PLANFORBIO

Planning and management tools for biodiversity in a range of Irish forests

Optimum scenarios for Hen Harrier conservation in Ireland

HENHARRIER

FINAL REPORT

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By

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Executive Summary

Though widely distributed across the island of Ireland, Hen Harriers (*Circus cyaneus*) are relatively rare with a current estimated breeding population of just 128-172 pairs in the Republic of Ireland, and 63 territorial pairs in Northern Ireland. Hen Harriers have declined in range and population over the past 200 years, and the breeding population is now concentrated in the south and west of Ireland, particularly in the counties of Cork, Limerick and Kerry. Despite some, more recent, population increases, this species remains vulnerable and is listed as a species of conservation concern on Annex 1 of the European Union Birds Directive. This Directive requires that Ireland takes measures to ensure the persistence of Hen Harriers through designation of Special Protection Areas (SPAs), within which appropriate steps must be taken to provide and maintain suitable habitat for Hen Harriers. There are six designated Hen Harrier SPAs in Ireland at present, all of which all include suitable Hen Harrier breeding habitat such as heaths and bogs, rough grassland and conifer plantations. These SPAs must be managed in order to ensure the provision of suitable habitat in the face of future developments and land use change. The aim of the present study was to increase our knowledge of Hen Harrier breeding biology and habitat requirements to inform conservation management of this species in Ireland. During five breeding seasons from 2007 to 2011 detailed data was collected on Hen Harrier ecology in four study areas in Ireland using a range of appropriate methodologies including direct observations, nest cameras, GPS tags, pellet analysis and wing-tagging of juveniles.

In order to meet our obligations to Hen Harriers under the EU Birds Directive it is essential that we are able to monitor land use change over time and to predict the impact of proposed land use change on Hen Harriers. To this end we created a customised GIS habitat database for Hen Harrier SPAs in Ireland to facilitate analysis of the degree to which land use change may affect Hen Harrier breeding success. This database will require updating to take account of future changes in the landscape within SPAs, but provides a framework and reference point against which such updating, and future monitoring can take place.

Habitat change is the biggest single factor implicated in biodiversity loss today and is of critical importance to Hen Harriers, which are traditionally birds of open heathers and moors and depend on open habitat for foraging. The GIS habitat database that was created during this project was used to investigate Hen Harrier nesting habitat preferences and the influence of habitat composition at the landscape scale on nest-site selection. We also investigated whether changes in the numbers of breeding Hen Harriers between the 2000 and 2005 National Surveys in Ireland were in any way related to nesting habitat, and whether there was evidence of Hen Harrier nesting distribution being restricted by cover of unsuitable habitat for nesting and foraging. The main nesting habitats selected by Hen Harriers were pre-thicket stage forests, particularly of second rotation plantations of exotic conifers. Improved grassland was strongly avoided as a nesting habitat and landscapes with a high percentage cover of grassland were also avoided. There was no evidence that the area of post-closure plantations impacted negatively on Hen Harrier nest distribution. There was a positive association between changes in numbers of Hen Harrier nests between 2000 and 2005 and changes in the area of pre-thicket second rotation plantations over the same period. These findings suggest that the overall effect of plantation forests on breeding Hen Harriers in Ireland is positive, and that further agricultural intensification of grassland in areas where Hen Harriers breed is likely to have a negative impact. With an increasing proportion of afforestation taking place in grassland habitats, some of which are of low value to Hen Harriers, the influence of afforestation is likely to be increasingly a positive one.

Studies of Hen Harrier habitat use are commonly based on data collected by direct observation. This is an inefficient method for studying Hen Harriers, due to the low rate at which observations are made on this rare and wide-ranging species. Remote tracking would allow detailed information on habitat use by Hen Harriers to be collected much more efficiently but, until recently, such work has been constrained by the relatively small size of this raptor (which restricts the weight of the device that it can carry), as well as the cost of available technologies. Recent advances in remote tracking have resulted in the development of systems that are better suited to studying Hen Harriers. Following a thorough review of available technologies and published literature that considered the tag size, battery lifetime, positional accuracy, data retrieval and cost of available technologies, GPS (Global Positioning System) tags were selected for collection of foraging data from breeding adult Hen Harriers. In collaboration with Italian company TechnoSmArt, tags combining GPS units with a custom-

designed attachment mechanism (allowing the tag to fall off after data had been collected) and VHF transmitters (to enable tag retrieval) were developed. Using these tags, accurate data on habitat use by foraging Hen Harriers were collected remotely for the first time, at a much higher resolution that every before possible with this bird species, from three breeding adults in the Ballyhouras. Analysis of the GPS data shows that these birds range over greater distances than was found by researchers using VHF telemetry to study ranging behaviour of Hen Harriers in Scotland. During four days of tracking, the maximum distance from the nest travelled by a GPS-tracked female was 7.5 km and by a male was 11.4 km. Both forest and non-forest habitats were used in proportion to their availability but, within these categories, Hen Harriers showed preferences for second rotation pre-thicket forest, particularly forests between 3 and 9 years of age, and for grasslands managed at low intensity. These preferences broadly confirm the findings of previous studies on Hen Harrier foraging, but provide much more detailed information on which to base management recommendations.

The protection of Hen Harriers in Ireland through the designation of SPAs also relies on accurate information on their breeding biology and breeding in Ireland. Such information allows the development of effective conservation strategies including, but not exclusively to, those centred on habitat management. Between 2007 and 2011 a detailed study of the breeding biology of Hen Harriers in four study areas (Slieve Aughty Mountains, West Clare, Kerry and Ballyhoura Mountains) in Ireland was undertaken. The study sites in the Slieve Aughty Mountains and in Kerry are designated SPAs, while the other two study sites hold relatively dense concentrations of breeding Hen Harriers. The aim of this study was to provide an understanding of the breeding ecology of Hen Harriers in order to inform conservation and land use planning. Data were collected during the breeding season between April and August each year. Territories were located by vantage point watches, nest locations subsequently identified and nest visits undertaken to gather information on breeding biology. The number of pairs of breeding Hen Harriers detected in each of three study areas, and included in our analyses, declined over the five years of the study. Nest success and fledged brood sizes were similar across study sites and did not show consistent trends during this period, except in West Clare where success rate of nests decreased. Although the number of young fledged by successful Hen Harrier nests in this study was low, and the breeding productivity over the course of the study was low, this theoretically sufficient to allow Hen Harrier populations in these areas to remain stable, provided that juvenile survival and recruitment to the breeding population are sufficiently high. Detailed studies of juvenile Hen Harrier survival to breeding age in Ireland are therefore required to explore this further.

