for Hen Harriers (Whitfield & Madders, 2006a, Madden & Porter, 2007, Ruddock *et al.*, 2012), with low proportions (5-15%) of observations at rotor sweep height (Johnson *et al.*, 2000c, Young & Erickson, 2003, Garvin *et al.*, 2011, Busse, 2014). Furthermore, some bird species modify their flight behaviour in response to the presence of wind turbine structures (Larsen & Guillemette, 2007, Rees, 2012). However, there is little information on how the flight behaviour of Hen Harriers in areas with wind turbines differs to that in areas without wind farm developments, and whether the reported proportion of time spent at blade height is due to a behavioural response by birds to the presence of turbines. Furthermore, no information is available on flight patterns of newly-fledged Hen Harriers, which are known to be at risk of collisions with other man-made structures (Madders, 2004, Bright *et al.*, 2009a), but whose vulnerability to wind turbines has not been assessed. Collision mortality may lead to population level impacts on birds where the level of mortality coupled with the population's ability to buffer itself against a rise in mortality is poor. Where collision mortality is sufficiently high, nest failure rates may also be higher which may impact on the regional population. Estimates of morality levels are therefore required in order to assess impacts of wind turbines on bird populations (Drewitt & Langston, 2008).

Although Hen Harriers *Circus cyaneus* are considered to be at lower risk of collisions with wind turbines than other raptor species, fatalities are occasionally reported. At the Altamont Pass Wind Resource Area in North America, Northern Harriers *Circus hudsonius* spend a disproportionate amount of time flying within 50m of turbines, though few collisions occur (Drewitt & Langston, 2008). In Ireland, there have been no systematic published studies involving carcass searches, but fatalities due to collision with wind turbines have been reported for Hen Harrier (Scott & McHaffie, 2008), White-tailed Eagle *Haliaeetus albicilla* (Mee, 2014) and Sparrowhawk *Accipiter nisus* (Cullen & Willians, 2010). In the context of on-going wind energy development across Ireland, there is a pressing need for research on the potential impacts of wind farms Hen Harrier ecology in the Irish context, including effects on flight behaviour. Here we (i) present data on flight heights of Hen Harriers engaged in different behaviours to determine which aspects of the species' ecology leave them most vulnerable to collisions with turbines, (ii) compare flight heights and behaviours of Hen Harriers at sites with and without wind farm developments, (iii) analyse flight heights of newly-fledged Hen Harriers, and (iv) assess the collision risk for Hen Harriers at a large, modern Irish wind farm.

6. 2 Methods

Data were collected in 2012 and 2013 during the breeding season (April – August) at twelve study sites across the Hen Harrier's range in Ireland (counties Kerry, Limerick, Tipperary, Clare, and Galway). At each site, vantage point watches lasting between 1.5 and 5 hours, following the methodology of (SNH, 2010a), were carried out overlooking areas of suitable Hen Harrier habitat within operational wind farms (hereafter 'wind farm sites') and areas of suitable Hen Harrier habitat in areas with no wind farm development, located at least 2km from the nearest wind turbine (hereafter 'control sites'). Upon detection of a Hen Harrier, field workers recorded data on the bird's sex and age, behaviour (i.e. sky dance, food pass, hunting, flying with prey, soaring, circling, in transition flight, alarm flights), estimated flight height and position and movement by mapping the bird's flight line on a topographical map of the area. Flight height estimates were categorised into 25m height bands (i.e. <25m, 25-49m, 50-74m, 75-99m, 100-124m, >125m, Figure 6.2) to facilitate comparison of data with standard turbine rotor sweep heights at Irish wind farms (these range from approximately 25m to 125m, depending on turbine model).

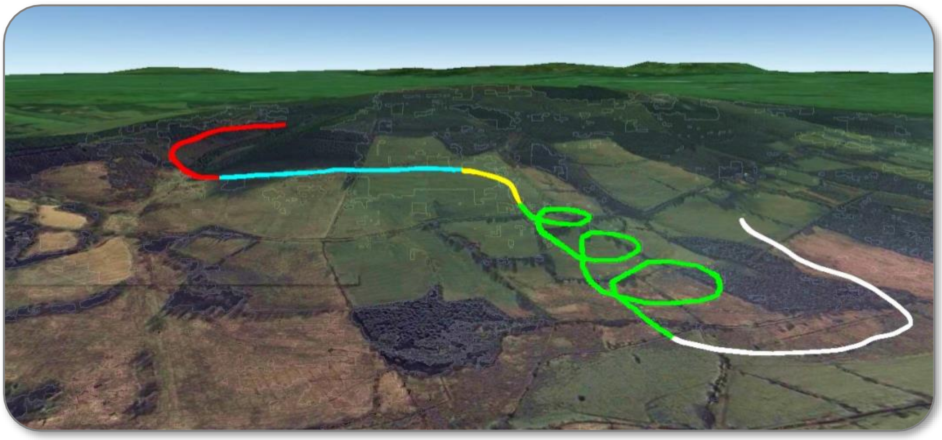


Figure 6.2: Example of Hen Harrier flight data collected in this study. Colours represent flight height categories.

6. 2. 1 Flight heights

The proportion of time spent by Hen Harriers at different flight heights was calculated for the following behaviours: sky dancing, hunting and other behaviours. Data from wind farm and control sites were used to determine whether presence of wind turbines affected flight heights of Hen Harriers. Data from nest observations were used to compare flight heights of young birds during the fledging stage to those of adult birds. Proportions of times spent at different height bands were compared by means of Mann-Whitney tests.

6. 2. 2 Collision risk

Analysis of collision risk for Hen Harriers was carried out at a large modern wind farm in Ireland using data from the 2012 and 2013 breeding seasons. For all calculations Hen Harriers were assumed to have the characteristics shown in Table 6.1.

Table 6.1: Hen Harrier characteristics used in this study (after Provan & Whitfield, 2007).

Length	0.48m
Wingspan	1.10m
Flight speed	12 m s^{-1}
Turbine avoidance rate	99%

The turbines at this wind farm are some of the largest in Ireland at present (hub heights of 80m and rotor diameters of up to 90m). Data on Hen Harrier flights were collected from five vantage points which yielded a total of 470 observation hours. For each vantage point a viewshed (the volume of space in which birds are theoretically detectable, taking into account the area's topography) was calculated using ArcGIS 10 (ESRI). Viewsheds were adjusted to a 2km detection threshold and a 180 degree visibility arc, as observations beyond these limits cannot be considered accurate (Band *et al.*, 2007). These were then clipped to retain the part of the viewshed within the wind farm (defined as a 500m buffer around all turbines, Fig. 6.3). Flight lines were digitised and clipped, to retain only those part-flights that were within the 2km viewshed and the wind farm. Data from these flight segments were used for the collision risk calculations (Fig. 6.4).

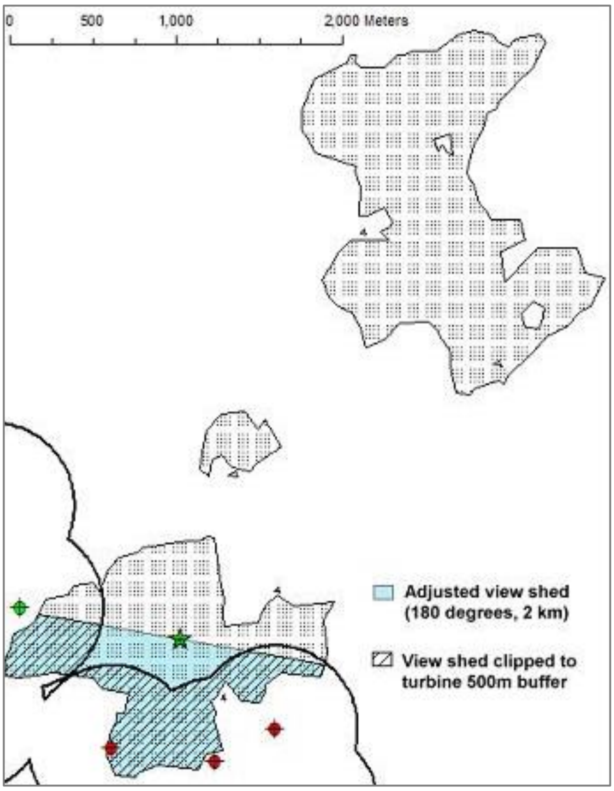


Figure 6.3: Viewshed calculated for one of the vantage points (green star). A hypothetical 360°, unlimited view shed is shown with a stippled fill. The adjusted viewshed to a threshold of 2km and angle of view of 180° is shown in blue. Turbines are represented by red and green dots, a 500m buffer around turbines is represented by a thick black line.

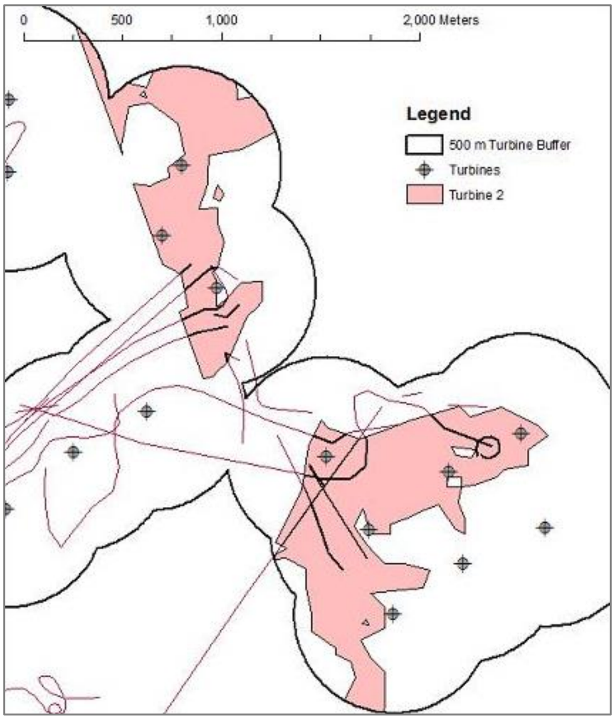


Figure 6.4: Flights recorded from the Turbine 2 vantage point and those sections (thick black lines) retained for collision risk analyses.

Flight lengths were calculated for all retained flight segments and flight heights were categorised as ‘at risk’ (within turbine rotor sweep height) or ‘not at risk’ (flight heights outside turbine rotor sweep height). Two estimates of at-risk flight duration were obtained: estimate 1 is the most conservative in that all of the clipped flight was assumed to be at collision risk height; estimate 2 is less conservative in that it incorporates a measure of the proportion of the flight that was at risk height. Flight data obtained in this way was used to calculate collision risk, following the Band / Scottish Natural Heritage model (SNH, 2000, Band *et al.*, 2007), applying a correction for avoidance rates (SNH, 2010b):

$$\begin{matrix} n\ birds\ colliding \\ per\ breeding\ season \end{matrix} = \begin{pmatrix} n\ of\ birds\ flying \\ through\ the\ rotor \\ per\ breeding\ season \end{pmatrix} * \begin{pmatrix} probability\ that\ a \\ bird\ flying\ through\ the \\ rotor\ is\ hit\ by\ turbine\ blades \end{pmatrix}$$

Details on formulas and calculations for collision risk analyses can be found in Appendix 1.

The collision calculations in this study use an estimate of the number of daylight hours during which birds may have been flying. For the purposes of this assessment it was assumed that the Hen Harrier breeding season lasted from March 16th to August 15th when there were 2,265 hours of daylight (Forsythe *et al.*, 1995). It was assumed for the purposes of these calculations that the turbines operate for 85% of day light hours. The remaining 15% of time represents periods of unsuitable wind speeds and turbine maintenance. Survey effort is a combination of the area watched and the duration of the watch (hectares watched x hours watched). Survey effort is used to weight the data from different vantage points because, assuming equal activity, recorded activity should increase with survey effort. Survey effort weights were calculated as the proportion of a VP's survey effort of the total survey effort.

6. 3 Results

6. 3. 1 Flight height

Over the two seasons of fieldwork that comprised this study 1,500 minutes of flight behaviour were recorded at wind farm and control study sites. During these flights Hen Harriers were regularly seen to fly over wind farms and quite close to wind turbines, often within 100m (Fig. 6.5).

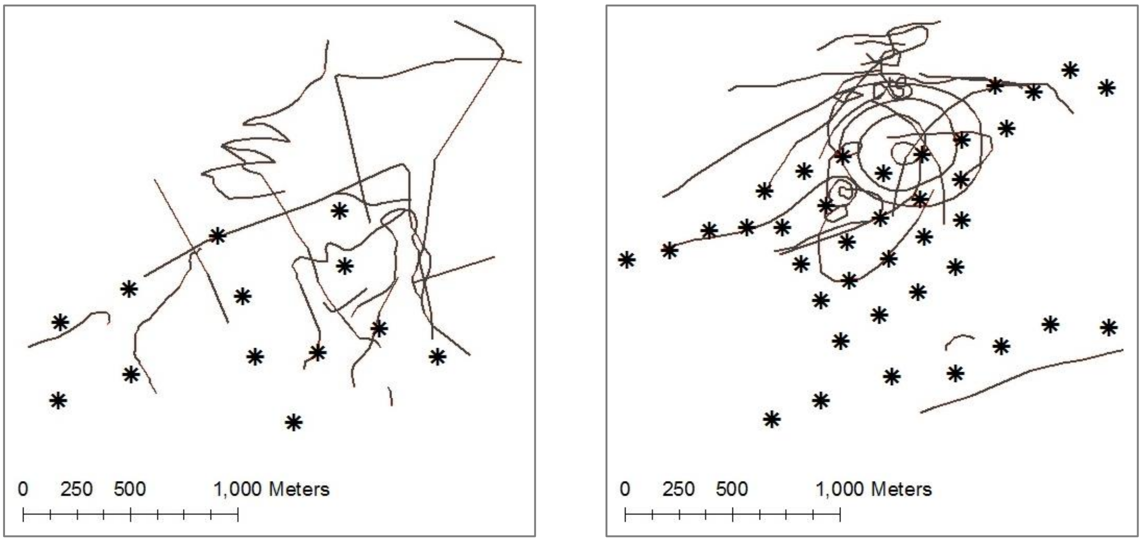


Figure 6.5: Examples of Hen Harrier flight paths (grey lines) over wind farms. Asterisks represent individual turbines.

Hen Harriers were observed displaying sky dancing behaviour during a total of 53 minutes, hunting and foraging during 485 minutes and other activities during 1472 minutes (Fig. 6.6). Flight heights varied according to the behaviour in which birds were engaged, with sky dancing behaviour ranging from 2m to 100m above the ground (Fig. 6.7), all hunting behaviour occurring below 25m, and other behaviours occurring mainly below 25m, but ranging up to over 125m.

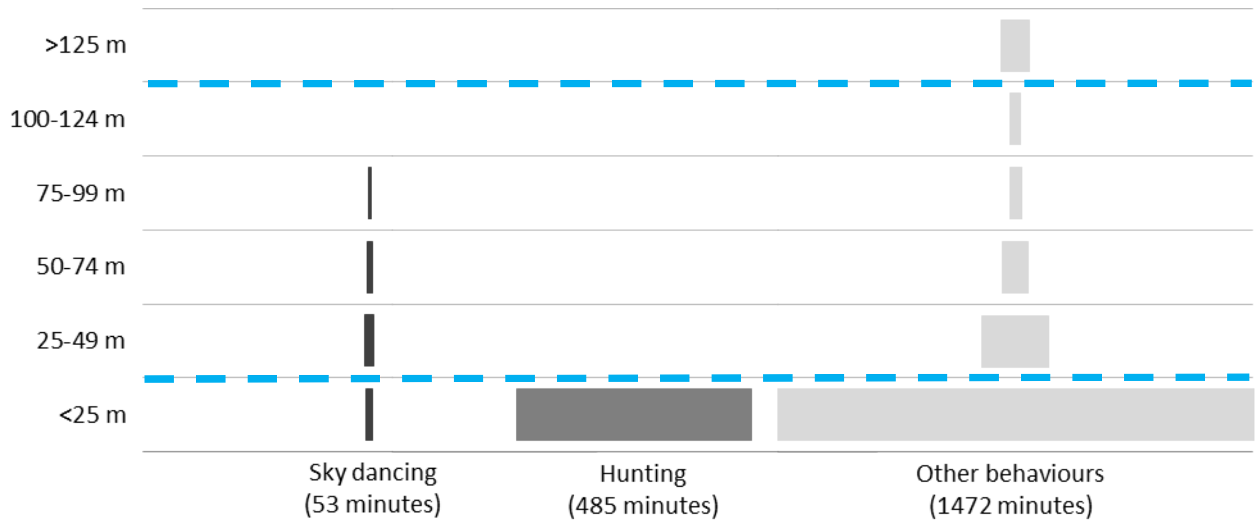


Figure 6.6: Proportion of time spent by Hen Harriers engaged in different behaviours. The time spent at different height bands is represented for each behaviour. Dotted lines indicate the lower and higher limit of turbine blade sweeps across Irish wind farms (23m – 125m).