Hen Harriers in Ireland currently appear to have responded favourably to recent afforestation of their upland breeding areas and, over the past two centuries and more, have proven their ability to adapt successfully to anthropogenic habitat changes in the landscapes they inhabit. However, some changes to these landscapes, including upland afforestation, are a relatively recent phenomenon and this species has co-existed with forested areas for only a few decades, and it is possible that its use of such landscapes may not be optimal. We therefore examined the relationship between breeding success and breeding habitat in Ireland to provide conservation managers with up-to-date information on which to base decisions about management and land use change in areas with Hen Harriers. We tested whether nest success and brood size were related to habitat type, both at the nest site and in the surrounding landscape. Neither measure of breeding productivity was related to total forest cover or to percentage cover of closed canopy forest in the landscape. However, in a subset of areas, second rotation pre-thicket forest (young forests planted on land from which a first rotation has already been harvested) was associated with low levels of breeding success. This may be due to local factors related to predation, disturbance or prey availability. The fact that second rotation pre-thicket forest is a preferred habitat for nesting in Ireland suggests that Hen Harriers may be making suboptimal selections from the habitats available to them in the landscape. However, further long-term investigation is required to improve our understanding of this relationship, enabling more effective conservation of Hen Harriers in forested landscapes.

Hen Harriers are breeding successfully in Ireland at present and populations appear to be functioning sufficiently well at our study sites to allow them to persist in the forested landscapes that have replaced much of their traditional breeding habitat. Into the future careful targeted management is required to ensure their long-term survival and reproduction. This project provides detailed scientific data on Hen Harriers that is essential if Ireland is to meet its obligations to protect Hen Harriers and their habitats under the EU Birds Directive, which can only be achieved with the support of good policies and management practices. A number of recommendations are made, addressing different aspects of policy and practice and priorities for future research. There is scope to build on this significant body of work in the future to provide a more thorough understanding of Hen Harrier population ecology in Ireland, particularly in light of continued land use and climate change. The challenges that we face in this regard include investigations of the role of habitat quality in breeding success, the interaction between breeding and roosting populations, the fate of fledged young in Ireland and the source of our breeding population and factors of importance to Hen Harrier populations in the changing landscapes of the future.

Young Hen Harrier

Introduction

Background

Hen Harriers (*Circus cyaneus*) are medium sized, ground-nesting birds of prey that breed throughout Europe, North America and some parts of Asia, and extend their range further south in the winter to parts of North Africa, Asia and South America. Hen Harriers were once widespread throughout Ireland, but by the early 20th century their numbers had been substantially reduced by a combination of habitat loss and persecution (O'Flynn, 1983). The population increased again to an estimated 250-350 breeding pairs by the 1970s (Watson, 1977), but Hen Harriers are now a species of conservation concern in Ireland, having undergone another decline in breeding range over the past 25 years (Lynas *et al.*, 2007). Though widely distributed in Ireland, these birds are relatively rare with a current estimated breeding population of just 128-172 pairs in the Republic of Ireland (Ruddock *et al.*, 2012), and 63 territorial pairs in Northern Ireland (Sim *et al.*, 2007). The breeding population is concentrated in the south and west of Ireland, particularly in counties Cork, Limerick and Kerry, which support approximately one third of the breeding Irish Hen Harrier population (Norriss *et al.*, 2002; Barton *et al.*, 2006).

Figure 1. Hen Harrier chick in its nest on the forest floor.

Hen Harriers are vulnerable throughout their European range (Burfield and von Bommel, 2004) and are protected under Annex 1 of the European Birds Directive (209/147/EC). This Directive requires that Ireland takes measures to ensure the survival and reproduction of Hen Harriers through designation of Special Protection Areas (SPAs) containing suitable habitat. Within SPAs appropriate steps must be taken to avoid habitat loss or deterioration, and to limit activities that could negatively impact on this species. EU member states are also obliged to ensure the effective protection of populations outside of these protection areas. Hen Harriers are ground nesting birds (Figure 1) that breed between April and July in upland areas and over-winter over a broader range that includes low-lying agricultural areas. They are traditionally regarded as birds of open moorland (Gibbons *et al.*, 1993), but use recently established conifer plantations for hunting and nesting during the breeding season (Madders, 2003b). However, Hen Harriers cease to use plantations after canopy closure, and though Hen Harriers do utilise young second rotation forests (Norriss *et al.*, 2002; Barton *et al.*, 2006), this behaviour has not been reported from other parts of their range (Petty and Anderson, 1986), and these forests may be of less value to Hen Harriers than in their first rotation (O'Donoghue, 2004). A recent study suggested that Hen Harriers avoid landscapes where there is less than 30% bog, heath, rough pasture and young forest (Wilson *et al.*, 2006).

There are six designated Hen Harrier Special Protection Areas in Ireland, including parts of Clare, Cork, Galway, Kerry, Laois, Limerick, Monaghan, Offaly and Tipperary (Figure 2), all holding breeding pairs of Hen Harriers. These areas are comprised principally of heaths and bogs, rough grassland and conifer plantations, which are all important breeding habitats for this bird (Redpath *et al.*, 1998; Norriss *et al.*, 2002). These SPAs must be managed so that they remain suitable for Hen Harriers, whilst also meeting the economic and societal requirements of all relevant stakeholders. Although these areas were selected because they contained suitable habitat, even in the absence of further changes in land use, forest maturation in these SPAs over the next decade will result in a substantial decrease in the proportion of suitable habitat in many of these areas (Wilson *et al.*, 2006). We therefore need to know more about the habitat requirements of Hen Harriers in Ireland to ensure that this species can be adequately provided for within the SPAs.

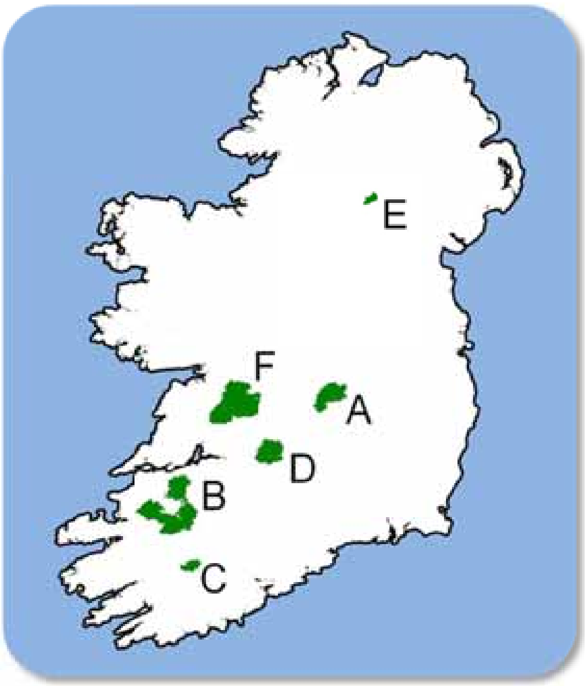

Figure 2. The six designated Special Protection Areas for Hen Harriers in Ireland (A: SPA 004160, B: SPA 004161, C: SPA 004162, D: SPA 004165, E: SPA 004167, F: SPA 004168).

Information on both breeding biology and breeding performance, together with an understanding of the factors that limit distribution, are essential in identifying effective planning and conservation measures for bird species. This is particularly relevant in light of the expected sensitivity of Hen Harriers to forestry and wind energy developments (Madders and Whitfield, 2006; Bright *et al.*, 2008; Pearce-Higgins *et al.*, 2009). Detailed studies of foraging behaviour and breeding success of Hen Harriers will enable detailed comparisons between habitats to better understand the within-habitat variation that determines the value of land to breeding and foraging Hen Harriers. The 30% threshold of suitable habitat cover estimated by Wilson *et al.* (2006) is only an approximation of Hen Harrier habitat requirements, and makes no distinction between habitat types that may differ from one another in their value to this species. More detailed data are needed to inform decisions about whether or not land use changes in the SPAs are likely to affect their carrying capacity for Hen Harriers in the long term. Land managers need to be able to assess land use changes in the context of current land cover, and also to be able to predict how maturation of existing plantations will impact on suitability of landscapes for Hen Harriers in the future.

The vulnerability of Hen Harrier populations in Ireland and the UK has prompted many studies on this species resulting in a body of work on the possible causes and mechanisms for their decline, as well as potential conservation management strategies for this species. National Hen Harrier surveys are now conducted at intervals of five years in the UK, Isle of Man and Ireland to monitor Hen Harrier populations (Sim *et al.*, 2007; Ruddock *et al.*, 2012). Until recently, little work had been carried out on Irish Hen Harrier populations, but work in Scotland, England, Wales and the Isle of Man has provided information on Hen Harrier breeding biology (Picozzi, 1984; Etheridge *et al.*, 1997; Meek *et al.*, 1998; Green and Etheridge, 1999; Amar *et al.*, 2007b) and population ecology (Meek *et al.*, 1998; Amar *et al.*, 2003; Amar *et al.*, 2005; Amar and Redpath, 2005; Whitfield *et al.*, 2008).

Evidence-based information, vital for conservation management, has been collected on the effects of land use change on Hen Harrier populations (Amar and Redpath, 2005), in particular agricultural intensification (Pain et al., 1997) and managed grouse (*Lagopus lagopus*) moors (Green and Etheridge, 1999; Redpath et al., 2002a) in parts of Scotland and the Isle of Man. Persecution associated with managed moorlands is significant in parts of Scotland (Etheridge *et al.*, 1997), but does not impact Irish Hen Harrier populations to the same extent. The role of food availability in the success of Hen Harrier populations has received much attention as a potential mechanism for the decline associated with land use change (Picozzi, 1980; Amar *et al.*, 2003; Amar *et al.*, 2005). Recognition of the importance of habitat management in the conservation of Hen Harrier populations has led to a body of work on their habitat requirements, which differ between regions (Madders, 2000; Arroyo *et al.*, 2009) and the relationship between habitat and breeding success (Amar *et al.*, 2007b; Amar *et al.*, 2007a). Hen Harriers are vulnerable to human interference and land use change and, in this context, the effects of climate (Redpath *et al.*, 2002b; Whitfield *et al.*, 2008) and developments in the wind energy industry are receiving increasing attention (Bright *et al.*, 2008). Similar research on conservation management of Hen Harriers in Ireland is essential to allow us to deliver effective conservation management plans for this species as required by the European Union Birds Directive.

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

- Increase our knowledge of Hen Harrier ecology and foraging behaviour.
- Determine the value to Hen Harriers of the main habitats in the SPAs.
- Improve our understanding of Hen Harrier habitat requirements at the landscape level, and revise recommendations accordingly, incorporating these into an Indicative Strategy for Hen Harrier management in the SPAs.
- Compile a GIS database of land use and habitat types within the SPAs, to function both as a tool for decision-making by SPA managers and stakeholders, and as a source of data for researchers.

Project Structure

This project was funded by COFORD for a period of 5 years from 2007 to 2012 as part of the PLANFORBIO Research Programme. Additional financial support was provided each year by National Parks & Wildlife Service (NPWS) to increase manpower available for data collection during the breeding season. In addition Barry O'Donoghue, NPWS staff member, completed his PhD as part of this project, and was granted time during the breeding seasons of 2007 and 2008 to conduct fieldwork. Data and expertise were provided to this project by the Irish Raptor Study Group (IRSG). The research was divided into a number of Work Packages, each of which addressed a specific aim of the project as shown in Figure 3.

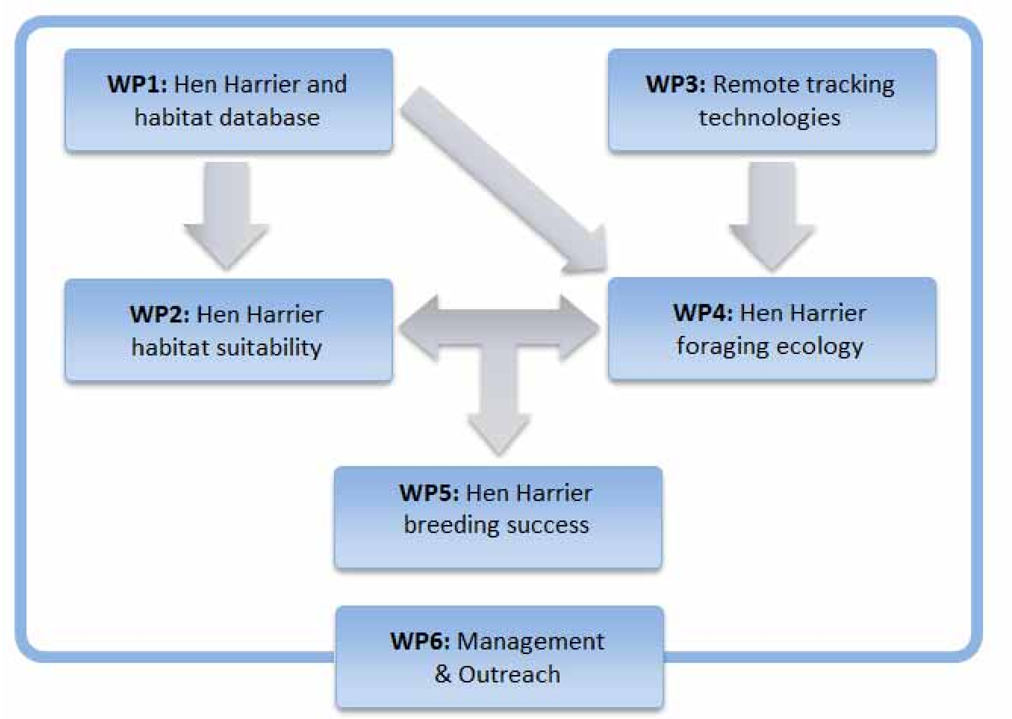

Figure 3. HENHARRIER project design.