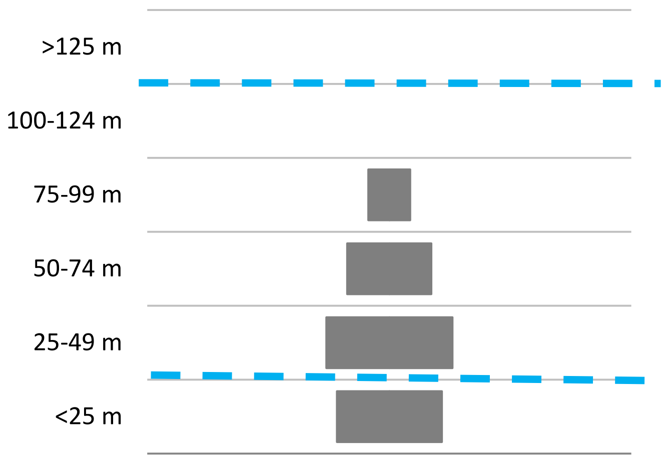


Figure 6.7: Detail of the proportion of time spent at different heights by Hen Harriers during sky dancing behaviour (53 total observation minutes). Dotted lines indicate the lower and higher limit of turbine blade sweeps across Irish wind farms (23m – 125m).

The proportion of time dedicated to each of these behaviours also varied. Of the total time during which Hen Harriers were observed, 2.6% was dedicated to sky dancing, 24.2% to hunting and 73.2% to other behaviours. When flight heights across all wind farm sites were grouped into 'at risk' and 'not at risk' categories according to their height in relation to turbine rotor sweep height for each wind farm turbine model, just 11.8% of flights recorded were within turbine rotor sweep height. Of the 1613 observation minutes included in the analysis 82.8% occurred below turbine blade height and 5.4% above turbine blade height.

For comparison of flight heights during all behaviours at wind farm and control sites, we used data from observations of male birds only (183 minutes at control sites, 442 minutes at wind farm sites), as some female observations were associated with nest sites. This is a conservative approach as females attending nests are likely to fly at lower elevations than other birds. Flight heights of males at wind farm and control sites are shown in Fig. 6.8.

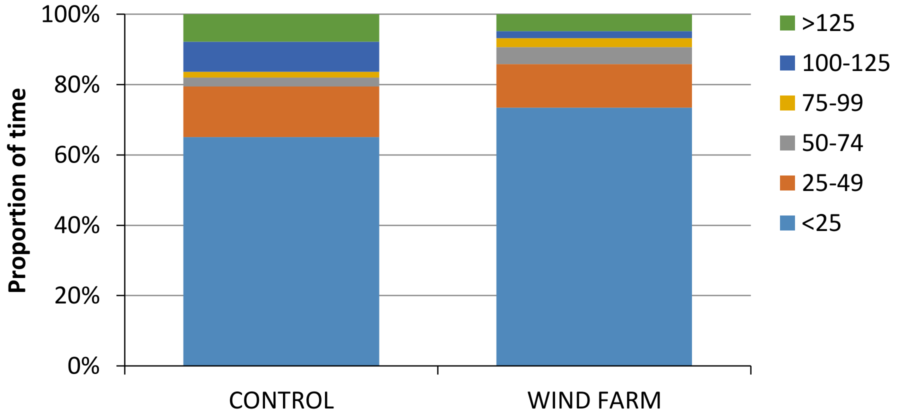


Figure 6.8: Fleight heights of male birds at wind farm (442 total observation minutes) and control sites (184 total observation minutes).

Male Hen Harriers spent more time flying below 25m at wind farm sites (73.5%) than at control sites (65.1%), but this difference was not statistically significant (U = 2375.5, P = 0.610). Males spent less time above turbine rotor sweep height (>125m) at wind farm sites (4.8%) than at control sites (7.8%), but again this difference was not significant (U = 2682, P = 0.497). Comparison of flight heights of newly fledged juvenile birds across all sites indicated that these spent significantly more time flying at low heights (<25m) than adult birds (U = 4154.5, P = 0.027). While adults spent 83.2% of their flight time below 25m, newly fledged birds spent up to 99.1% of their time in this height band.

6. 3. 2 Collision risk

Analysis of collision risks at the studied wind farm indicated a risk of collision of 0.099 birds per breeding season using the conservative approach (estimate 1, assuming all flights were at blade height) and of 0.031 birds per breeding season when recorded flight heights were taken into account (estimate 2). Over a wind farm life time of 25 years, the number of Hen Harrier fatalities from collisions with turbines thus estimated would range between 0.778 and 2.477 birds (this figure refers solely to the breeding season, as collision risk during other seasons was not assessed here).

6. 4 Discussion

The findings of the current study highlight important differences in the flight heights of Hen Harriers during different behaviours and provide an insight into the associated risks of collision with wind turbines. When they are engaged in hunting behaviour, Hen Harriers are generally outside of the area of greatest risk of collision with wind turbines. By contrast, courtship displays such as sky dancing occur at heights of up to 100m, overlapping with the rotor sweep areas of most wind turbines currently in use in Ireland. Although not recorded in this study, Hen Harriers have been reported to engage in sky dancing behaviour at heights of up to 150m (Hardey *et al.*, 2013). During other behaviours, particularly circling and soaring, Hen Harriers also fly at heights which could potentially put them at risk of colliding with wind turbines. Although Hen Harriers spent much less time sky dancing than they do circling or soaring, the nature of these courtship displays may increase the associated risk. Birds engaged in sky dancing rise and fall at high speeds, often turning on their backs mid-flight during these displays. Hen Harriers that are displaying in this way may be less likely to detect and avoid turbine blades than when they are circling or soaring.

At wind farm sites, although Hen Harriers spent most of their time flying below the reach of turbine blades (82.8%), 11.8% of flights recorded were within potential rotor sweep height. A previous study covering observations of 51 wind farms in Poland reported that Hen Harriers there spent just 4.7% of their flight time at turbine blade height (Busse, 2014), while studies of single wind farms in Wales and Scotland have reported figures as high as 27% and 55%, respectively (Dick, 2011, Stanek, 2013). Hen Harriers spent less time at these heights than other raptor species that have been studied, including Golden Eagles *Aquila chrysaetos* (43-56% at blade height (Johnson *et al.*, 2000c, Young & Erickson, 2003)), White-tailed Eagles *Haliaeetus albicilla* (24% at blade height (Nygård *et al.*, 2010)), or Red Kites *Milvus milvus* (35% - 52% at blade height (Dick, 2011, Busse, 2014)).

The results of this study on Hen Harriers also showed that the time spent flying at heights with risk of collision (25m – 125m) was similar between wind farm and control sites. This suggests that Hen Harriers do not modify their flight height in areas where wind turbines have been installed. However, previous work has shown Hen Harriers to demonstrate avoidance behaviour close to individual wind turbines and this has been estimated at 99% (Whitfield

& Madders, 2006a), although studies of Northern Harriers *Circus hudsonius* in the United States have estimated slightly lower avoidance rates of between 91.9% and 99.9% (Whitfield & Madders, 2006a). While our findings suggest that average Hen Harrier flight height is not affected by the presence of turbines, it is possible that birds may modify their flight height during the small proportion of time that they are within close proximity of individual turbines.

Analysis of flight behaviour of recently fledged Hen Harriers (< five weeks old) in this study showed that birds in this age group spend almost all of their flight time below 25m (99.1% of observation time). This is significantly more time spent in this height band than adult birds (83.2%), suggesting that during the early stages immediately after they have fledged from the nest, birds are at a lower risk of collision than adults. It must be noted, however, that this study only assessed flights by young birds in the proximity of the nest. Once birds move away from the nest and start dispersing, their flight patterns may change. Inexperience accounts for higher mortality rates in young Hen Harriers (Watson, 1977, Picozzi, 1984) and lack of dexterity in flight has been shown to play a role in increased rates of electrocution in juvenile Golden Eagles Aquila *chrysaetos* (Lehman *et al.*, 2007) and wind farm mortality in Griffon Vultures *Gyps fulvus* (de Lucas *et al.*, 2012). Dispersing juvenile Hen Harriers may also show lower rates avoidance of turbines than adult birds. A better understanding of these factors will require research on avoidance rates, and systematic studies of mortality by carcass searches over large spatial and temporal scales would provide information on how mortality associated with wind turbines might differentially affect different age groups.

Data from collision risk analysis indicate a collision risk of between 0.031 and 0.099 birds per breeding season for Hen Harriers in this study. These values are higher than those reported by other studies. In our study, an active nest was located near to the wind farm during both study years, leading to increased Hen Harrier activity which may have influenced collision risk estimates. This suggests that collision risks may be affected by the proximity of nest sites, and that the careful siting of wind farm developments may help to reduce these risks. However, the collision probability calculated in this study provides the worst possible outcome in terms of Hen Harrier collisions as all assumptions were conservative. Nonetheless the probability of collision calculated here is quite low. Collision risk estimates using the Band/Scottish Natural Heritage model (SNH, 2000, Band *et al.*, 2007) include a series of assumptions and potential sources of bias (Chamberlain *et al.*, 2005, Follestad *et al.*, 2006, Madders & Whitfield, 2006, SNH, 2012c) and are thus subject to wide or very wide margins of. In particular, observations of birds flying close to turbines produce more accurate flight height estimates, as turbines provide a useful visual reference of known dimensions for fieldworkers. This bias in height estimate accuracy is especially relevant for studies assessing collision risks at sites prior to construction, where there are no visual references which can provide a scale of heights. This particular source of error was bridged in our study by calculating a 'maximum risk estimate' where all flights were considered to be at risk. A second important source of bias refers to Hen Harriers which were using the observed areas but were not detected by fieldworkers, as probability of detection is unlikely to be random with respect to either flight height (e.g. birds flying close to the ground are harder to detect) or to flight behaviour (e.g. sky dancing birds are more likely to be seen than hunting birds). This suggests that the proportion of times that birds spend at rotor sweep height is likely to be overestimated, ensuring that collision risk estimates given here are conservatively high. As a consequence of these limitations, collision risks should not be used alone as an accurate indicator of mortality risk (de Lucas *et al.*, 2008), but rather as an estimate useful for comparisons between wind farm construction or planning scenarios (Everaert *et al.*, 2011). Future work may be able to overcome fieldwork biases with the use of GPS tags that provide not only an accurate position on the ground, but also accurate elevations above sea level. Data obtained with these devices may allow for improvements in the accuracy of collision risk estimates.

Our study found no differences in the flight heights of Hen Harriers between wind farm and control sites. Hen Harriers at wind farms were found to spend almost 12% of their flight time within wind turbine rotor sweep height, and collision risk calculations at a wind farm with high levels of Hen Harrier activity estimated between 0.031 and 0.099 fatalities per breeding season. Newly fledged birds still frequenting the nest site area flew at heights under turbine blade range for most of the time, although these parameters might change once juveniles start dispersing. Mortality risks reported here need to be considered in the context of cumulative impacts for Hen Harrier populations in Ireland, both from wind farm developments and from other factors which affect the species (direct persecution, afforestation, agricultural intensification, etc.). This approach can help to inform strategies for minimising the impact of wind farm developments on Hen Harriers.

It is important to note that no collision mortality of Hen Harriers was recorded during the current study, though we did not set out to collect mortality data. There appear to be very few documented cases of Hen Harrier collision mortality in the literature (Johnson *et al.*, 2001, Smallwood & Thelander, 2004, Whitfield & Madders, 2006b, Scott & McHaffie, 2008). In a review by Kingsley & Whittmam (2005) only six collisions are documented at the Altamont Wind Resource Area and Foote Creek in the United States. In another study from the United States Derby *et al.* (2008) noted that just three Northern Harrier fatalities at existing wind energy facilities had been reported in publicly available documents by 2008, despite the fact they were commonly observed during point counts conducted for these project". However, at the Altamont Pass Wind Resource Area in the United States Smallwood & Karas (2008) reported seven Northern Harrier deaths over a 17 year period between 1989 and 2007. The Altamont Pass Wind Resource Area is the largest concentration of wind turbines anywhere in the world and is located in a busy bird migration route.

Although mortalities are sometimes reported, Northern Harriers had the lowest death rate of all species included in a review of wind farm impacts on birds conducted by Drewitt & Langston (2008) and Hen Harriers belong to one of the groups that were reported to experience the least impact of wind energy development in a review by Stewart *et al.* (2007). They found that bird taxon had a significant impact on the effect of wind farms on bird abundance with a rank order (largest decline first) of Anseriformes (ducks), followed by Charadriiformes (waders), Falconiformes and Accipitriformes (raptors) and Passeriformes (songbirds). Johnson *et al.* (2000a) completed a comprehensive four year survey of the Buffalo Ridge Wind Farm Area in the United States, the world’s largest single wind farm project, where Northern harriers were the fourth most frequently occurring species. Because of the size of wind farm, and the relative abundance of Northern Harriers at the site, this study provides a good guide to the possible impacts of wind farms on Hen Harriers. During the 4-year study period 2,840 fatality searches were conducted on plots associated with operational turbines and Northern Harriers were not one of the recorded fatalities despite their relative abundance.

It is important to note that the estimates used for the studies in the current study use the worst case scenario such that if any part of a recorded flight was at collision risk altitude the bird was assumed to be at risk of a collision for the whole of its flight. Therefore, the figures quoted in the text are the maximum possible estimates; if adjustments are made to take account of variable flight altitudes the estimates would be reduced.

Work Package 5
7. Hen Harrier foraging behaviour

Impacts of land use change are often mediated by through effects on habitat quality and foraging success. In order to describe the forging behaviour of Hen Harriers at wind farms, data on the flight patterns of Hen Harriers were collected using GPS tags deployed on adult birds during the 2012 and 2013 breeding seasons (under licence and supervision of NPWS). Data on foraging behaviour were also collected using vantage point watches of Hen Harrier territories at twelve wind farm and control sites during the breeding seasons (April – August) of 2012 and 2013. Data from the GPS tagged female Hen Harrier indicates that natural and semi-natural open habitats, peatland and clear fell were flown over more often than would be expected by chance in relation to their availability in the study areas. Data derived from vantage point watches showed that although the availability of open and young forested habitat was similar at wind farm and control study sites, the use of forested areas was lower at wind farm sites and the use of natural and semi-natural open areas was higher, relative to control sites.

7. 1 Introduction

Hen Harriers are a protected bird species and are listed on Annex 1 of the EU Birds Directive (2009/147/EC) and are on the Amber List of birds of conservation concern in Ireland due to their continued vulnerability and unstable population (Colhoun & Cummins, 2013). All EU member states are required to protect Annex 1 listed species through the protection of suitable habitat through the designation of Special Protection Areas (SPAs). Hen Harriers breed in the Irish uplands between March and August each year, typically between 200m and 400m above sea level (Watson, 1977, Ruddock *et al.*, 2012). They breed in open, upland habitats such as heather moor, bog, scrub, grasslands and young conifer plantations, while avoiding closed canopy forest (Madders, 2000, Wilson *et al.*, 2010). Nesting habitat and foraging habitat requirements of Hen Harriers differ (Arroyo *et al.*, 2009). They typically nest in moorland dominated by heather (Amar *et al.*, 2007) and in Ireland use young conifer plantations for nesting (Wilson *et al.*, 2009) and forage in nearby open areas of grassland, scrub and young forests (Madders, 2000, Arroyo *et al.*, 2009, Massey *et al.*, 2009, Irwin *et al.*, 2011).