Work Package 1

Create Hen Harrier and habitat databases for SPAs

Background

The EU Birds Directive (2009/147/EC), which provides protection for all wild bird species naturally occurring in the European Union, recognises that habitat loss and degradation are the most serious threats to the conservation of wild birds. It therefore protects habitats for endangered species listed in Annex 1, including Hen Harriers, in order to ensure their survival and reproduction (Donald *et al.*, 2007). The primary instrument used by this directive for bird conservation involves the establishment of Special Protection Areas (SPAs) which require forests, and other habitats and land uses, to be managed in a way that ensures their suitability for protected species.

In compliance with these regulations Ireland has designated six sites that provide suitable Hen Harrier breeding habitat as SPAs in Ireland (Wilson *et al.*, 2010). These include habitats such as heaths and bogs, rough grassland and conifer plantations (Norriss *et al.*, 2002; Barton *et al.*, 2006). In order to monitor the suitability of habitats for Hen Harriers it is necessary to monitor land use change over time, and to be able to predict the impact of proposed land use change on Hen Harriers.

The aim of this Work Package was to create a customised GIS habitat database for Hen Harrier SPAs to facilitate analyses of the degree to which agricultural improvement, grazing levels and cover of many different vegetation categories, including forests, affect parameters associated with Hen Harrier breeding success. The information in this database is of critical importance to the analyses undertaken in Work Packages 2, 4 and 5 of this project. Forestry proposals in Hen Harrier SPAs are currently evaluated on a first-come, first-served basis, with no proposals being accepted on peatland habitats, and an annual quota set on total area within the boundaries of each SPA. As well as providing baseline habitat data for Hen Harrier SPAs, this database may also be used by managers and legislators to inform forestry policy and strategic planning in the SPAs.

Methodology

The Geodatabase appended to this work package contains all the main datasets that contributed to the habitat-based analyses in this project. These were:

1. **FIPS (Forest Inventory and Planning System)**: this dataset contains detailed information on planting date and tree species composition for forests planted with recent grant-aid (from 1988 onwards), and broader information about forest age and type for forests established before this time.
2. **Coillte inventory**: this comprises detailed information about planting year and tree species composition for each sub-compartment (i.e. stand) in Coillte-owned plantation forests.
3. **NPWS SPA habitat data**: this dataset was compiled in 2006 for the purposes of delineating the boundaries of Hen Harrier SPAs according to presence of suitable habitats for Hen Harriers (Rough Grassland, Forest, and Heath/Bog).
4. **Landcover data:** these data were compiled by Teagasc for the Forest Service in 1997, and based principally on broad vegetation and landcover types identified from aerial photos and satellite imagery. It is probably the best classification of non-forest habitats available for the entire country, being higher resolution than the CORINE datasets, and utilising a land use classification much better suited to Ireland.

Each habitat analysis requires a different combination of information from the above datasets, depending on the areas and period of time under consideration, and the categories of habitat for which data is to be extracted. Figure 4 summarises the process by which information derived from these spatial datasets were combined and examined during GIS analyses of habitat.

Firstly, the parent datasets were updated with the most recent data available. Afforestation data in FIPS can be updated on a near-annual basis using planting grant information, while felling data updates to the Coillte inventory can be derived from felling management plans, as well as from updates to the Coillte inventory itself. Information in the attribute tables of these datasets were queried and applied to identify the polygons representing habitats of interest. All information for private forests (including all newly planted forests in their first rotation) was taken from FIPS. Information from state-owned forests (including the majority of recently felled forests and young 'restock' in its second commercial rotation) was taken from the Coillte database. Information on non-forest habitats within the boundaries of SPAs (and areas previously under consideration as proposed SPAs) was taken from the NPWS SPA habitat dataset. Non-forest habitat data for other areas were based on the landcover dataset. Once the relevant polygons in each of these datasets were identified, they were used to clip one another (so that polygons representing different habitats did not overlap with one another) in the following order of priority: young forests > closed canopy forests > non-forest habitats. The clipped sets of polygons were then merged (using the GIS function Union) to form a single shapefile or layer.