These habitats have historically been subject to land use change, which has been shown to impact on their populations through the destruction or degradation of their preferred habitat (O'Flynn, 1983, Amar & Redpath, 2005, Amar *et al.*, 2011, Hayhow *et al.*, 2013). The impacts of land use change on Hen Harrier populations are likely to be mediated through impacts on foraging success and productivity (Madders, 2000, Redpath *et al.*, 2002a, Amar *et al.*, 2003, Amar *et al.*, 2007). Hen Harriers preferentially forage over habitats where they have maximum foraging and prey strike success rates (Madders, 2000, Massey *et al.*, 2009). Where bird population levels and productivity are limited by the availability of suitable habitat conservation measures are required to protect suitable habitat. Knowledge of the spatial and habitat use is therefore fundamental to the effective management and protection of species such as the Hen Harrier (Arroyo *et al.*, 2006, Drewitt & Langston, 2006). This is particularly true for the conservation of Hen Harriers in upland areas where wind energy development is expanding. Research has shown that birds making regular foraging flights to provision chicks are more susceptible to collision because they tend to fly closer to the structures as they fly between nesting and foraging areas (Drewitt & Langston, 2006).

Typically Hen Harrier habitat use patterns vary across the breeding season and between female and male birds. Male hunting intensity increases after chicks hatch and males range far more widely than females (Arroyo *et al.*, 2009). Adult male Hen Harriers forage at distances of up to 10km from nests while females hunt mainly within

500m of the nest (Madders, 2003, Arroyo *et al.*, 2009, Irwin *et al.*, 2012). Hen Harriers are ground foragers that search for prey over suitable habitats at low heights (<25m) close to the vegetation surface (Madders, 2000). Understanding Hen Harrier foraging behaviour in relation to wind turbines is key for effective assessment of the impact of wind energy development on the species. Methods to measure flight behaviour in and around wind farms include traditional data collection using vantage point watches and novel remote tracking techniques. Vantage point watches are labour intensive and, because of the rarity of Hen Harriers in Ireland, typically produce a low yield of data as it is difficult to locate and follow animals using direct observations (Irwin *et al.*, 2012). These have, nonetheless, been successfully used in the investigation of wind farm impacts on birds (Walker *et al.*, 2005, Madders & Whitfield, 2006, Minderman *et al.*, 2012). Remote tracking archival technologies such as Global Positioning System (GPS) are increasingly being used to collect positional data from free-ranging birds (Kotzerka *et al.*, 2010, López-López *et al.*, 2013, Sandgren *et al.*, 2013) and, despite typically being dependent on a small sample size of birds, have potential for application in the assessment of wind farm impacts (Bevanger *et al.*, 2008).

Research at offshore and coastal wind farms has shown that birds divert their flight paths around wind farms, avoiding turbines in clusters rather than individually (Desholm & Kahlertm, 2005, Larsen & Guillemette, 2007). Golden Eagles *Aquila chrysaetos* in Scotland show a similar pattern of wind farm site avoidance, rather than a response to individual turbines (Walker *et al.*, 2005). The effect of birds altering their flight paths to avoid wind farms is a response to reductions in habitat availability close to wind farms raises concerns about the possible impact of the extensive development of large-scale wind farms (Larsen & Guillemette, 2007). Furthermore this effect is of concern because of the possibility of increased energy expenditure when birds have to fly further as a result of avoiding a turbine array. Potential effects depend on species, flight height, distance to turbines, layout and operational status of turbines, and can be highly variable, ranging from a slight 'check' in flight direction, height or speed, through to significant diversions which may reduce the numbers of birds using areas beyond the wind farm (Drewitt & Langston, 2006). In a review of studies of displacement of Hen Harrier foraging flight from areas close to wind turbines, Whitfield & Madders (2006a) concluded that Hen Harrier foraging is not typically displaced by wind energy development and, where it does occur, it is likely to be limited to within 100m of wind turbines.

GPS tagging systems can be used to follow the paths of individual birds, providing detailed information on the foraging behaviour and habitat use of species that are poorly suited to extended direct observations. GPS tags receive signals from an array of satellites of known position. The time elapsed between transmission and reception of the signal from each satellite allows calculation of the distance between the satellite and the tag, and signals from four or more satellites allow calculation of the tags position to within an accuracy of 10 metres or less. Because GPS does not involve sending a signal from the tag, it is not possible to retrieve information on the tag remotely using GPS technology. This means that positional information collected by GPS tags must either be archived on the tag, requiring that the tag be physically retrieved to download the information from it, or information can be sent remotely using another (i.e. non-GPS) technology such as satellite, mobile phone network, VHF or 'Bluetooth' radio frequencies. The addition of these technologies to tags substantially increases their weight, limiting the range of species on which such devices can be deployed. However, having to rely on recapture of target individuals is often not a feasible approach either because these individuals would be very difficult to recapture or because recapturing them could be detrimental to the birds' welfare. In such cases a means of retrieving archival devices without the need for individual recapture is required.

The aim of this Work Package was to collect detailed information on the movement of adult Hen Harriers at wind farm and control sites during the breeding season using GPS (Global Positioning Satellite) tags and data collected during vantage point watches. In particular, we wanted to determine whether habitat use by foraging Hen Harriers differed at wind farm and control sites.

7. 2 Methods

7. 2. 1 Collection of data using GPS tags

Data on the flight patterns of Hen Harriers were collected using GPS tags deployed on adult birds during the 2012 and 2013 breeding seasons (under licence and supervision of NPWS). Trapping of adult birds was undertaken at nests where chicks had hatched, with male trapping attempts taking place only until chicks were two weeks old and female trapping attempts taking place when chicks were more than two weeks old. Female behaviour at active nests targeted for trapping was monitored closely during the breeding season to identify when hatching had occurred. At nests where visits were not deemed to pose a risk to nest success, brood size and chick age were assessed as close to hatching as possible by visiting the nest. At other nests, chick age was estimated by observing the behaviour of adult female birds. In determining which nests were suitable for capture and tagging of birds, consideration was given to the proximity of the nests to operational wind farms, to the suitability of the nest site in terms of minimising disturbance to birds during trapping attempts and to the likelihood of activities attracting public attention. Adult Hen Harriers observed to respond aggressively to the presence of researchers or other intruders in the vicinity of the nest were targeted preferentially for capture, as these birds are likely to be easier to capture than more timid individuals.

7. 2. 1. 1 Capture of birds and tag fitting

A total of 15 capture attempts were undertaken during this study and GPS tags were deployed on five adult Hen Harriers in total during this study. Birds were trapped using either a mist-net or a dho-gaza net with a stuffed fox deployed in front of it as a decoy. Nets were positioned more than 30m from Hen Harrier nests, as agreed on a case-by-case basis with local NPWS conservation rangers and district conservation officers. Hen Harriers were captured in the nets while mobbing the decoy. Birds were extracted from the net immediately after capture and fitted with GPS units attached to a VHF tag. Tags were attached by means of a harness incorporating a 'weak link' designed for the tag's detachment after 1-3 weeks of deployment (Irwin et al. 2012). Tags were waterproof and protected from possible interference from tagged birds. The maximum weight of tags was <3% of the bird's body weight. This is within the range of weights considered safe for devices deployed on harriers and other raptor species (Trierweiler *et al.*, 2007, Gschweng *et al.*, 2009). The entire procedure, from capture to release of the birds, took less than 15 minutes. All trapping activities were planned and carried out in such a way as to minimise distress of captured birds and chicks.

Adult male Hen Harrier with tag attached (GPS and VHF included) prior to release.

Immediately after capture events, nests were provisioned with food. This practise minimises the need for adults to hunt after capture and can help reinforce adult feeding behaviour of chicks. Nests were monitored closely after all adult captures, until project members and NPWS staff were satisfied that normal provisioning behaviour had resumed. Where captured adults did not return to the nest on the same day of capture, nests were provisioned until their return. At one nest, the captured male abandoned nest after tagging. To compensate for the loss of provisioning by the male, and to ensure successful fledging of the chicks, this nest was provisioned daily for three weeks until the chicks had fledged successfully.

7. 2. 1. 2 GPS data and tag retrieval

GPS loggers were programmed to be active every five minutes for 20 seconds and record a position each second. Once tags detached, they were retrieved by using a hand held antenna to home in on the VHF signal emitted by the radio transmitter incorporated in the tag, which was designed to remain active for 8 weeks following deployment. Once tags were retrieved, positional data were downloaded from the GPS units using dedicated GiPSy 2 software.

One of the tags, deployed on an adult female Hen Harrier at a control study site, was retrieved having recorded 5 days and 5 hours of data on foraging flight. A second tag, deployed on a male bird at a wind farm study site, malfunctioned resulting in its taking fixes at a lower rate than normal and ceasing to function altogether after less than one day. As birds typically take some time to adjust to wearing a tag and harness, this meant that the few data collected by this tag would not be representative of its normal foraging behaviour. A third tag, deployed on an adult male at a control study site, was lost due to abandonment of the nest by the male as described in section 7. 2. 1. 1. A fourth nest, at which a tag was deployed on an adult male at a wind farm study site, was predated two weeks after tagging and the male consequently abandoned the nest site before the tag became detached and could be retrieved. The fifth nest, at which a tag was deployed on an adult male at a wind farm study site, fledged successfully and the male left the breeding area before the tag became detached and could be retrieved. Extensive ground-searching with VHF receivers was undertaken in suitable habitat close to each of these three nest sites, covering most areas of the Stacks mountains and the adjacent Glanarudderies and Mullaghareirk mountains. To increase the chances of locating the tags, an aerial survey was also undertaken, allowing coverage of a greater area including coastal areas known to be used by wintering Hen Harriers in Kerry, Cork, Waterford and Wexford but unfortunately none of the tags were relocated.

Surveys of study areas were undertaken using VHF receivers on the ground and from the air to locate GPS tags during 2013 fieldwork.

7. 2. 2 Collection of data during vantage point watches

Data on foraging behaviour were also collected using vantage point watches of Hen Harrier territories at twelve wind farm and control sites during the breeding seasons (April – August) of 2012 and 2013. Data were collected on sex, and age of the bird; the division of time between different behaviours. Habitats used by Hen Harriers while hunting were recorded and classified into one of the following groups: improved grassland, natural and semi-natural open land (natural grassland, scrub and rough grazing areas), peatland, closed canopy, prethicket, thicket, clear fell and other (tracks, roads, bare ground, open water, etc.). Habitats of the viewsheds (areas overlooked during vantage point watches) were classified into the same habitat groups using ArcGIS 10 (ESRI). As a national habitat map for Ireland does not exist, this was created for the study sites using the 0.3m resolution satellite images from 2012 available in ArcGIS 10 at 1:15,000 scale. Study sites were first divided into forest and non-forest areas based on Forest Inventory Planning System boundaries (FIPS, 2013). This was necessary to differentiate between forest and agricultural grassland areas which have a similar spectral signature. The Maximum Likelihood Classification method was used to create separate forest and non-forest habitat images. These were then mosaicked to create a continuous image. Water bodies (lakes and rivers greater than fourth order) and roads were added separately. Quality control was performed for each study site to check consistency of classification across all areas. A total of 1415 hours of watches were carried out during which 56.5 hours of Hen Harrier observations were recorded. Of these, over nine hours corresponded to foraging flights by adult males and females.

7. 2. 3 Data analysis

Although it had been proposed to collect fine scale data on habitat use by Hen Harriers in relation to wind turbines using GPS tags, insufficient data were collected using this method. It was possible to achieve the objectives of Work Package 5 on the foraging behaviour of adult Hen Harriers using data collected at wind farm and control study sites using data collected during vantage point watches as outlined in the project proposal. Data collected using GPS tags during the 2012 field season were used to determine habitats over which Hen Harriers flew during different activities (foraging, courtship displays, soaring, circling, etc.). GPS data includes all flights, while vantage point watch data represent only time spent foraging. These data do not reflect habitat use in the strict sense, as birds were not necessarily interacting with the habitats they were flying over (e.g. a bird soaring at 100m cannot be considered to be 'using' the habitat it is soaring over). However, it does provide a useful a frame of reference for analyses of Hen Harrier foraging habitats.

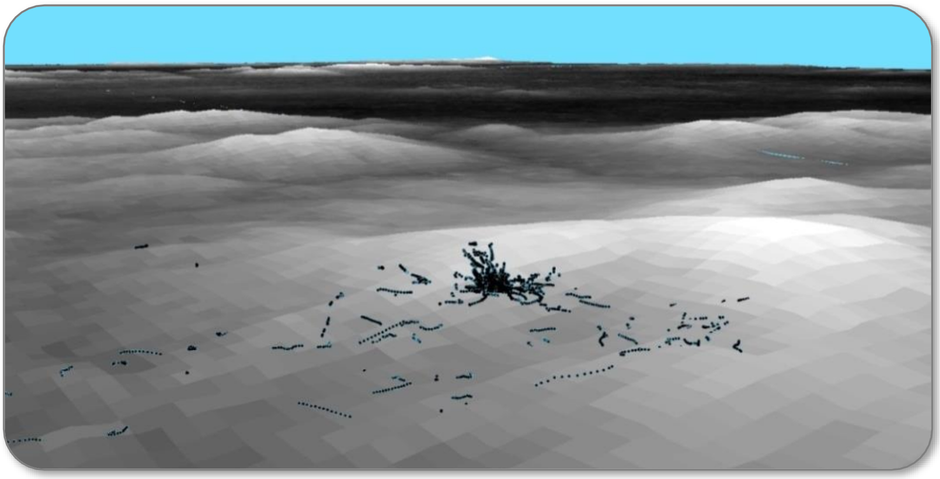


Figure 7.1: GPS track data, with concentration of GPS fixes around nest site.

GPS locations were clipped to the viewshed defined by a vantage point overlooking the nest and surrounding areas. As the data corresponded to a nesting female, a large proportion of the GPS fixes were at, or near the nest (Fig. 7.1). A 400m buffer around the nest site was used to remove these points as they were transition flights which would overweight the habitats around the nest. For the remaining GPS locations recorded, a track was generated joining the fixes in ArcGIS 10 (ESRI). A buffer of 10m was defined around this track and overlaid with habitat maps to determine the areas (m^2) of habitats overflown (Fig. 7.2). The values obtained for each track were then added for all GPS tracks to calculate the total area of habitats overflown by Hen Harriers. These were then converted to proportions of each habitat type flown over by the bird (total area of a habitat class / total area of track buffers) and compare to the proportion of habitats available in the viewshed.

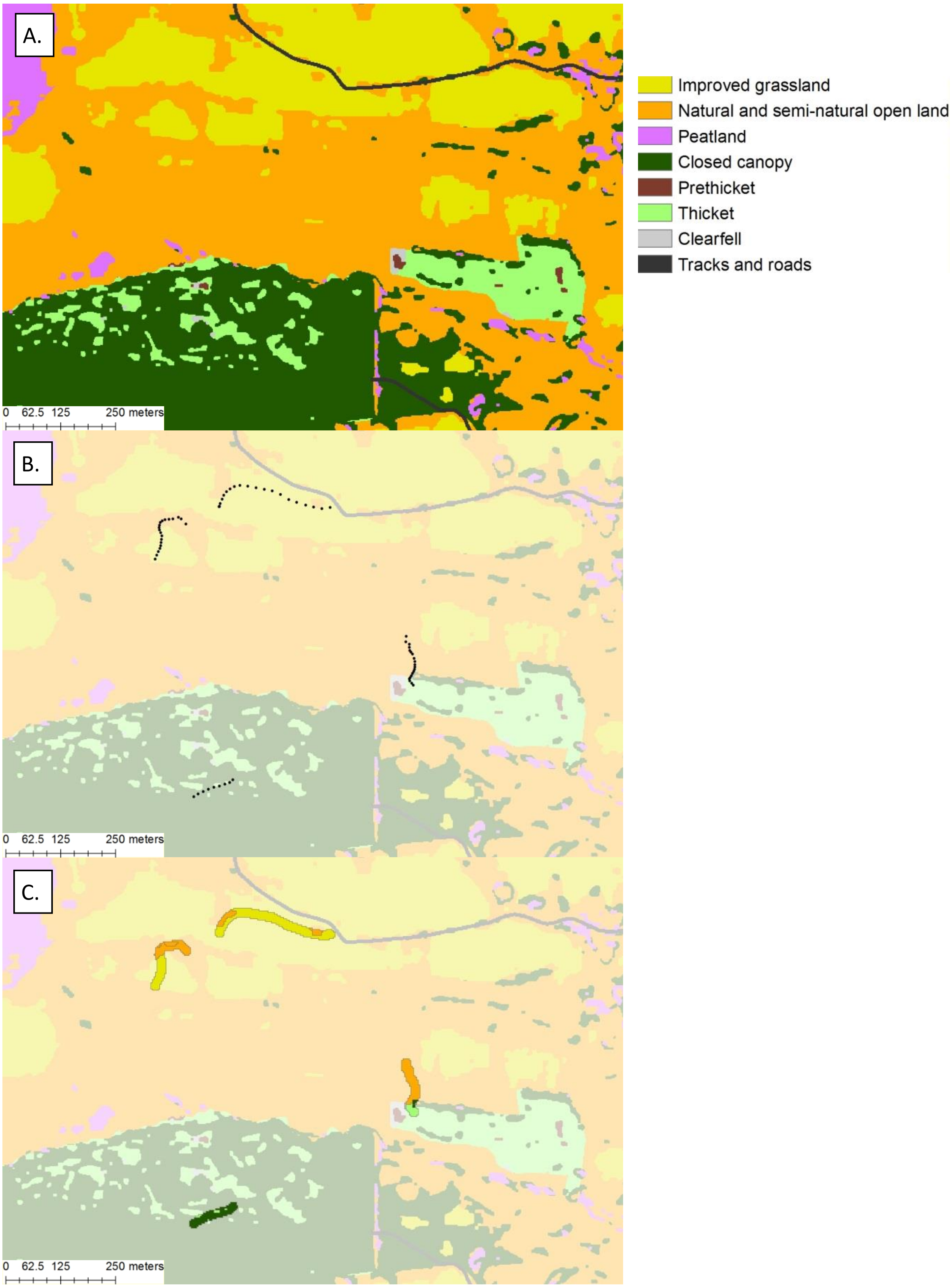


Figure 7.2: Extraction of habitat data from gps tracks. A) Habitat classification of the area used by the tagged Hen Harrier. B) Tracks obtained from the GPS tag overlayed on the habitat map. C) Ten metre buffer around tracks for which habitats overflown by Hen Harriers were extracted.

Data from vantage point watches was used to calculate the proportion of time Hen Harriers spent foraging in each habitat. This was then compared to the proportion of each habitat available in the corresponding viewshed. Overall values of foraging habitat and available habitat were calculated for control and wind farm sites. Foraging preferences were estimated by dividing the proportion of time that harriers spent foraging in each habitat by the proportion of that habitat that was available in the viewshed:

$$w_i = \left(\frac{u_i}{u_T}\right) / \left(\frac{A_i}{A_T}\right)$$

where w_i is the selection ratio, u_i is the time harriers spent foraging in habitat *i*, u_T is the total foraging time, A_i is the area of habitat *i* in the viewshed and A_T is the total area of the viewshed (Madders, 2000). These were used to calculate standardised selection ratios B_i for each habitat, which represent the probability that a Hen Harrier would select that habitat next, if all were equally available.

7. 3 Results

Data from the GPS tagged female Hen Harrier indicates that natural and semi-natural open habitats, peatland and clear fell were flown over more often than would be expected by chance in relation to their availability in the study areas (Fig. 7.3). On the other hand, improved grassland were used less frequently than expected.

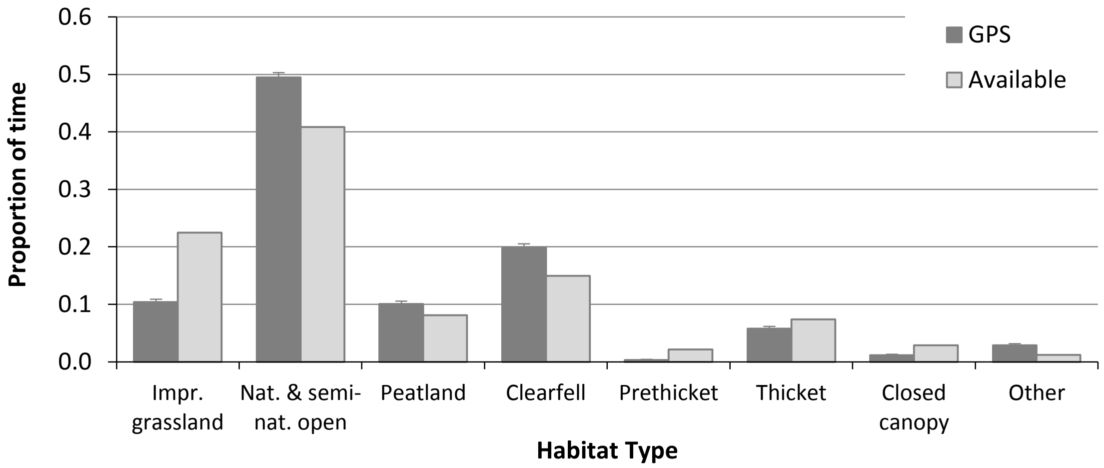


Figure 7.3: Proportion of time spent by the GPS tagged female Hen Harrier in the different habitats (dark grey bars) compared with the habitats available in the area (light grey bars).

Results of the analysis of Hen Harrier foraging habitats at wind farm and control sites can be seen in Figs 7.4 and 7.5. At control study sites, Hen Harriers foraged preferentially over peatland and thicket habitats while avoiding closed canopy and natural and semi-natural open habitats. At wind farm sites, birds also preferentially foraged in peatland, but to a lesser extent and at wind farm study sites Hen Harriers were seen to avoid closed canopy areas. Contrary to foraging patterns observed at control study sites, Hen Harriers at wind farms did not use thicket areas for hunting, but rather they hunted preferentially in areas of natural and semi-natural open habitats.

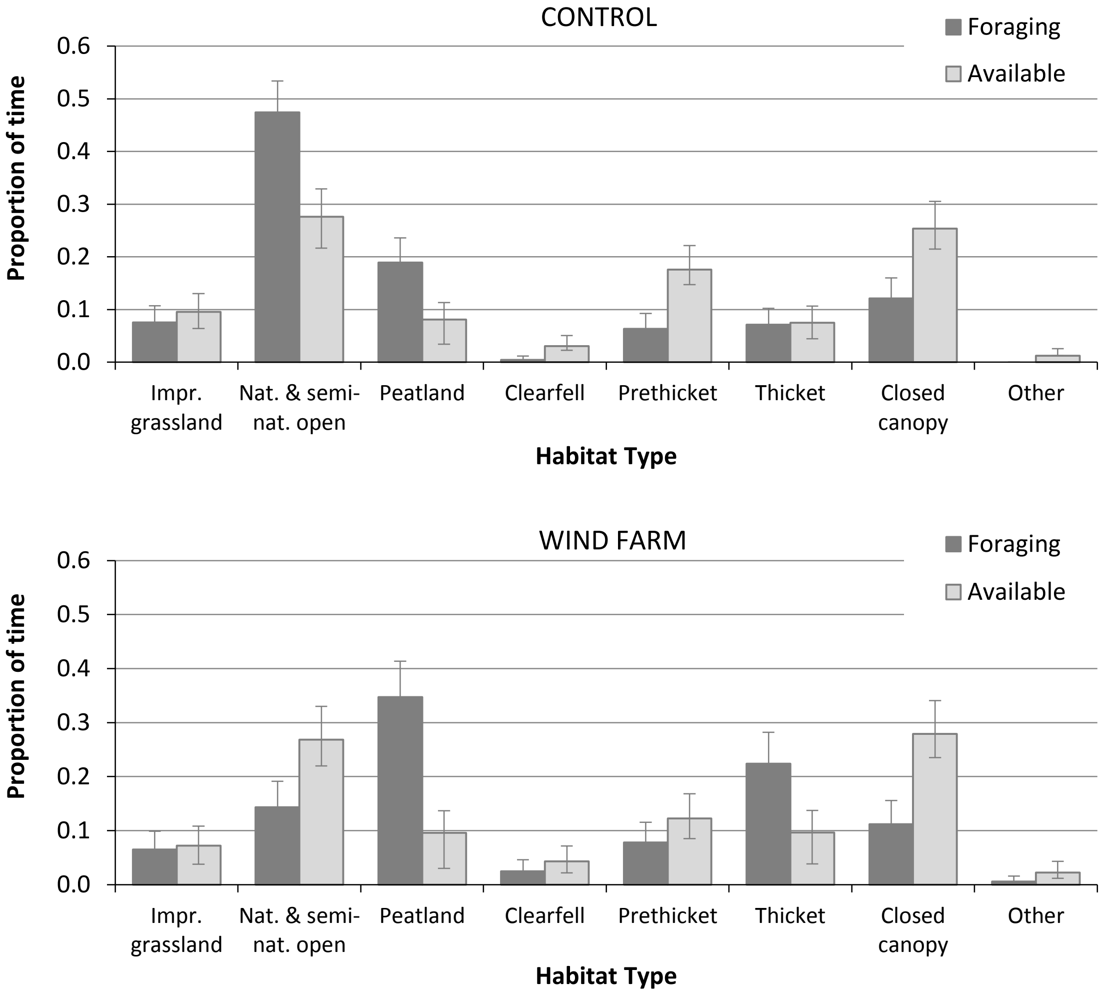


Figure 7.4: Foraging habitats used by Hen Harriers (dark grey bars) compared to available habitats (light grey bars) at wind farm sites (below, n = 369 minutes of foraging observations) and control sites (above, n=172 minutes of foraging observations).

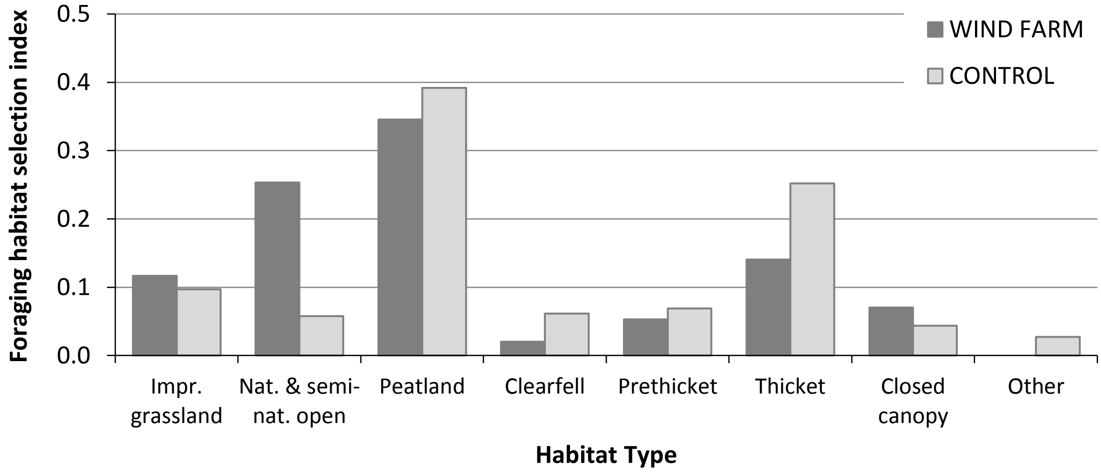


Figure 7.5: Hen Harrier foraging habitat selection indices, B_i, at wind farm sites (dark grey bars) and control sites (light grey bars).

7. 4 Discussion

The results of this study highlight the importance for Hen Harriers of open habitats which hold high diversity and densities of prey species (rough grassland, natural grasslands, scrub and peatland). In our study, with study sites mainly distributed in upland areas, peatland habitats are particularly important for hunting Hen Harriers. Previous work in Scotland has shown that Hen Harriers strongly select pre-thicket and thicket first rotations plantation forests for foraging (Madders, 2000). In Ireland they make greater use of forest than open habitats related to the location of the nests (Irwin *et al.*, 2012).

Wind turbines have been shown to have negligible displacement effect on foraging Hen Harriers (Whitfield & Madders, 2006a, Madden & Porter, 2007). The current study is the first to examine habitat selection by foraging Hen Harriers at operational wind farms. Here, the observed patterns of habitat selection differed between wind farm and control sites in the use of young forest plantations (pre-thicket and thicket) and areas of open country (scrub, rough and natural grassland). The availability (frequency of occurrence) of the eight habitat types in this study was similar at wind farm and control sites. However, at wind farm study sites, Hen Harriers favoured open habitats over afforested areas. Hen Harriers at control sites foraged preferentially over peatland and young forest plantations, while those at wind farm sites foraged preferentially over natural and semi-natural open habitat and to a lesser extent over peatland. These differences in foraging habitat may be due to Hen Harrier's foraging efficiency in these habitats, or to their distribution at wind farm sites.

Areas with wind turbines tend to be subject to higher levels of noise (from higher wind speeds or from turbine operation). In this situation, it could be expected that Hen Harriers, which rely heavily on acoustic cues for locating prey (Rice, 1982), would have lower foraging success in these areas. Habitat selection by Hen Harriers is positively correlated with foraging success rates and they have been shown to actively select habitats where they experience the highest prey strike and capture rates (Madders, 2000). This would result in the avoidance of forested areas where vegetation-wind interactions produce higher noise levels and areas where turbine noise may influence acoustic cues used by hunting Hen Harriers.

Furthermore, foraging habitat selection by Hen Harriers is related to the availability of prey items (Madders, 2000, Redpath *et al.*, 2002a) and so any impacts of wind turbines on Hen Harrier prey items may indirectly affect habitat selection. Results from our research on prey densities at wind farm sites (see Work Package 2) show reduced densities of forest passerine species in close proximity to turbines. Although these effects are linked to changes in the availability of these forested habitats, it is possible that they influence selection of foraging habitats by Hen Harriers. Alternatively, the distribution of habitats which are avoided by Hen Harriers at wind farm sites may be located in areas which are avoided by hunting birds. Pearce-Higgins *et al.* (2009b) found that wind farm development resulted in a reduction of Hen Harrier flight activity, with reductions of up to 52% in use of wind farm areas. If wind farms are located in heavily afforested areas, this displacement may result in the patterns of habitat use described in our study.

The factors that influence habitat selection by Hen Harriers are complex, and relate to nest site location, habitat availability and prey abundance (Madders, 2000, Arroyo *et al.*, 2009, Wilson *et al.*, 2009). Previous work by Robson as part of a before/after study at a single wind farm in Scotland showed that prior to wind turbine installation, 55% of flight activity occurred over forested land, but that this was reduced to 7% following clear felling associated with wind farm construction. Thus, changes in habitat use by Hen Harriers was not affected by the installation of wind turbines *per se*, but by the changes in habitat which come about as a direct result of wind farm construction and associated work (Robson, 2011). In the current study no difference was observed in the habitat composition at wind farm and control sites. However, as shown in Work Package 2, distribution of turbines with respect to habitat features is not random. The associated habitat changes in the immediate surroundings of turbines may be a relevant factor affecting foraging habitat selection.

The differences in foraging habitats at wind farm and control sites recorded here may have implications for Hen Harriers beyond foraging ecology. Changes in land use of preferred habitat of bird species' can potentially lead to reductions in breeding productivity related to reduced prey abundances (Amar *et al.*, 2003). Amar *et al.* (2007) linked changes in Hen Harrier foraging habitats to food limitation and ultimately reproductive performance of breeding pairs (Amar *et al.*, 2007). In this context, a better understanding of the effects of wind energy development on Hen Harrier foraging ecology can shed light on impacts of wind farms on breeding success (see Work Package 3). Future research can be greatly aided with the use of technologies such as those used in this study. Information on Hen Harrier movements at control and wind farm sites obtained by using GPS tags can provide high quality data which will improve current knowledge on the species' interactions with wind farm developments.