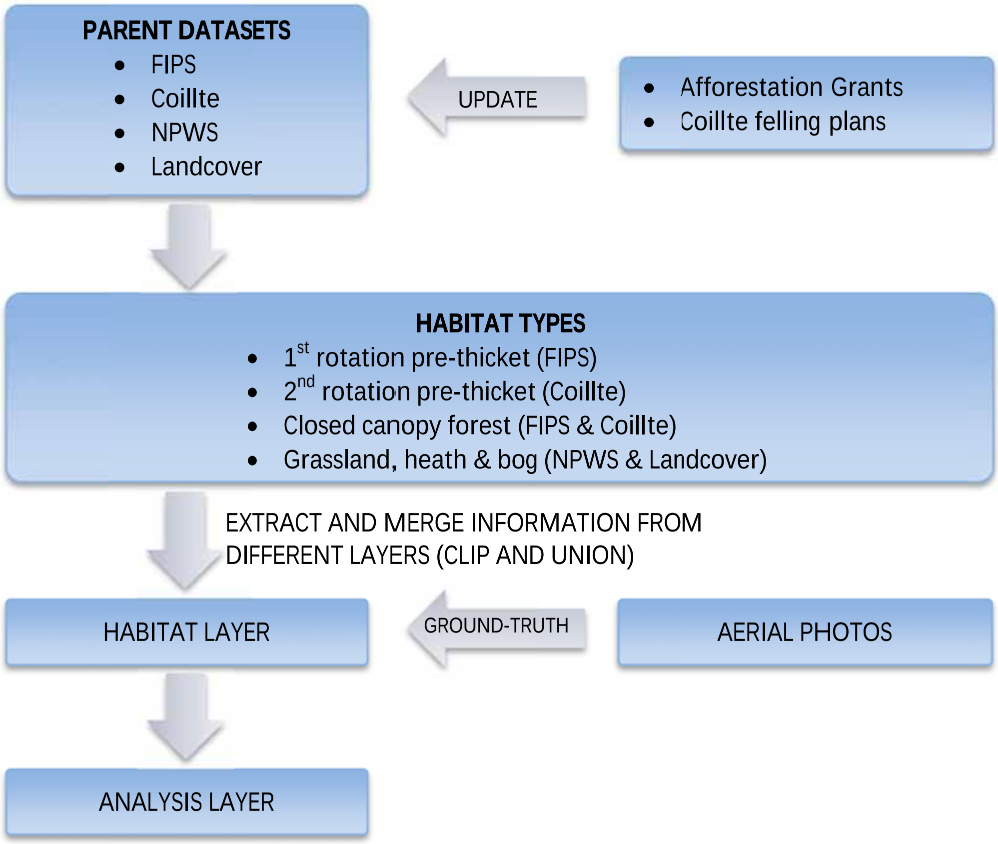

Figure 4. Flow diagram showing the process of GIS dataset preparation for analysis.

The information in this layer was checked to make sure it is up to date – particularly with regard to transition between blocks of closed canopy forest and younger 'pre-thicket' growth stages. Collection of habitat data in the field can provide high quality and up to date information on the habitats of interest, but is time and labour intensive. Where aerial photographs were available, checks were made against these, with additional field-based ground-truthing to check that habitats are being correctly classified from photos. Currently, the most recent set of aerial photographs for which there is near-complete coverage of the whole country was flown in 2004/2005, but more recent photographs (from 2006 to 2010) are available for some parts of the country through the Google Maps website.

The pre-processed habitats and landcover datasets were incorporated into the HENHARRIER Geodatabase which accompanies this report (Scarrott, 2012) using ArcInfo 10.0. It contains 8 HENHARRIER Geodatabase Feature Class datasets, 8 Raster datasets, and 2 Geodatabase table datasets. Wherever possible, metadata compliant to ISO19115 standards (advocated under the EU INSPIRE Directive 2007/2/EC) was added to spatial datasets before they were incorporated into the Geodatabase. Note that complete metadata compilation was not possible for the landcover datasets, as the required information was not available. However, contact details for the authors of these data have been provided, so that users of this database that require more detail regarding the compilation and interpretation of these data can contact them directly. Also of interest is that each dataset has a completion date assigned to it in the metadata. This allows for the datasets to form the basis for on-going habitat monitoring to be established with future updates and new habitats datasets collected at a later date.

Information on all Hen Harriers ringed and/or wing-tagged and the Hen Harrier nests located during the project (2007-2011) was also entered into the Geodatabase, accompanied by ISO19115-compliant metadata. Ringing and wing-tagging details include the codes and colours or wing-tags, the ring number, gender, and several biometric measurements such as weight, wing length and tarsus width. Details of nests included the position of the nest, the number of eggs and/or chicks found in the nest, whether it was successful or not, and the number of chicks estimated to have fledged from the nest. Finally, GPS tracks of three adult breeding Hen Harriers fitted with GPS tags during 2010 and 2011 was added to the database. To aid interpretation, consideration, and interpretation of the data collected during the HENHARRIER project, an ArcMap 10.0 visualization document accompanies the Geodatabase. Note that four baseline datasets were created and added specifically for visualisation purposes only. These supporting data give visually interpretive information on relief derived from NASA's SRTM mission, and land administration boundaries derived from Central Statistics Office data. The metadata accompanying these datasets are also fully ISO19115-compliant.

The ArcMap visualisation document has been specifically designed to encourage the user to explore datasets held in the Geodatabase. It allows access, visualisation and further analysis of the spatial data component within the HENHARRIER project. It also allows for further integration of these data into the overall PLANFORBIO database, with the additional capacity to be updated with future research records if required. More extensive information on the datasets held in the Geodatabase, and visualized in the GIS can be found in the HENHARRIER GIS User Manual, provided on the HENHARRIER-GIS CD accompanying this report. Also note that the visualisation document is available on the accompanying CD as an ArcMap Document for licensed users of ArcGIS software, and also as a less functional, though useful ArcReader document for un-licensed users of ArcGIS.

Results

The land use and habitat datasets included in the database accurately reflected land use composition for the period close in time to when the relevant datasets were assembled. For the majority of the data, this was around 2006, so assembling data on habitat relating to nests and study areas at the start of the project was quite straightforward. However, even at the outset of the study, some discrepancies between the information in these datasets and habitat on the ground were apparent, due to inaccurate classifications, or to recent changes in land use.

Figure 5 shows how the information from these different datasets was assembled and categorized for an analysis, and the typical level of correction to these data resulting from field-based ground-truthing and comparison with aerial photographs.

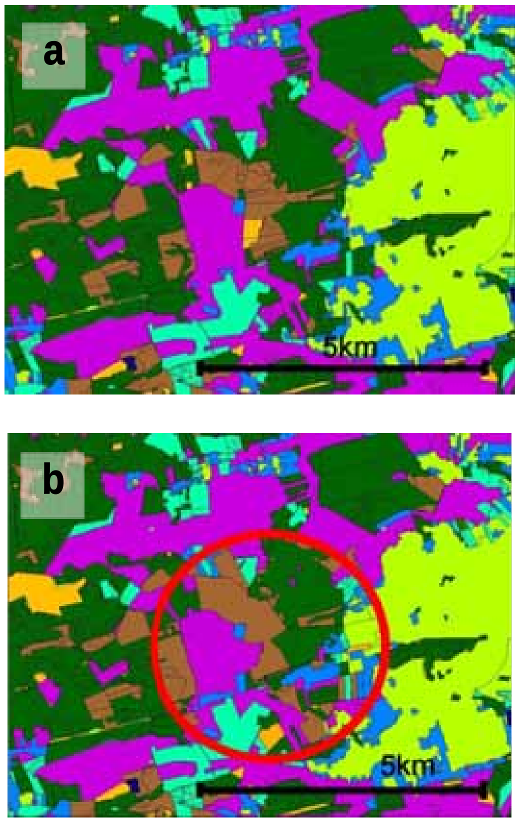

Figure 5. Screenshots showing a. Layered habitat information from the different datasets, prioritized as described in the text and showing 2007 habitat categories, and b. The same composite image, but with a 2-km radius section corrected according to ground-truthing and analysis of aerial photos. Habitats are coded as follows: dark green = closed canopy forest, turquoise = 1st rotation pre-thicket, brown = 2nd rotation pre-thicket, purple = heath & bog, blue = rough grassland, light green = agriculturally improved grassland, orange = other habitats.