Work Package 6
8. Guidance for wind farm assessments

8. 1 Introduction

8. 1. 1 Work Package Structure

This Work Package is structured into two sections. The first section of this chapter (Section 8. 2) provides an overview of current knowledge of the impacts of wind farm developments on Hen Harriers *Circus cyaneus* and common practice for impact assessments. The second section (Section 8. 4. 1) combines the information derived from the literature review with the findings of the WINDHARRIER research project to develop a framework for guidelines for assessment of the impacts of wind farm developments on Hen Harriers in an Irish context. Within each section, a separate subsection is dedicated to each major topic.

Where relevant, information is also provided on other bird species which share ecological characteristics with Hen Harriers and may therefore provide insights on aspects which are poorly known for the study species of this document. This is of particular relevance for other Harrier species and especially Northern Harriers *Circus hudsonius* which were long considered to be conspecific to Hen Harriers (del Hoyo & Collar, 2014).

8. 1. 2 Impact Assessment

Planning permission is required for the development of wind farms in Ireland. In most cases the Competent Authority (CA) is the local authority. However, for wind farms with more than 25 turbines, or with a total output greater than 50 MW, planning permission must be sought directly from An Bord Pleanála through the Strategic Infrastructure Development (SID) process. There is a statutory requirement for an Ecological Impact Assessment (EcIA) for proposed wind farms where either:

1. The development requires an Environmental Impact Assessment (EIA).
2. The development requires an Appropriate Assessment (AA).

In addition, even when neither of these circumstances applies, it is open to the Competent Authority to request an EcIA if it is considered that this information is necessary for decision on the application to be reached.

Environmental Impact Assessment (EIA) is a mandatory part of the planning application process in Ireland for wind farm developments with more than 5 wind turbines, or those having a total output greater than 5 MW. In addition, an EIA for developments under this threshold may be required where the Competent Authority considers that the development is likely to have a significant environmental impact (sub-threshold EIA). The legislative requirements for wind farm EIAs are set out in the Planning and Development (Amendment) Act 2010 (Act No. 30 of 2010) and of the Planning and Development Regulations, 2001 (S.I. No. 600 of 2001). General guidance on the requirements for sub-threshold EIAs are provided by the Department of the Environment, Heritage & Local Government (DoEHLG, 2003).

Where there is a requirement for an EIA an Environmental Impact Statement (EIS) must be prepared. As part of an EIS, an Ecological Impact Assessment (EcIA) must be carried out to identify all of the likely significant impacts and to assess all ecological features of biodiversity/nature conservation importance that may be affected. General guidance on the required information content, and on the preparation, of an EIS is provided in Environmental Protection Agency Advice Notes and Guidelines (EPA, 2002, EPA, 2003). Specific guidance on EIAs and EISs in relation to wind farm developments is provided by the Department of the Environment, Heritage & Local Government (DoEHLG, 2006) and the Irish Wind Energy Association (IWEA, 2012).

Furthermore, Appropriate Assessment (AA) is required under articles 6(3) and 6(4) of the Habitats Directive (92/43/EEC) for any activity that is likely to cause significant impacts to a Natura 2000 site (a Special Area of Conservation (SAC) or a Special Protection Area (SPA)). Where a full AA is required, a detailed EcIA must be prepared. In contrast to EIA scenarios, this EcIA is only required to assess the potential impacts to the features listed as Qualifying Interests (QIs), in the case of SACs and Special Conservation Interests (SCIs) in the case of SPAs. The procedures to be followed in relation to AA in Ireland are defined by the Department of Environment and Local Government (DoEHLG, 2009). Guidance is also provided by the European Commission on Appropriate Assessment in general (European Commission, 2002) and in relation to wind farm developments (European Commission, 2011).

Ecological impact assessment (EcIA) is '*the process of identifying, quantifying and evaluating the potential impacts of defined actions on ecosystems or their components*'(Treweek, 1999). It is a key component of both Environmental Impact Assessments (EIAs) and Appropriate Assessments (AAs). The standard best practice guidance for EcIA in Britain and Ireland are the Guidelines for Ecological Impact Assessment in the United Kingdom (IEEM, 2006). While these guidelines refer to the United Kingdom in their title, they are widely accepted as defining best practice in Ireland also and a revised version is in preparation that will explicitly include Ireland. Specific guidance on EcIA in an Irish context is provided by National Roads Authority (NRA, 2009) while guidance on appropriate survey methods is provided by National Roads Authority (NRA, 2008). The typical stages involved in Ecological Impact Assessment are described in Table 8.1. However, EcIA is an iterative process and so these stages are not always carried out sequentially.

Table 8.1: Typical stages of Ecological Impact Assessment

Stage	Scope
Scoping	Determination of the issues that need to be addressed and the data collection/survey work required to address these issues.
Baseline data collection	Compilation of data (from desktop review and field survey) on the ecological features that may be affected by the activity being assessed.
Evaluation	Assessment of the ecological importance of the features that may be affected. This is often done using a geographical scale (i.e., International, National, Regional, Local, etc.).
Impact assessment	Quantification of the magnitude of the potential impacts and assessing the ecological significance of the impacts, of the activity being assessed on the important ecological features that might be affected (ecological significance is different from statistical significance and refers to the biodiversity/nature conservation importance of the feature being affected and the magnitude/long-term consequences of the impact on that feature).
Mitigation	Identification of mitigation measures that may be eliminate, reduce or compensate for the impacts identified in the impact assessment stage.
Residual impact assessment	Assessment of the impacts that will remain following implementation of the mitigation measures.

In addition to assessing the impact of the wind farm development in isolation, both EIAs and AAs also require that the EcIA assesses the potential impact of the wind farm development in-combination with other wind farms (existing, permitted, or planned) and/or other relevant activities (e.g. afforestation) (Cumulative Impacts). The assessment of cumulative impacts a key issue in many assessments of wind farm projects in relation to Hen Harriers. General guidance on cumulative impact assessment for wind farm projects is provided by the (European Commission, 2011). Detailed guidance on scope and methodology for cumulative assessments of wind farm impacts on bird populations is provided by (SNH, 2012a).

8. 1. 3 Impact Assessment Methods

Once the predicted impacts have been quantified (e.g. predicted collision rate, predicted displacement effect), it is necessary to assess the significance of the predicted impacts. The Institute of Ecology and Environment Management (Now the Chartered Institute of Ecology and Environmental Management) has produced guidelines for ecological impact assessment in the United Kingdom (IEEM, 2006). While they are not specific to wind farm assessments, these guidelines represent best practice and are widely followed in Ireland. The European Commission provides some general guidance on distinguishing between significant and insignificant effects for wind farm projects (European Commission, 2011), but this guidance is not specific enough to be used for hard cases, such as marginal impacts on Hen Harriers (e.g. a very low predicted collision risk). In theory, population modelling (e.g. Hötker *et al.*, 2005, Masden *et al.*, 2010), would allow determination as to whether the predicted impact is likely to cause a population decline. However, in practice, this is likely to be outside the scope of assessments of individual wind farm projects, although this could be applied at a strategic level (e.g. cumulative assessments at the SPA scale).

At designated Natura 2000 sites, it is necessary to show that the wind farm project will not have impacts that will affect the ability of the site to maintain, or be restored to, the targets specified in the conservation objectives for the site. National Parks & Wildlife Service have not yet prepared site-specific conservation objectives for the Hen Harrier SPAs in Ireland, but the general requirements for Favourable Conservation Status (FCS), as defined in the EU Habitats Directive (92/43/EEC), are that:

1. Population dynamics data indicate that the species is maintaining itself on a long-term basis as a viable component of its natural habitats.
2. The natural range of the species is neither being reduced nor is likely to be reduced for the foreseeable future.
3. There is, and will probably continue to be, a sufficiently large habitat to maintain its populations on a long-term basis.

Scottish Natural Heritage (SNH, 2006) provide useful general guidance for assessing significance of impacts outside of designated sites, as follows:

1. Sites are to be assessed in terms of the impact on the conservation status, as defined by Favourable Conservation Status (FCS) in the Habitats Directive.
2. Displacement will not necessarily affect FCS, which “does not does not demand a given number of the species”, but “if the loss of habitat is substantial and widespread, then it should be regarded as reducing the natural range of the species”.
3. Where a species is already in decline, the test should be whether the proposal would add substantially to the difficulty of taking action to reverse the decline. In some cases, minor adverse impacts, while adding to the existing impacts, may be insignificant in comparison and “should not be deemed to add substantially to the existing problem”.
4. Local change of distribution should not be used at a very local level to argue that local losses are significant.

8. 2 Review of impacts and impact assessment

8. 2. 1 Collision risk

8. 2. 1. 1 Mortality

Hen Harriers are considered a species at risk of collision with wind turbines in Europe and Ireland (Percival, 2003b, European Commission, 2011) but reports of deaths are rare. Systematic searches for Hen Harrier carcasses, which use standardised methodologies (resulting in comparable data) are not routinely carried out (see section 6.2.4.4 Survey methods: Carcass searches) and anecdotal data are commonly reported only in grey literature. In a review of available information on Hen Harrier collisions with wind turbines (Whitfield & Madders, 2005) reported that mortalities were only recorded in 3 of 10 studies conducted in North America and Spain and that Hen Harriers are less vulnerable to collision than other raptor species. Hen Harrier fatalities as a consequence of collision with wind turbines have been reported in Northern Ireland (1 suspected case) (Scott & McHaffie, 2008), Scotland (2 fatalities at a wind farm considered of low collision risk) (Stanek, 2013), Spain (1 fatality) (Lekuona & Ursúa, 2007) and the United States (7 Northern Harrier *Circus hudsonius* fatalities) (Young & Erickson, 2003, Smallwood & Thelander, 2004, Johnson & Erickson, 2011). To date, no work has been published on systematic searches for bird carcasses at wind farm sites in Ireland.

8. 2. 1. 2 Flight height

Most studies report low flight heights for Hen Harriers (Whitfield & Madders, 2006a, Madden & Porter, 2007, Ruddock & Whitfield, 2007), with low proportions (5-15%) of observations at rotor sweep height (Johnson *et al.*, 2000b, Young & Erickson, 2003, Garvin *et al.*, 2011, Busse, 2014). However, this is not always the case with records of high percentages of time spent at blade height at some wind farms (Dick 2011). Of particular interest is a study using triangulation methods (these allow a more accurate assessment of flight heights than traditional estimates) which found 55% of observations at a Scottish wind farm and control sites were within the rotor zone. The average time within the rotor zone increased from April (45%) to July (86%) with females flying on average significantly higher than males (Stanek, 2013).

8. 2. 1. 3 Turbine avoidance behaviour

Birds are known to display behavioural avoidance of wind turbines (defined as an 'action taken by a bird, when close to an operational wind farm, which prevents a collision' (SNH, 2010b). Scottish Natural Heritage guidelines are commonly used in Europe and suggest an avoidance rate of 99% for Hen Harriers (SNH, 2010b). In North America, avoidance rates estimated for Northern Harriers at two wind farms were considerably lower, with values of 98.0-99.9% and 91.9-93.9% (Whitfield & Madders, 2005). Chamberlain *et al.* (2005) warn of the importance of accuracy with regards to avoidance rates, as small correction factors can have a considerable effect on calculated collision risks (they reported the case of a Golden Eagle *Aquila chrysaetos* case study, where a decrease in avoidance rate from 0.995 to 0.990 caused a doubling of the estimated mortality rate).

8. 2. 1. 4 Collision risk assessments

Analysis of the risk of collision posed to Hen Harriers by wind turbines in Ireland and Britain have largely followed the Band / Scottish Natural Heritage model (for key guidance documents see SNH (2000), (Band *et al.*, 2007)(Band et al. 2007) and (Natural England 2010); for guidance on the interpretation of the outputs see (Chamberlain et al. 2005)). These models are commonly used to evaluate the risk posed by a single wind farm and calculate the number of transits (birds flying through wind turbine rotors) and the probability that a bird flying through the rotor sweep will collide with a turbine blade (SNH, 2000). Although this model does not include avoidance, a correction can be added to the final estimate if required (SNH, 2010b).

Estimates from the Band/Scottish Natural Heritage model include a series of assumptions and can vary importantly in response to avoidance rates (Chamberlain *et al.*, 2005), observation hours (Douglas *et al.*, 2012), fieldworker in recording bird activity and flight heights (Madders & Whitfield, 2006) and effects of changes in habitat occurring between time of collision risk assessment and wind farm operation (e.g. clear felling may result in increased foraging in wind farm areas which may in turn increase risk of collisions (SNH, 2012d)). Therefore collision risks should not be used as a reliable predictor (de Lucas *et al.*, 2008) but as an estimate that can vary in time depending on the Hen Harrier behaviour but can be used to make comparisons between different wind farm construction and planning scenarios or mitigating measures (Everaert *et al.*, 2011).

Alternative models for assessing collision risk are continually being developed and can be expected to improve in accuracy, particularly with continued advancements in tagging technologies. The following is a brief, non-comprehensive, list of alternative models and references (it must be noted that methodologies are not easily accessible for all models listed).

- The Biosis Research Deterministic Avian Collision Risk Assessment Model (Smales, 2006).
- A model described by Holmstrom *et al.* (2011), which accounts for different angles of avian approach and uses Monte Carlo sampling to account for the statistical distributions of wind and flight characteristics.
- A model that is in development, using GPS data from tagged White-tailed Eagles *Haliaeetus albicilla* used to model collision risk using Brownian-bridge interpolation simulations (Bevanger *et al.*, 2010).
- An individual-based modelling approach, which combines simulations of flight paths across a wind farm, taking account of variation in weather conditions and other factors and uses a collision risk model based on Tucker (1996) (Strickland *et al.*, 2011).
- An agent-based, spatially explicit model, which simulates the foraging behaviour of Red Kite *Milvus milvus*, and determines the collision risk of Red Kites as a function of the distance between the wind turbine and the nest and a number of other parameters (Eichhorn *et al.*, 2012).
- (Madders & Whitfield 2006) review several other models that have been used for collision risk assessment.
- An alternative approach is to use empirically derived collision rates from studies that relate bird movements across wind farms to observed mortality rates (Everaert *et al.*, 2011, Everaert & Peymen, 2013). This method is limited by the fact collision rates are strongly influenced by local factors.

8. 2. 1. 5 Population modelling

Population modelling can be used to assess the impact of mortality from wind turbine collisions (as estimated by collision risk modelling) on bird populations. This approach has been used for a number of species (Smales, 2005, Smales & Muir, 2005), but rarely for Hen Harriers. Masden (2010) predicted declines for population of Hen Harriers in Orkney from 70 adult birds to between 11 and 32 birds depending on the extent of wind farm development. However, she attributed this decline to loss of habitats, rather than to the effects of direct mortality. Hötker *et al.* (2005) modelled population trends using data for Montagu's Harriers *Circus pygargus* in the Netherlands, and found that over a period of 20 years, a 0.1% increase in mortality rate resulted in a 2.8% decrease in population size, and a 0.5% increase in mortality resulted in a population decline of an estimated 14.8%.

8. 2. 1. 6 Concluding remarks and cumulative impacts

Research indicates that Hen Harriers are at lower risk of collision mortality than other raptor species (see Work Package 4) and that this may be negligible in comparison with natural mortality. However, a guidance document issued by Scottish Natural Heritage (SNH, 2012a) identifies that, when combined with additional mortality sources (e.g. multiple wind farms, direct persecution), it may potentially lead to population declines which can only be avoided by not introducing the new source of impact.