Analyses of habitat pertaining to nests and bird movements studied later in the project required more extensive correction of these datasets, either using updates from the providers of the datasets (readily available for the forest datasets, but not for the data relating to the non-forest habitats), or recently flown, high-resolution aerial photos viewable in Google Maps. For some limited areas around nests for which such sources of information were either not available or were deemed to be inaccurate, extensive ground-truthing in the field was carried out. Hen Harrier ringing/tagging and nest information can be displayed at two spatial scales, each appropriate to the intended audience. The full version of the database, whose circulation will be limited to people and organizations who have been approved access to nest locations, will show precise positions for these data. However, because data on breeding Hen Harriers are deemed to be sensitive, due to the species being protected and potentially vulnerable to disturbance, a restricted version of the database will be made available to the general public, in which the same information will be shown at the spatial scale of the study site. The information held in the database can be subjected to further analysis, interpretation, consideration, and exploration using the HENHARRIER GIS. Some examples of these possibilities are illustrated in the figures below.

Figure 6. Extracting information about a tagged Hen Harrier using the HENHARRIER-GIS.

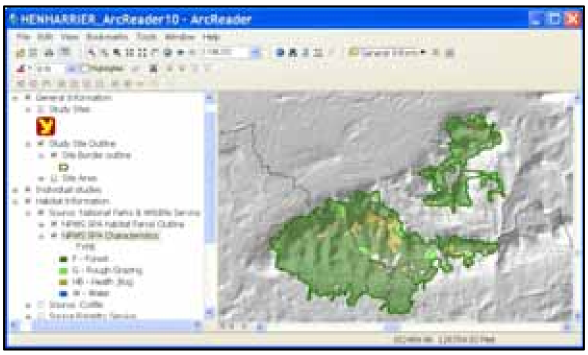

Figure 7. Visualising NPWS habitats and terrain using the HENHARRIER-GIS.

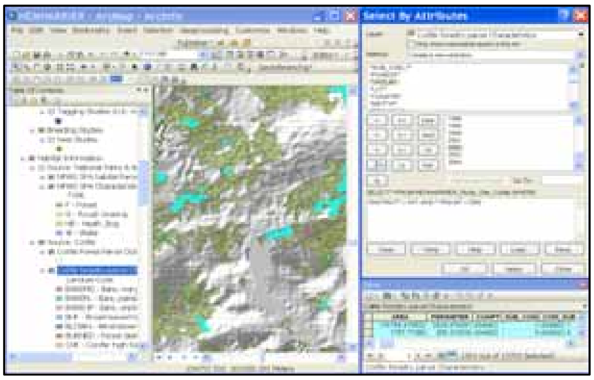

Figure 8. Exploring Coillte habitats parcels using the HENHARRIER-GIS.

Figure 9. Clarifying the "Who, What, Where, Why and How?" about a GPS tracking dataset using its ISO19115-compliant Metadata.

Discussion

The datasets contained in the Geodatabase provide a reference point against which future changes in habitat and land use in Ireland can be monitored. Changes in land use, and in the nature and value to Hen Harriers of habitats, have been part and parcel of the upland landscapes in which Hen Harriers have lived for millennia. It is worth bearing in mind that the vast majority of landscapes and habitats occupied by Hen Harriers today are the products of extensive alteration and continuous management by humans. The persistence of Hen Harriers in upland areas is testament to the adaptability of this species to such change. However, the rate at which changes are now taking place in many upland areas, and the socio-economic pressures that drive them, make it vital to periodically take stock of habitats in Hen Harrier areas, and to try to relate habitat changes to changes in occupancy, abundance and measures of breeding success. The Geodatabase produced here provides a store of the most useful habitats datasets identified, accompanied by information of their sources, and who to contact when updates are required.

Together, the datasets in this database provide effective coverage of all forest and non-forest habitats utilised by Hen Harriers in this study. However, they will need to be kept up-to-date for them to continue to be useful for analysis of Hen Harrier habitat requirements. This is particularly the case for datasets pertaining to commercially managed plantation forests, because the cyclical activities of felling, re-planting and tree growth that characterise this land use mean that inconsistencies between forest datasets and the land they represent accumulate rapidly after this information has been collected.

Unlike afforestation, felling and replanting are not grant-aided, and though the former takes place under license from the Forest Service, neither of these activities is formally recorded by the Irish State. Currently, the vast majority of felling and replanting happens in Coillte forests and is recorded in the Coillte inventory. However, there is a substantial lag between occurrence of these activities and their logging in the database. Coillte have 10-year felling plans outlining the forests they intend to fell and replant, but these plans are subject to change in response to factors such as licensing, market demand for timber, and the situations of contractors who fell, transport and process the timber. At the time of writing this report, many forests felled after 2007 have still not been recorded as felled and replanted in the Coillte inventory. Moreover, an increasing proportion of felling in the future will comprise privately planted forests, for which felling is not formally recorded in any national dataset.

Though non-forest habitats are generally more stable over time than forests, land use change does take place in open habitats. Large-scale changes in uplands relevant to Hen Harriers arise from afforestation, agricultural intensification and farmland abandonment. However, this classification is increasingly out of date, and requires re-evaluation and updating in many areas to take account of recent land use changes. Because virtually all new plantings are grant-aided, information on afforestation is effectively captured by the Forest Service in FIPS. This dataset is formally updated every 5-10 years, but informal updates based on approved planting grants can be obtained from the Forest Service on a near-annual basis. Although not as accurate as the formal updates these provide useful information on afforestation. Changes in agricultural management are not so effectively captured. The data on non-forest habitats included in this database derives from one-off surveys that, at least so far, have not been repeated or updated. Over time, these data will therefore become increasingly divergent from the habitats they represent, requiring an increasing amount of ground-truthing before they are used in analyses.

Recommendation 1: Felling and replanting are not currently grant-aided in Ireland, and though the former takes place under license from the Forest Service, neither of these activities is formally recorded by the Irish State. All felling and replanting in Ireland should be formally recorded within 6 months in a national GIS database. This might be achieved by increasing the frequency of FIPS updates, and broadening their remit to include establishment of second rotation forests as well as new plantings.