8. 2. 2 Disturbance

8. 2. 2. 1 Disturbance distances

Reports on disturbance distances for Hen Harriers vary depending on the disturbance source. Disturbance responses to single pedestrian approach have been reported to range from 500m to 1000m, but with a possibility of acute sensitivity of some pairs (Currie & Elliott, 1997, Romin & Muck, 2002, Ruddock & Whitfield, 2007). Disturbance distances recorded from operational turbines were in the range of 250m, with some disruption reported up to 500m (Madders, 2004). It is worth noting that disturbance distances summarised here can be expected to vary greatly depending on individual tolerance, variability between populations or other ecological factors (e.g. habitat and vegetation or location of nests).

8. 2. 2. 2 Construction disturbance

Very little information is available on the effects of wind farm construction activities on Hen Harriers. Monitoring of one wind farm in the United States and two in Scotland found no significant decrease in the use of sites during construction by Northern Harriers and Hen Harriers, respectively (Johnson *et al.*, 2000b, Haworth Conservation, 2013). Construction disturbance on nesting birds has been estimated at 500m, with some disruption extending up to 1km along lines of sight (Madders, 2004), although (Forrest *et al.*, 2011) reported successful breeding of a pair within 110m of construction activities, where exclusion zones were implemented to reduce disturbance. However, recent work by (Pearce-Higgins *et al.*, 2012) (which did not assess effects on Hen Harriers) suggests that declines in upland bird species as a consequence of wind farm presence occur during the construction phase (with declines reported for Red Grouse *Lagopus lagopus scoticus*, Curlew *Numenius arquata* and Snipe *Gallinago gallinago*).

8. 2. 2. 3 Concluding remarks and cumulative impacts

Variations in Hen Harrier response to disturbance might be expected depending upon the availability of suitable alternative habitat away from wind farms and the costs associated with moving to and utilising this alternative habitat (Gill *et al.*, 2001). These costs can be expected to be case specific and will depend on habitat availability, population density in the impacted area, etc. As a consequence of displacement, birds may enter into conflict with other territorial pairs, select habitats sub-optimal for breeding or foraging (Wilson *et al.*, 2012), or not be able to breed successfully. Furthermore, Whitfield & Madders (2006b) suggest that conservative assessments can be made assuming 100% disturbance within a specified threshold distance, but due to habituation and non-linear response effects it may not be possible to assess these thresholds quantitatively (SNH, 2012b).

8. 2. 3 Displacement

8. 2. 3. 1 Displacement Impacts

Hen Harriers are classified as showing ‘evidence or indications of risk or impact’ from habitat displacement and ‘small or non-significant risk or impact’ from barrier effects according to EU guidance documents (European Commission, 2011). The species has been shown to be tolerant of wind farm developments in other habitats, but responses in upland areas are less well known (Percival, 2003b).

Displacement of nesting attempts has been reported at ranges of 200m to 300m around turbines (Madders & Whitfield, 2006, Whitfield & Madders, 2006b). However, (Robson, 2012) reported nesting within 200m of operational turbines in Scotland. In Ireland, before-after monitoring has yielded contrasting results. A study in county Galway found the Hen Harrier breeding population (10—11 pairs) to remain stable across the monitoring period (Madden & Porter, 2007), while monitoring of a single territory in county Kerry reported a significant increase in the distance of the nest site to turbines and a decline in productivity and breeding behaviours (sky dancing and food passes) (O'Donoghue *et al.*, 2011). Before-after monitoring of four wind farm sites in Scotland found no effects on breeding numbers or distances of nests to turbines (Forrest *et al.*, 2011, Robson, 2012, Haworth Conservation, 2013).

Displacement of foraging and flight behaviour has been recorded close to wind turbines in Britain (100m for foraging and 250m for flight) (Madders & Whitfield, 2006, Whitfield & Madders, 2006b, Pearce-Higgins *et al.*, 2009a). Pearce-Higgins *et al.* (2009b) reported a reduction of 52.5% in Hen Harrier flight activity within 500m of the turbine array. A study in the United States reported similar results for Northern Harriers, with a drop in flight activity of over 50% within the wind farm (Garvin *et al.*, 2011), although a second study reported frequent flights of Northern Harriers within 50m of turbines (Thelander *et al.*, 2003).

8. 2. 3. 2 Concluding remarks and cumulative impacts

The effect of displacement impacts on conservation status can be expected to depend on the population status and the availability of suitable habitats. If Hen Harriers are displaced into areas with sufficient capacity (territory space, suitable nesting and foraging habitat, etc.) to absorb them, the cumulative impact will be reduced. If, on the other hand there is a cumulative loss of habitat which is significant and widespread, displacement can reduce the species range (SNH, 2012a).

8. 2. 4 Survey methods

8. 2. 4. 1 Breeding surveys

Breeding surveys should be carried out to locate Hen Harrier nest sites in the vicinity of proposed wind farm sites. Draft guidelines for Ireland recommend surveying an area covering a 5km radius from outer turbines by means of vantage point watches during a single year (see NPWS (2003) for detailed methodology). Current guidance from Scottish Natural Heritage (SNH, 2014a) states that these surveys should cover a 2km radius from the development boundary and have a duration of two years (see Hardey *et al.* (2013) and SNH (2014c) for detailed methodology).

8. 2. 4. 2 Winter surveys

Winter surveys are required to locate communal Hen Harrier winter roosts in the vicinity of proposed wind farm sites. Guidance from Scottish Natural Heritage (SNH, 2014a) is similar to that for breeding surveys, i.e. covering a 2km radius from the development/planning application boundary and during a period of two years. For details on winter roost survey methodologies see Hardey *et al.* (2013), Natural England (2007) and NRA (2008).

8. 2. 4. 3 Flight activity surveys

Flight activity surveys are an important component of survey work required for wind farm impact assessments. Vantage point surveys are the standard method used in Ireland and Britain (see SNH (2014b) for methodology). A key issue is the importance of selecting suitable vantage points that cover the entire study area, but which avoid the observer affecting patterns of bird usage of the area. For Hen Harrier, guidance specifies 36 hours of breeding season (April-August inclusive) and 36 hours of non-breeding season watches per vantage point, with a greater survey effort recommended for high sensitivity sites.

Despite their use as the standard method for assessing flight activity, vantage point surveys are not exempt to potential biases (Madders & Whitfield, 2006, Band *et al.*, 2007). An important source of bias rarely addressed is observer bias, especially with regard to estimation of flight heights. These are particularly difficult to determine in pre-construction surveys and likely to vary between observers. Recent work proposes the use of triangulation to increase the accuracy of flight height estimates (Stanek, 2013), although this methodology requires two surveyors and presents some practical issues. Tagging technologies may provide a useful solution to this problem Bevanger *et al.* (2010), although the information they can be expected to yield will be applicable at a general scale rather than for specific wind farm sites and assessments.

Standard survey methodologies in the United States differ from vantage point surveys by assigning circular plots of fixed radius (800m) which are watched for short periods (20-40 minutes) (Strickland *et al.*, 2011).

8. 2. 4. 4 Carcass searches

Carcass searches have been used mainly in mainland Europe (Barrios & Rodríguez, 2004, de Lucas *et al.*, 2004, de Lucas *et al.*, 2005, Lekuona & Ursúa, 2007, de Lucas *et al.*, 2008, Farfán *et al.*, 2009, Krijgsveld *et al.*, 2009, Everaert *et al.*, 2011, Ferrer *et al.*, 2012) and the United States (Johnson *et al.*, 2000b, Kerlinger, 2002, Johnson *et al.*, 2003, Schmidt *et al.*, 2003, Thelander *et al.*, 2003, Young & Erickson, 2003, Young *et al.*, 2003a, Young *et al.*, 2003b, Erickson *et al.*, 2014). Appropriate design of carcass searches must consider frequency of searches, number of turbines to search, size of search area around each turbine (Strickland *et al.*, 2011), the possible use of trained dogs (Paula *et al.*, 2011), correction factors for scavenging and observer efficiency, distance sampling methods to correct for birds falling outside the search area and statistical methodology (Bernardino *et al.*, 2013, Stevens & Dennis, 2013). Detailed guidance on carcass search methodology and interpretation and analysis of results is available from a number of sources (Australian Wind Energy, 2005, Anon, 2007a, SNH, 2009, Natural England, 2010, Strickland *et al.*, 2011).

8. 2. 4. 5 Other surveys

Surveying other aspects of ecological relevance, such as habitat quality, prey abundance and availability may be useful in some contexts (SNH, 2014a) and in particular for comprehensive assessment of indirect impacts on Hen Harriers. Although (SNH, 2014a) guidance has largely superseded Irish guidelines, they do not include habitat classifications which are provided by Irish guidelines (NPWS, 2003, Forest Service, 2012) and which have continued to be used in recent assessments.

8. 2. 5 Population assessment tools

8. 2. 5. 1 Sensitivity mapping

Bird sensitivity mapping is a recently developed tool used to aid wind energy developers and policy makers to foresee and minimise potential impacts. In this context ‘sensitivity’ is defined as the ecological and conservation importance of a species at the site being assessed (Percival, 2007). The sensitivity of an individual bird species to wind energy development is determined by its designation on the EU Birds Directive, its ecological sensitivity, whether it is subject to special conservation measures and whether the site contains regionally or nationally important numbers of the species (Percival 2007). For a detailed context and methodologies, see (Muldoon & Mc Guinness, 2014). Although this should not be used as a replacement for site specific assessments, it will provide information at a broader scale of the importance of different areas for vulnerable bird species (including Hen Harriers). This work is currently underway and will result in the production of a Bird Sensitivity Map for Ireland which will aid in strategic planning of future wind energy developments. Similar maps have previously been produced in Scotland (Bright *et al.*, 2006).

8. 2. 5. 2 Population modelling

Cumulative impacts of wind farm developments and other factors affecting Hen Harrier populations (e.g. direct persecution, changes in land use) can be best assessed by means of population modelling. There have been few attempts to model Hen Harrier population trends (see Work Package 1) or to use these models to predict future trends. Recent studies have used this approach to model the impact of Hen Harrier populations on Red Grouse numbers (Elston *et al.*, 2014) and the interaction between human-induced changes in land use and persecution on Hen Harrier populations (Heinonen *et al.*, 2014). Masden (2010) modelled populations in relation to wind farm developments and estimated that a declining population of Hen Harriers in Orkney starting with 70 adult birds, would decrease to 32 after just 50 years, using mortality estimates based on operational turbines at the time (n = 7). Predicted population numbers decreased if the number of turbines deployed was increased, down to 11 adults with 112 operational turbines. Removal of collision risk form the model indicated that the majority of impacts were associated to habitat loss.

8. 2. 6 Guidance documents

In Ireland and Britain, standard practice guidance for wind farm ecological assessment is provided by Scottish Natural Heritage. Their website has two pages with links to all relevant guidance documents:

1. Wind farm impacts on bird guidance (www.snh.gov.uk/planning-and-development/renewable-energy/onshore-wind/windfarm-impacts-on-birds-guidance).
2. Bird collision risks guidance (www.snh.gov.uk/planning-and-development/renewable-energy/onshore-wind/bird-collision-risks-guidance).

Table 8.1 provides a list of useful guidance documents and detailed methodologies.

Table 8.1: Some recent guidance documents and methodologies for wind farm ecological assessment, with particular reference to Hen Harriers highlighted.

Country / Region	Organisation	Year	Scope	Reference to Hen Harriers	Citation
Europe	Council of Europe	2004	Generic guidance, including a review of key issues, and guidance on EIA methodology (including BACI design).	No	(Langston & Pullan, 2004)
Europe	European Commission	2011	Mainly procedural guidance on wind farm Appropriate Assessments.	No	(European Commission, 2011)
Europe		2013	Raptor (including Hen Harrier) survey methodologies.	Yes	(Hardey *et al.*, 2013)
Ireland	BirdWatch Ireland	2014	Draft bird sensitivity mapping for wind energy developments and associated infrastructure.	Yes	(Muldoon & Mc Guinness, 2014)
Ireland		2003	Generic guidance, including a review of key issues, and guidance on survey methodology, collision risk assessment, and assessment of significance. Now superseded by more recent SNH guidance.	Yes	(Percival, 2003a)
Ireland	National Parks and Wildlife Service	2003	Draft guidance on Hen Harrier survey methodology. Largely superseded by more recent SNH guidance, except in the use of habitat surveys and proposed classifications.	Yes	(NPWS, 2003)
Ireland	Forest Service	2012	Guidance on forestry assessments providing guidance regarding afforestation and disturbance in Hen	Yes	(Forest Service, 2012)

Country / Region	Organisation	Year	Scope	Reference to Hen Harriers	Citation
			Harrier SPAs, and Hen Harrier habitat classifications.		
Scotland	Scottish Natural Heritage	2000	Detailed guidance on collision risk modelling, with accompanying spread sheet for carrying out calculations.	No	(SNH, 2010b)
Scotland	Scottish Natural Heritage	2006	Guidance on assessing wind farm developments that do not affect designated sites.	Yes	(SNH, 2006)
Scotland	Scottish Natural Heritage	2009	Guidance on monitoring methods, including carcass searches.	Yes	(SNH, 2009)
Scotland	Scottish Natural Heritage	2010	Review of the concept of avoidance rates, the methodology for their derivation, limitations in their use in collision risk assessment, and recommended avoidance rate figures to be used for a range of sensitive species, including Hen Harriers.	Yes	(SNH, 2010b)
Scotland	Scottish Natural Heritage	2012	Review of the issues to be considered in cumulative impact assessments of onshore wind farms on landscape and birds, with guidance on procedural issues and how to combine impacts from multiple developments for cumulative assessments.	No	(SNH, 2012a)
Scotland	Scottish Natural Heritage	2012	Guidance on how SNH will deal with development planning situations where there is less raptor activity or fewer raptors than expected.	No	(SNH, 2012b)
Scotland	Scottish Natural Heritage	2013	Guidance on assessing connectivity between development proposals and SPAs.	Yes	(SNH, 2013)
Scotland	Scottish Natural Heritage	2014	Defines pre-development bird survey standards for proposed wind farms in Scotland. Includes general guidance, and species-specific survey methods. This is the third version of these guidelines, with previous versions in 2005 and 2010.	Yes	(SNH, 2014c)
Scotland	Scottish Natural Heritage	2014	Discusses factors affecting the use of flight speed and biometric data in collision risk modelling and provides a list of published sources for such data.	Yes	(SNH, 2014b)
Scotland	Scottish Natural Heritage	2014	Guidance on assessing small-scale wind farms.	No	(SNH, 2014a)
England	English Nature, RSPB, WWF-UK, BWEA	2001	Generic guidance document.	No	(English Nature *et al.*, 2001)
England	Natural England	2007	Guidance on wind farm survey requirements relating specifically to a number of coastal / lowland SPAs in north-east England.	Yes	(Natural England, 2007)
England	RSPB/Natural England	2009	Mapping of sensitivity to wind farm impacts for birds.	Yes	(Bright *et al.*, 2009b)
England	Natural England	2010	Guidance on wind farm survey requirements and impact assessments.	Yes	(Natural England, 2010)
Belgium Flanders	Instituut voor Natuur- en Bosonderzoek	2011	Generic (but detailed) guidance on survey methods and impact assessment.	No	(Everaert *et al.*, 2011)
Belgium Flanders	Instituut voor Natuur- en Bosonderzoek	2013	Generic (but detailed) guidance on impact assessment and assessing significance.	No	(Everaert & Peymen, 2013)
Poland		2014	Review paper which describes methodologies used in Poland.		(Busse, 2013)

Country / Region	Organisation	Year	Scope	Reference to Hen Harriers	Citation
Canada	Environment Canada & Canadian Wildlife Service	2006	Generic guidance document.	No	(Environment Canada, 2006)
USA	National Wind Coordinating Committee	1999	Generic guidance focusing mainly on issues of sampling design and statistical analysis and general research design (not specific to wind farms).	No	(Anderson *et al.*, 1999)
USA	National Wind Coordinating Committee	2011	Update of Anderson et al. (1999), with much specific guidance about pre-construction survey methods, collision risk modelling, impact assessment and carcass searches.	No	(Strickland *et al.*, 2011)
USA California	California Energy Commission	2007	Detailed guidance document, including screening, survey methods, mitigation and monitoring.	No	(California Energy Commission and California Department of Fish and Game, 2007)
USA Washington	Washington Department of Fish and Wildlife	2009	Guidance on survey methods and impact assessment.	No	(Washington Department of Fish and Wildlife, 2009)
USA Wyoming	Wyoming Game and Fish Commission	2010	Guidance on survey methods.	No	(Wyoming Game and Fish Commission, 2010)
South Africa	BirdLife South Africa / Endangered Wildlife Trust	2012	Generic guidance on survey methods.	No	(Jenkins *et al.*, 2012)
Australia	Australian Wind Energy Association	2005	Generic guidance on survey methods and risk assessment.	No	(Australian Wind Energy, 2005)

8. 4 Recommendations for impact assessment and monitoring

Scope of this study:

1. The objectives of the WINDHARRIER project were to (i) determine the nature and extent of wind energy-related impacts on Hen Harrier foraging, (ii) determine whether wind farms appear to be avoided by nesting Hen Harriers, and whether proximity to wind farms is related to Hen Harrier breeding success, (iii) evaluate the best way to assess the cumulative impact of wind turbines, either within a wind farm site or at the scale of a whole SPA, (iv) quantify any direct mortality risks posed by wind turbines for Hen Harriers, especially as related to recently fledged birds and (v) develop appropriate mitigation measures to facilitate future sustainable wind energy development.