More regular updating of the habitat datasets included in this database would have clear benefits for future analyses of Hen Harrier habitat requirements, as well as for many other ecological and biodiversity studies. Two actions that would be particularly helpful in this regard are an update to the landcover dataset, and a broadening of FIPS updates to include restocked forest as well as new plantings. The landcover data was compiled 15 years ago, providing information on non-forest habitats at a higher resolution than is available from any other source with national coverage. However, its value relative to coarser datasets such as CORINE continues to be diminished by the changes to habitats which have occurred since the land use dataset was created. These data were originally created by combining automated interpretation of imagery derived from remote-sensing data with field and lab based ground-truthing. If this process could be further automated, this dataset could be updated whenever new remote imaging became available, allowing the dataset to be kept more up to date than has previously been possible. Broadening FIPS updates to include second (and subsequent) rotation plantings would provide a useful source of information against which to check and verify information in Coillte felling plans. More importantly, it would ensure that forest habitat changes relating to harvesting and replanting of private forests are captured consistently on a national scale. Without taking account of such changes, forest inventory information available for ROI will become increasingly difficult to interpret, and less useful for monitoring Hen Harrier habitats.

Recommendation 2: The quality and frequency of updating of data on non-forest habitats is in even greater need of improvement. Two actions that would be helpful in this regard would be to establish a system whereby landcover data can be updated regularly (preferably in an automated manner, using remote sensing datasets), and to explore the possibility of using CSO data on farm surveys as a proxy for land use data.

Collating the information contained in this Geodatabase and spatially analysing it using GIS allowed for a more effective analysis of Hen Harrier habitat than would be possible using any single dataset in isolation. The only datasets in this database that included information on all habitats of interest were the NPWS SPA habitat dataset and the Landcover dataset. Neither makes a distinction between first and second rotation forests, and neither has been updated since their creation. Currently, the only regularly-updated dataset that covers all the habitats of interest on a national scale is the EU habitat database, CORINE. The spatial resolution of this dataset is low compared to that of the datasets used in this analysis, and the relevance of some habitat classifications (particularly agricultural habitats) to Ireland is also low. Added to this, the fact that CORINE is only updated once every 5-10 years means that changes relating to forest felling and replanting, which are among the land use changes of greatest relevance to Hen Harriers, may be incorrectly represented. By combining the information from several datasets, as described above, we were able to assess Hen Harriers nesting habitat preferences in relation to habitat availability (Work Package 5), and also examine whether variation in breeding success could be related to habitat (Work Package 2). Both of these analyses were conducted at the level of the nest site and also at the scale of the wider landscape. Based on the outcome of these analyses, we were also able to use these datasets to zone study areas according to their suitability for afforestation (Work Package 2).

Recommendation 3: In addition to developing a land cover dataset for Ireland, we recommend a study aimed at calibrating CORINE data to facilitate its use in studies of birds in Ireland, possibly using data from the CBS (Countryside Bird Survey).

Provision of the spatial datasets in a Geodatabase, accompanied by a visualisation tool, allows for further future exploration and use of the collated datasets. Such investigations could take the form of comparisons with new datasets, or updated habitat and landcover information, or exploring the links between habitat structure, species abundance, habitat quality, behaviour of individuals, and other variables of interest. This work would be complemented by investigations of the socioeconomic impacts of habitat management for Hen Harrier conservation. With relevant, complete metadata, the clarifications on who one needs to contact regarding the data, and the restrictions on data access and use which apply (particularly relevant to species listed on Annex 1 of the EU Birds Directive) are clearly and unambiguously stated. This can aid more rigorous compliance in terms of data-sharing and usage to the ideals envisioned in EU Directives such as 92/43/EEC (Habitats) and 2009/147/EC (Birds).

Recommendation 4: Hen Harrier conservation would benefit from a socioeconomic study of the benefits of complying with EU regulations to ensure that land uses are compatible with Hen Harrier conservation.

Work Package 2

Model Hen Harrier habitat suitability

Background

Habitat change is the single most important factor implicated in the declines of threatened and endangered bird species (BirdLife International, 2000). Many species are unable to persist in the face of habitat changes (Cerezo *et al.*, 2010; Biamonte *et al.*, 2011; Clavel *et al.*, 2011), and even where species appear to cope with changes to the habitats they use, the habitat preferences of such species may become mismatched with the actual value of habitats available to them. This situation has been described as an 'ecological trap' by Gates and Gyssell (1978). One of the most profound and widespread habitat changes in recent times has been between forests and open habitats. Deforestation is of particular conservation concern in a global context (Buchanan *et al.*, 2009; Loiselle *et al.*, 2010; Sodhi *et al.*, 2010), but the conversion of open, non-forested habitats of high conservation value to commercial forest has also attracted considerable attention (Brambilla *et al.*, 2007; Brockerhoff *et al.*, 2008; Lantschner *et al.*, 2008). Over the past 60 years, many previously open upland areas in Ireland have been extensively afforested (Avery and Leslie, 1990; O'Leary *et al.*, 2000), with total national forest cover rising from less than 2% to over 10% during this period. Many upland birds of conservation interest, including waders, raptors and passerines, respond negatively to afforestation, (Hancock and Avery, 1998; Buchanan *et al.*, 2003; Whitfield *et al.*, 2007), but others appear to be more compatible with newly established forested landscapes.

One such species is the Hen Harrier, a species that previously bred almost exclusively in open habitats such as heather moors and extensive farmland (Watson, 1977; O'Flynn, 1983). However, now that the areas in which Irish Hen Harriers traditionally bred have been extensively afforested, they have adapted to nesting in young conifer plantations and are now frequently associated with these forests. A study of Hen Harrier nests found in Ireland during the national breeding surveys of 2000 and 2005 (Norriss *et al.*, 2002; Barton *et al.*, 2006) found that the main habitats selected for nesting by Hen Harriers were the pre-thicket stages of first and, particularly, second rotation plantations dominated by exotic conifers (Wilson *et al.*, 2009). This study also showed that landscapes with a high percentage cover of improved grassland were avoided by Hen Harriers when selecting nest sites. Restocked plantation forest has only become widely available to Hen Harriers in Ireland in recent decades, and so the preferences expressed in relation to this habitat, in terms of nest site selection, may not be entirely adaptive or translate into high breeding success.

At present, afforestation is regulated in Hen Harrier SPAs by applying an annual limit to each area, such that afforestation is allowed to continue each year up to the point that the annual limit is reached. No preference is currently given to planting in different parts of the SPAs, according to existing levels of forest cover or other habitats. However, it would be in the interests of Hen Harriers to take such factors into account, to ensure that percentage cover of neither forest nor other habitats are allowed to reach levels that are unfavourable for this species. An alternative approach to regulating land use change at the level of the whole SPA would be to divide areas with Hen Harriers into different zones, according to availability of suitable open habitats and percentage cover of forests. Different rules could then be applied to land use changes in each zone. Similar approaches have been adopted in other countries, and have widely recognised advantages in situations where there are potential conflicts between development pressures, landscape concerns, public amenity and conservation objectives (Goodstadt, 1996; Mikusinski *et al.*, 2007; Pant and Naig, 2007). This is a simple method of enabling assessment of proposed land use changes to be made in the context of surrounding land uses. It would ensure that habitat composition over large areas (but at a smaller scale, relevant to Hen Harriers) can be maintained within broad parameters that, according to the best information available, are favourable for this species.