2. It is beyond the scope of this study to assess the impact of other potential interactions between Hen Harriers and wind farm developments, such as effects of land use change and habitat availability, disturbance related to wind farm construction activities, effects on winter roosting behaviour, or other aspects not covered in the original project proposal.

3. The aim of these recommendations is to provide a framework for best practice for the assessment of these aspects based on research undertaken within the WINDHARRIER project and other information available at this time in scientific and grey literature. Aspects not covered by our study (point 2) are mentioned where relevant, but are not dealt with comprehensively.

4. These recommendations refer specifically to Hen Harriers and should not be used for the assessment of wind farm impacts on other bird species.

All bird species in Ireland are protected by the EU Birds Directive (2009/147/EC) which sets out a comprehensive scheme of protection for all wild bird species in Member States. A subset of bird species, including Hen Harriers, have been identified in this Directive, and listed in Annex I, as requiring special conservation measures in relation to their habitats. Environmental Impact Assessment (EIA) is a systematic process that examines the potential environmental consequences of proposed developments.

In arriving at these recommendations, we have drawn on a number of sources, both individually and collectively, both from the results of the primary data collected during the current study, from published materials and through expert knowledge across the sector. We set out to collate existing research and findings, provide a context from our data and set out a broad framework which, when viewed in conjunction with best practice elsewhere, will provide key information for assessment and monitoring of Hen Harriers in the future. The following key recommendations for the assessment of wind farm impacts on Hen Harriers are made, subject to the limitations of this project.

Currently there is no existing guidance document for the assessment of wind farm development impacts on Hen Harriers, or other bird species, in the Irish context. Formal guidance documents (similar to those available in Scotland and elsewhere) would provide standardised protocols, methodologies and data collation formats which would standardise and facilitate the assessment of the impact of individual developments and of cumulative impacts.

Key findings of the WINDHARRIER project

To provide a context for recommendations, here we summarise the key findings of the WINDHARRIER project.

Work Package 1: Hen Harrier populations

- There was a marginally statistically non-significant negative relationship between wind farm presence and Hen Harrier breeding numbers.
- Hen Harrier population trends were negatively affected by a complex interaction between wind farm developments in areas at elevations of 200-400m.

Work Package 2: Bird communities

- Bird densities were lower within 100m of wind turbines, when compared with control areas.
- Differences in bird densities (within 100m) were related to habitat changes caused by wind farm construction.
- The extent of differences in bird densities depends on the extent of areas affected by changes in habitat during wind farm construction.
- The species of birds affected by these differences will depend on which habitats are modified during wind farm construction.
- Open country bird species' densities were lower at wind farm sites. This may be due to large scale effects of wind farms, landscape differences in habitats, or differences in management practices, but further research is required to determine the cause of these patterns.

Work Package 3: Hen Harrier breeding parameters

- Hen Harrier breeding success was statistically non-significantly lower within 1000m of wind turbines.
- Results were limited by available sample size, giving cause for caution in their interpretation.
- Combined with findings from Work Package 2 and Work Package 4, it is possible that lower breeding success recorded within 1000m of wind turbines reflects a biologically relevant pattern.

Work Package 4: Hen Harrier flight behaviour

- During sky dancing displays, Hen Harriers achieved flight heights which put them at potential risk of wind turbines.
- Average flight heights of adult Hen Harriers did not change in response to wind turbine presence, although it is possible that birds altered their flight height in the proximity of individual turbines.
- Adult male Hen Harriers spent up to 12% of their flight time at wind turbine rotor sweep height.
- Newly fledged juvenile Hen Harriers had not yet moved out of the nest site area spent the majority of their time below turbine rotor sweep height.

Work Package 5: Hen Harrier foraging behaviour

- Selection of foraging habitats by Hen Harriers was different at wind farm than at control sites.
- At wind farm sites, Hen Harriers selected open habitats (rough and natural grasslands, scrub and peatland) while birds at control sites foraged preferrently over peatland and young forests.
- These differences may be due to the distribution and modification of habitats around turbines or to the effects of wind noise (natural and wind turbine induced) on Hen Harrier foraging efficiency.

8. 4. 1 Recommendations for the assessment of wind farm impacts on Hen Harriers

Potential wind farm impacts on Hen Harriers can best be assessed using 'before – after' monitoring within the areas where the development is planned. A Before-After, Control-Impact (BACI) study design provides the most robust data for the assessment of potential impacts. Assessment during development can give an indication of potential impacts caused by wind farm construction activities.

Please note that potential impacts on winter roosts are not covered in this section, as they require specific assessment and are not covered in the recommendations outlined below.

8. 4. 1. 1 Design of assessments

1. Assessments and surveys should be appropriately designed before work commences to ensure that robust, high quality data, appropriate for impact assessment is collected.
2. Assessments should be undertaken by appropriately qualified workers with proven experience in the field of raptor surveys and wind farm assessments.
3. Surveys of breeding Hen Harriers should cover the development area extending at least to a 2km radius from the boundaries defined by outermost proposed turbines planned within a single continuous wind farm. This will allow for appropriate assessment of wind farm extensions or developments adjacent to existing turbine arrays.
4. Flight activity surveys should include the development area extending at least to a 0.5km radius from the boundaries defined by outermost proposed turbines.

8. 4. 1. 2 Duration of assessment

1. Surveys running for two or more years prior to construction will allow for the detection of pairs breeding in alternate years. This will provide insight into nest site movements between years, an aspect that cannot be assessed using single year surveys but which is important for defining areas requiring protection.
2. In some instances, if reliable and comprehensive information exists on confirmed nest site locations over a period of years leading up to planning and construction, a single year survey may suffice to ensure that all breeding pairs are considered.
3. On-going surveys and monitoring of known sites during the construction phase can allow for assessment of potential impacts of construction activities.
4. The need for post-construction monitoring is site-dependent:
    a. Surveys running for two or more years prior to construction will allow for the detection of pairs breeding in alternate years. This will provide insight into nest site movements between years, an aspect that cannot be assessed using single year surveys but which is important for defining areas requiring protection.
    b. In some instances, if reliable and comprehensive information exists on confirmed nest site locations over a period of years leading up to planning and construction, a single year survey may suffice to ensure that all breeding pairs are considered.
    c. On-going surveys and monitoring of known sites during the construction phase can allow for assessment of potential impacts of construction activities.
    d. The need for post-construction monitoring is site-dependent:

8. 4. 1. 3 Survey methods

1. Survey work should be aimed at locating all territories (including breeding and non-breeding pairs) and monitoring breeding success in the survey area during each survey year.

2. Surveys of flight activity should be carried out by means of vantage point watches to assess collision risk and foraging use of the survey area. Each vantage point can be considered to provide reliable coverage of visible areas within 2km of the observer using a 180° angle of view. Selection of vantage points should ensure maximum possible coverage of the area to be surveyed (see above). Selection of vantage points can be aided with the use of viewshed analyses to formally delineate the areas visible from each vantage point. Collision risk estimates are specific to the time of year at which flight activity surveys are carried out.
    a. Flight activity surveys should be timed to ensure an accurate representation of all flight behaviours, including those which have a seasonal nature.
    b. Appropriate timing can ensure that areas used by Hen Harriers for displays and sky dancing are reliably recorded prior to construction. Multiple survey years would be valuable in accomplishing this.
    c. Accurate recording of flight height is essential to provide suitable data for collision risk assessment.
3. Habitat surveys (pre- and post-construction) allow assessment of changes in habitat caused by management and construction activities, including the loss or alteration of suitable nesting and foraging habitats.
4. There is a need for systematic carcass search studies in an Irish context, to estimate mortality rates of Hen Harriers and other bird species and bats due to turbine collisions.
    a. These carcass searches should be carried out at all existing wind farms in areas with active Hen Harrier breeding sites.
    b. Mortality rates due to collision with turbines can be expected to vary depending on turbine model, making it advisable to carry out carcass searches at a range of wind farms which represent different models.
    c. Carcass disappearance rates are likely to vary according to local predator and scavenger densities and activities. Appropriate experimental assessment of carcass disappearance rates can inform interpretation of search results.

8. 4. 2 Recommendations for the assessment of cumulative impacts on Hen Harriers

8. 4. 2. 1 Context for individual wind farm impact assessments

1. Impact assessments focused on a broad range of environmental factors (including, but not limited to, changes and effects on habitats, land use, passerine bird communities, small mammal communities, and other plant and animal species of conservation concern) provide a comprehensive understanding of the overall environmental impacts. By contrast, impact assessments that focus on a single species (such as Hen Harriers) are at risk of overlooking effects on other important ecosystem groups (e.g. Hen Harrier prey base) which may ultimately affect the focus species.
2. By taking into consideration nearby existing or planned developments, impact assessments for individual wind farms can provide an appropriate context for cumulative impact assessments. Similarly, other nearby development activities, land use changes and operations that may not be related to wind energy developments (e.g. construction, forestry, agriculture, recreation), but have the potential to affect Hen Harrier nesting and foraging habitats can also contribute to cumulative impacts and should be considered.
3. Information on regional Hen Harrier population densities and trends can also provide a useful context to determine the nature of cumulative impacts.

8. 4. 2. 2 Bird sensitivity mapping

1. Bird sensitivity maps have proven a useful tool in Scotland and other countries and are currently being prepared for Hen Harriers (and other species) in Ireland. When completed, they may provide a useful tool indicating areas likely to be of high sensitivity to wind farm developments due to potential impacts on Hen

Harrier populations (see BirdWatch Ireland Bird Sensitivity Map site for further details: www.birdwatchireland.ie/OurWork/PolicyAdvocacyanoverview/BirdSensitivityMapping/tabid/1312/Default.aspx).

2. However, such sensitivity maps should be interpreted critically, in the context of the evidence on which they are based. The existing sensitivity map for Ireland has not benefited from the outputs of this study and these should be incorporated into this process at the earliest opportunity.

8. 4. 2. 3 Population modelling

1. Population modelling studies can evaluate the cumulative impact of wind farm developments at a population scale. These studies should integrate data on Hen Harrier populations from the Republic of Ireland and Northern Ireland to examine this concept across the island of Ireland. This type of work can be facilitated by the centralisation of data collected during wind farm impact assessments (see below).

8. 4. 2. 4 Data centralisation

1. Ecological monitoring results obtained from Environmental Impact Assessments offer a powerful tool for the assessment of cumulative impacts of wind farms on Hen Harriers. Monitoring data, from baseline, construction and post-construction phases at multiple wind farms sites, if collated, provides the only opportunity for cumulative impact assessment and data centralisation is key to achieve this goal.
2. Hen Harrier data
    a. It is imperative that information collected for individual wind farm impact assessments is centralised in a single repository which should be held by an independent stakeholder.
        i. Data collected by individual assessments should be standardised and formatted to facilitate later collation of outputs and assessment of cumulative impacts (if done appropriately, this process may be automated). Alternatively, it may be possible to include inputting data directly into a centralised database as a requirement of individual impact assessments.
        ii. Information to be collated should ideally include (but should not be limited to):
            - Location of nest sites and breeding success.
            - Vantage point watch data.
            - Results from individual wind farm collision risk assessments.
            - Results from carcass searches.
    b. Information collated from wind farm impact assessments can be combined with data collected during Hen Harrier National Surveys and other relevant studies involving data collection.
3. Wind farm data
    a. Information on wind farm developments can likewise be maintained in a centralised repository (much of this information is already available at www.iwea.com/windfarmsinireland). This would aid and streamline the assessment of cumulative impacts.
    b. Standardised data for all wind farm developments should include the following:
        i. Rigorous and detailed records of wind farm construction start and end dates, and of later developments within the same wind farm.
        ii. Rigorous records on dates of wind farm activation, and of activation of turbines constructed in later developments.
        iii. Reliable information on number and model of turbines at each wind farm.
        iv. Location of each wind farm (accurate coordinates for centre point of turbine array).
        v. Location of each turbine within each wind farm (accurate coordinates). This is of particular importance for assessment of cumulative impacts.
        vi. Design modifications and / or mitigation measures carried out for Hen Harriers or other birds.

Work Package 7

9. Recommendations for mitigation

9. 1 Introduction and Work Package structure

This Work Package is structured into two sections. The first section provides an overview of current practice for mitigation of the environmental impacts of wind farm developments with particular focus on mitigation for Hen Harriers *Circus cyaneus*. The second section consists of recommendation for mitigation of the impacts of wind farm developments on Hen Harriers in the Irish context, based on the information reviewed in the first section and findings of the WINDHARRIER project. Within each section, a separate subsection is dedicated to each major topic.

9. 2 Review of mitigation measures

9. 2. 1 Wind farm siting and planning

Location and siting of wind farm developments is a prime concern of the European public, especially in relation to areas of environmental importance (Wolsink, 2007). Furthermore, poorly planned siting without proper consideration for ecological impacts has led to the construction of wind farms in Europe and the United States which have had significant impacts on raptor populations (Barrios & Rodríguez, 2004, Smallwood & Thelander, 2008, Bevanger *et al.*, 2010). These effects can be reduced with careful planning and siting of wind farm developments (Dirksen *et al.*, 1998, Hötker *et al.*, 2005). This need for reducing impacts on wild bird populations has led to the refusal of some wind farm planning applications due to potential impacts on Hen Harriers, White-tailed Sea Eagles *Haliaaetus albicilla*, Golden Plover *Pluvialis apricaria*, amongst other species (data obtained from an information request to planning officers and ecological consultants). Within specific wind farm sites, careful configuration of turbine arrays can also help to reduce impacts on wild bird populations (see below) (Drewitt & Langston, 2008).

9. 2. 2 Collision mitigation

Changes in habitat at wind farm sites can alter the use of the wind farm area by birds. Clear felling of closed canopy can make areas which were previously unattractive to Hen Harriers, suitable for foraging or nesting (Scottish Natural Heritage 2012). If these areas are in the proximity of wind turbines, they have the potential to increase risk of collisions as birds use forage or nest in them more frequently. Management aimed at short swards can maintain low prey abundances (both small mammals and open country birds) (SNH, 2012d). Managing buffer areas adjacent to the wind farm to increase their suitability for Hen Harrier foraging and nesting may also help reduce use of clear felled areas (SNH, 2012d). For details on management to increase or decrease in suitability for Hen Harriers, please see SNH (2012d), Williams *et al.* (2010) and Inis Environmental Consultants (2014).

Other practices aimed at reducing collision risk for raptor species focus on design and operation of wind turbines. There follows a list of some mitigation measures which may be applicable to Hen Harriers and Irish wind farms (Hötker *et al.*, 2005, Drewitt & Langston, 2008, Cook *et al.*, 2011, Marques *et al.*, 2014).

- Selective shutdown of turbines when sensitive species are detected in the vicinity of the wind farm.
- Restriction of turbine operation during periods of high collision risk, such as sky dancing.
- Placement of wind turbines within site to avoid high risk areas, such as association with thermals.
- Reducing rotor speed to reduce the motion smear (Hodos, 2003).

- Habitat management to reduce suitability of habitat in vicinity of the turbines and/or increase suitability of habitat away from turbines (see above).

However, in most cases, methods for reducing collision risk are not specific to breeding Hen Harriers, but to birds in migration or to raptors with different flight behaviours (such as eagles, hawks, falcons, etc.). The following is a list of some such methods (Hötker *et al.*, 2005, Drewitt & Langston, 2008, Cook *et al.*, 2011, Marques *et al.*, 2014).

- Use of real-time surveillance systems (e.g., Thermal Animal Detection Systems (Drewitt & Langston, 2008) to detect birds approaching the turbines.
- Configuration of turbine arrays parallel to, rather than perpendicular to, flight paths.
- Close spacing of turbines to create a feature that is perceived as a solid barrier (but this may conflict with mitigation to prevent displacement / barrier effects).
- Increasing turbine size and reducing turbine number, or vice versa, depending upon the risk profile of the sensitive species.
- Use of tubular rather than lattice construction for the turbine towers to avoid providing perches.
- Increasing the visibility of turbines by painting blades with coloured patterns or using UV-reflective paint (Hodos, 2003). However, there is limited evidence of effectiveness (Young *et al.*, 2003b).
- Increasing the visibility of turbines by the use of lighting.
- Reducing lighting to avoid attracting birds to the turbines.
- Use of auditory or laser deterrents to deter birds from approaching turbines.
- Use of decoy towers to cause avoidance of turbines.
- Use of conspecific models to attract birds away from turbines.

9. 2. 3 Construction mitigation

Scottish guidance on good practice during wind farm construction (Anon, 2013b)(Scottish Renewables et al. 2013) recommends the preparation of a construction method statement which should include measures to protect sensitive species. These include walkover of track routes and the locations of site infrastructure (prior to and at key stages during construction) and the requirement for a Clerk of Works to monitor and record the adherence to buffers around nest site, carry out spot checks for nesting birds and advise on mitigation measures and monitoring their effectiveness.

Mitigation measures for the protection of nesting birds usually entail the creation of buffer areas around nest sites where operations are restricted during the breeding season. In Ireland a 500m buffer zone is used in wind farm planning conditions (An Bord Pleanála, 2006, An Bord Pleanála, 2012, An Bord Pleanála, 2013). However, the Irish Forest Service (Forest Service, 2012) defines a 1.2km radius around Hen Harrier nesting areas in which forestry operations are restricted during the breeding season (the 1.2km figure is based on half the maximum separation distance of annual nest locations within territories observed in the Slieve Aughty Mountains during the 2005-2010 period, plus an additional 500m buffer). In Britain, buffer distances for forestry operations range from 500m to 1000m (Currie & Elliott, 1997, Forestry Commission Scotland, 2006). Additional to defining buffer distances, mitigation measures for nesting raptors in the United States include an adjustment factor (from application of a full buffer to none). These adjustments depend on the type of activity or disturbance (in or out of vehicle, recreational, developed recreational, industrial or transportation), the duration and frequency of the activities and the nest stage and associated risk level for birds (courtship, nesting, incubation and brooding classified as high risk; fledging and post fledging dependency classified as moderate) (Romin & Muck, 2002, Whittington & Allen, 2008).

9. 2. 4 Mitigation of displacement effects

9. 2. 4. 1 Habitat offsetting

In recent decades, management for the creation and provision of habitats has been used to offset losses caused by infrastructure and commercial development pressures (Morris *et al.*, 2006, Gibbons & Lindenmayer, 2007). However, it is important to note that offset habitats rarely achieve the ecological complexity of the natural habitats they aim to replace (Morris *et al.*, 2006). In this context, habitat offsetting should be seen as a useful management tool, but not as a perfect solution to minimise displacement effects.

A few examples exist of the use of these measures to mitigate Hen Harrier habitat loss caused by wind farm developments in Ireland (Williams *et al.*, 2010, Crushell, 2012, Inis Environmental Consultants, 2014). At a wind farm in the Mullaghareirks, trials were carried out for the effectiveness of offset Hen Harrier foraging habitat (Williams *et al.*, 2010). Clear felled areas were managed to create various habitats (uncultivated clear-felled, replanted forestry, cultivated forestry and fallowed or scrub). Monitoring revealed differences in small mammal abundances in the different habitats, but low usage by Hen Harriers was attributed to the small size of the plots (4-15 ha). At the time of writing this report, the second phase of these trials has commenced and is on-going (IWEA, pers. comm.). An impact assessment for a different wind farm in the Mullaghareirks recommends, in consultation with NPWS, the creation of offset habitats at a distance of least 350 m from turbines in a 1:1 replacement ratio (Crushell, 2012). A mitigation plan for a wind farm in the Ballyhouras includes the creation of 37 ha to offset impacts in 26 ha by wind farm development following three different management prescriptions: pre-maturity felling, favourable thinning operations and low intensity forest management to promote Hen Harrier foraging habitats (Inis Environmental Consultants, 2014). However, most of the evidence presented to support these prescriptions is mainly anecdotal and does not appear in the published literature.

9. 2. 4. 2 Predator control

As part of the mitigation plan referenced in Habitat offsetting (see above), Inis Environmental Consultants (2014) recommend control of avian predators to enhance nest success. However, there is little evidence of predation by corvids having significant effects on Hen Harrier productivity in Ireland. Research in Scotland has shown that predator control has little effect on Hen Harrier population trends. Furthermore, rates of predation of nests of ground-nesting birds are highly site-specific, and require site based evidence before it is advisable to engage in predator control programmes to avoid misallocation of resources (Bolton *et al.*, 2007, Fernández-Bellon & Donaghy, 2011).

9. 2. 4. 3 Supplementary feeding

Supplementary feeding has been investigated as an experimental technique to reduce raptor-grouse conflicts in Britain and to increase Hen Harrier productivity. It involves daily provisioning of food during breeding season, excluding incubation period, with cost per Hen Harrier nest of £840–£923 (Redpath *et al.*, 2001). Results of this practice suggest that in areas of high prey availability supplementary feeding does not affect breeding parameters (Redpath *et al.*, 2001), while in areas of low prey availability it increases breeding densities but not clutch size or hatching success (Amar & Redpath, 2002).

9. 3 Recommendations for mitigation

Scope of this study:

1. The objectives of the WINDHARRIER project were to (i) determine the nature and extent of wind energy-related impacts on Hen Harrier foraging, (ii) determine whether wind farms appear to be avoided by nesting Hen Harriers, and whether proximity to wind farms is related to Hen Harrier breeding success, (iii) evaluate the best way to assess the cumulative impact of wind turbines, either within a wind farm site or at the scale of a whole SPA, (iv) quantify any direct mortality risks posed by wind turbines for Hen Harriers, especially as related to recently fledged birds and (v) develop appropriate mitigation measures to facilitate future sustainable wind energy development.

2. It is beyond the scope of this study to assess the impact of other potential interactions between Hen Harriers and wind farm developments, such as effects of land use change and habitat availability, disturbance related to wind farm construction activities, effects on winter roosting behaviour, or other aspects not covered in the original project proposal.

3. The aim of these recommendations is to provide a framework for best practice for the assessment of these aspects based on research undertaken within the WINDHARRIER project and other information available at this time in scientific and grey literature. Aspects not covered by our study (point 2) are mentioned where relevant, but are not dealt with comprehensively.

4. These recommendations refer specifically to Hen Harriers and should not be used for the assessment of wind farm impacts on other bird species.

The mitigation of negative environmental impacts is a key component of Environmental Impact Assessment and aims to minimize impacts by avoiding, minimising, restoring or offsetting negative impacts. Mitigation is carried out on a site by site basis, though mitigation can be off-site where required. Mitigation measures that can be considered in the context of wind energy developments on Hen Harriers and their habitats include modification of turbines to reduce collision risk, appropriate siting of wind farms and habitat management.

9. 3. 1 Planning

1. Potential impacts to Hen Harrier populations can be minimised by the siting of wind farm developments away from areas used by Hen Harriers for foraging or nesting.
2. To a lesser extent, potential impacts can be reduced by designing and locating turbine arrays and wind farm infrastructures in such a way as to minimise encroachment on areas used by Hen Harriers for foraging or nesting.
3. Other wind farm infrastructures
    a. In areas of suitable Hen Harrier breeding or foraging habitat, potential impacts can be reduced by careful siting of wind farm infrastructures (e.g. tracks, buildings) and, to a lesser extent, by reducing the areas allocated to these infrastructures.

9. 3. 2 Wind farm construction

1. At development sites where surveys have located breeding Hen Harriers, potential impacts of construction can be reduced by ceasing or minimising (as agreed with NPWS) construction activities during the Hen Harrier breeding season (April – August inclusive).

9. 3. 3 Wind farm operation

1. At operational wind farms, restricting operation schedules of specific turbines during periods of increased activity (e.g. wind turbines located in the proximity of active Hen Harrier territories or areas of sky dancing and display activity), may help reduce negative effects on breeding pairs.

9. 3. 4 Habitat offsetting measures

1. There is an urgency to assess the benefits of habitat offsetting for Hen Harriers, which is being implemented at some wind farms (see below, Future research). If research indicates that these mitigation measures are effective, guidelines on best practice for providing and monitoring such habitats are required.

9. 3. 5 Hen Harrier disturbance and displacement distances

1. Flight activity
   a. Research in Britain has shown displacement of Hen Harrier flight activity by wind turbines at ranges of 250 to 500m from turbine arrays, with some studies showing little or no displacement.
   b. Further research is required on the potential effects of turbine activity on foraging efficiency of Hen Harriers (see below, future research).
2. Nesting
   a. Research in Britain has shown disturbance at Hen Harrier nests at a range of distances from 500 to 1000m from wind farm construction activities, with other studies showing little or no disturbance. Data presented in this report indicate the possible existence of decreased breeding success for nests within 1000m of turbines, although it is not possible to confirm or dismiss these effects with the currently available data sets (collation of data collected in future will help to confirm the existence and nature of such a relationship).
3. Habitats and bird communities
   a. Data presented in this report indicate that displacement of passerine species adjacent to turbines may occur as a consequence of wind farm developments. The intensity and extent of this displacement depends on the extent and location of areas affected by habitat modification as a consequence of wind farm construction activities.

9. 3. 6 Wind farm management

1. The effectiveness of guidelines and regulations can be enhanced by appropriate communication and enforcement of these by the wind energy industry and regulating bodies.
   a. Existing systems within the industry successfully achieve the goals of communicating, training and ensuring regulations are adhered to regarding issues such as health and safety. This is accomplished through on- and off-site training, the use of posters and other promotional and educational material on sites, and good understanding of roles and responsibilities in ensuring that all people on site adhere to regulations.
   b. By placing similar emphasis to regulations regarding environmental impacts in general and minimising impacts to breeding Hen Harriers (and other relevant bird species), the effectiveness of measures recommended here can be greatly increased.
2. Environmental clerk of works
   a. The designation of an Ecological or Environmental Clerk of Works, qualified and experienced in wildlife conservation requirements and monitoring and recording, can provide on-site expert advice and monitoring compliance during the construction period.

9. 3. 7 Mitigation of cumulative impacts

1. For mitigation measures to be effective, these need to be framed within regional and nation-wide programmes that address cumulative impacts on Hen Harrier populations, rather than focusing on individual wind farms.
2. This can be facilitated by using a co-ordinated approach to assess cumulative impacts which involves standardised protocols and collation of data (see above).

9. 3. 8 Future research

1. Breeding success and wind farms
    a. In this study, the main constraint on definitively assessing the relationship between Hen Harrier breeding success and wind farms was the size of datasets available for this analysis. Continued and enhanced collation of Hen Harrier breeding data, from national surveys, scientific research projects and assessments for proposed and existing developments, will strengthen the available datasets with which to assess this relationship.
2. Collision risk assessment
    a. Further research is required on avoidance behaviour, as improved understanding of the occurrence and effectiveness of avoidance will increase the accuracy of estimates of collision risk.
    b. GPS technologies can provide substantial improvement on the quality of data used for these assessments and thus increase their accuracy.
3. Turbine effects on foraging activities
    a. Further research is needed to understand the potential effects of turbine operations on Hen Harrier foraging, particularly through disruption of auditory cues used by hunting Hen Harriers.
    b. GPS technologies can provide substantial improvement on the quality of data used for assessing foraging behaviour in relation to wind turbines and the selection of foraging habitats.
4. Habitat management around turbines
    a. Research is required to determine the effectiveness of managing habitat in buffer zones around wind turbines to reduce the use of these areas by Hen Harriers and other raptors to reduce collision risk. Where wind turbines are located in habitat suitable for foraging or nesting Hen Harriers, assessment of the impacts of modifying these habitats to make them unsuitable is required.
5. Habitat offsetting measures
    a. Habitat offsetting measures being implemented in some Irish wind farms may provide Hen Harrier foraging habitats at sites where natural habitats are affected by a planned development. However, systematic studies are required to assess the effectiveness of these measures to inform best practice and to determine whether this form of mitigation is reasonable to incorporate.
    b. Habitat offsetting should not be used as a resort to allow modification of existing suitable habitats, as research has shown that these habitats rarely achieve the ecological complexity of natural habitats.

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Appendix

Collision risk calculations

Flight distances to times
Flight distances at risk for both estimates were converted from distances (m) to duration (s) by dividing the flight length by an assumed flight speed of 12 m s^{-1} (SNH, 2014b).

Survey effort
Survey effort was used to weight the data from different vantage points because, assuming equal activity, recorded activity should increase with survey effort. Survey effort takes into account the area watched and the duration of the watch and is specified in ha·hr (hectares watched x hours watched).

Daylight hours
Collision calculations need an estimate of the number of daylight hours during which birds could be flying. The studied wind farm has 4,466 daylight hours (calculated using Forsythe *et al.*, 1995). For the purposes of this assessment it was assumed that the Hen Harrier breeding season lasted from March 16th to August 15th (survey data covered the period April 29th to August 10th), when there were 2,265 hours of daylight.

Turbine characteristics
Turbines at the studied wind farm had a 90m diameter with a maximum chord width of 3.5m, a 10 degree rotor pitch and 3.3 second rotation period (18.2 rpm). It is assumed that the turbines operate for 85% of day light hours. The remaining 15% of time represents period of unsuitable wind speeds and turbine maintenance.

Hen Harrier characteristics
Hen harriers were assumed to fly at 12 m s^{-1} with a wing span of 1.0m and a 0.48m body length (SNH, 2014b)

Wind farm characteristics
The wind farm has 15 turbines occupying 690.48 ha, measured as the area of a 500m wide buffer constructed around the turbines. The volume of the wind farm (Vw) is its area multiplied by the turbine diameter (90m assumed). The calculated value for Vw is 621,432,000m^3. The volume of the turbines (Vr) is the number of turbines multiplied by the rotor area and the turbine depth + the length of the hen harrier: 15 x $\pi 45^2$x(3.5+0.48) = 379,795m^3. The ratio of the turbine volume to the wind farm volume (Vr/Vw) is 0.0006112.

Collision probability
The probability that a transit through a turbine results in a collision was estimated using the standard SNH Band model (SNH, 2000, Band *et al.*, 2007) and the spreadsheet provided by Scottish Natural Heritage (SNH, 2000) Hen harriers were assumed to be using a flapping flight. The probability of a collision for birds in transit through a turbine was estimated as 8.59%.

Calculations
The different variables detailed previously are used to estimate collision risk through the following steps:

1. Weighted flight times = Flight time at risk * survey effort
2. Mean harrier activity = wind farm area * weighted flight times
3. Wind farm occupancy by harriers = mean activity * day light hours
4. Rotor occupancy by harriers = wind farm occupancy by harriers * Vr/Vw
5. Transit time = (blade depth + bird length) / flight speed
6. Number of transits = rotor occupancy by harriers / transit time
7. Collisions = number of transits * collision probability
8. Application of avoidance rate of 99%
9. Application of turbine downtime of 15%