With this in mind the data from the present study were used to investigate the relationship between nesting habitat and breeding success, using data from 140 nests collected during the first 3 years of this project (2007 – 2009). The results of this analysis were used along with other data on Hen Harriers to generate strategic zones for Hen Harrier breeding areas, according to availability of habitats in the surrounding landscape.

Methodology

Breeding success and habitat

Between 2007 and 2009 data on Hen Harrier breeding success and nesting habitat was conducted in the Ballyhoura Mountains, the Slieve Aughty Mountains, West Clare and Kerry. Together, these areas held approximately one third of the national breeding population (Barton *et al.*, 2006). Nest locations were identified by close observation of breeding pairs, and the outcome of breeding attempts monitored using data gathered during nest visits and also by remote observation of nests. Successful nests were identified by the presence of recently-fledged juveniles in the nesting area. The number of chicks fledged was estimated, either according to the number of healthy chicks present during the final nest visit or, for nests that were not visited, as the maximum number of fledged juveniles seen flying in the nesting area post-fledging.

Forested areas were assigned to three different categories – first rotation pre-thicket, second rotation pre-thicket, and other forest (mainly comprising closed canopy forest, but also including recently clearfelled areas). The two main sources were the Coillte forest inventory, and FIPS 2 (Forest Inventory and Planning System, the primary source of information for privately-owned forests). Forest habitat data was updated (Work Package 1) using information from the 10 year felling plan (2005 to 2015) and, in West Clare (where 61% of the forest area was privately owned), from examination of recent aerial photographs available on Google Maps to identify areas where recent felling had taken place. Open habitats were separated into just two categories, according to their suitability for foraging Hen Harriers: Suitable (comprising peatland heath and bog habitats, rough grassland and scrub) and Unsuitable (comprising improved grassland habitats and water). These categories were decided principally according to NPWS habitat maps of Hen Harrier proposed Special Areas of Protection (pSPAs), and the Irish Soils Land Cover dataset. Some 'ground-truthing' and comparison with aerial photographs was used to make corrections to these classifications, particularly in West Clare, which wasn't included in the NPWS habitat survey for pSPAs.

We investigated two separate measures of breeding success: nest success (whether or not any chicks fledged from a nest) and fledged brood size (number of chicks fledged from a successful nest). Two of our study sites, Kerry and West Clare, were similar to one another in terms of the levels of productivity in all three study years (see Work Package 5) and also in terms of habitat composition (Table 1), and were combined into a single 'Western' category.

Table 1. Size and proportion of land in each of six habitat categories in the four study areas.

Habitat category	Sl. Aughty Mts	Bally houras	Kerry	West Clare
Size (km^2)	674	106	292	412
1st rotation pre-thicket	0.09	0.06	0.17	0.13
2nd rotation pre-thicket	0.07	0.14	0.02	0.02
Post-closure forest	0.28	0.41	0.23	0.27
Improved grassland	0.08	0.07	0.12	0.07
Heath/bog	0.24	0.11	0.28	0.28
Rough grazing	0.20	0.10	0.17	0.18

The effects of study area, year and habitat on nest success were analysed using GLM (General Linear Modelling) in MARK 6.1 (White and Burnham, 1999) using the programme's nest survival analysis procedure (Rotella *et al.*, 2004). This takes account of the influence of nest stage at time of finding on apparent survival, calculating a daily survival rate for each nest. The explanatory variables considered for inclusion in the nest survival models were study area, year and 6 habitat variables at the landscape scale. These models were ranked according to AICc (Akaike Information Criterion corrected for small sample sizes), the top model being the one with the lowest AICc score. The strength of inference for each model depended on a) its ΔAICc score b) whether and to what extent the confidence intervals of the model parameters overlapped with zero, and c) the magnitude of the biological effects estimated by the model over the relevant conditions of interest in the study. A deviance-based r^2 value (ANODEV) was calculated for each of the top models, following White and Burnham (1999). This is a measure of the variation accounted for by each model of interest, relative to the variation accounted for by a general model containing all terms of interest. First, the residual deviance (D) was calculated for three models: the null (intercept only) model (MN), the model being tested (MT) and a general model (MG) containing all main and first-order interaction terms in the model set. ANODEV was then calculated using the formula:

$$r_{d^2} = 1 - \frac{D_{MT} - D_{MG}}{D_{MN} - D_{MG}}$$

Afforestation suitability

According to the findings of the analysis of breeding success and habitat, Hen Harrier breeding success decreases noticeably when the percentage of second rotation pre-thicket forest in the surrounding landscape is greater than 10% (Wilson *et al.*, 2009). In a forest landscape with a well-balanced age-structure, approximately one quarter of the forest estate will be in pre-thicket stage at any one time. A maximum threshold of 40% for total forest cover in the landscape would therefore ensure that the percentage of pre-thicket forest did not regularly exceed 10%. Previous work also suggests that suitable habitat cover should not be allowed to decrease below 30% in order for landscapes to remain attractive to breeding Hen Harriers (Wilson *et al.*, 2006). Given the negative relationship between second rotation pre-thicket forests and Hen Harrier breeding success (see below), this would be a prudent minimum threshold for percentage cover of suitable open habitats in areas being managed for Hen Harriers.

We made a strategic assessment of suitability for afforestation of three of our four study areas (we did not include West Clare because the NPWS habitat map that part of this assessment was based on did not cover this area). Using the Focal Statistics tool in the Neighbourhood Toolbox in ArcGIS 10, we created two raster maps of our study sites with a resolution of 100m. In one map, the value of each cell was equal to percentage cover of forest habitats within a 2 km radius. In the other, cell values were determined as the percentage cover of suitable non-forest habitats (rough pasture and heath/bog) within a 2 km radius.

These two classifications were used to derive two maps, each classifying areas within the study sites into three categories: a) < 20%, 20-40% and > 40% forest cover and b) <30%, 30 – 50% and > 50% suitable open habitat. These two maps were then combined to derive four zones of suitability for afforestation:

1. Most suitable: suitable open habitat cover > 50%, forest cover < 20%.
2. Probably suitable: suitable open habitat cover > 50% and forest cover 20-40%; or suitable open habitat cover 30-50% and forest cover < 20%.
3. Possibly suitable: suitable open habitat cover 30-50%, forest cover 20-40%.
4. Least suitable: suitable open habitat cover<30%, forest cover >40%.

Results

Breeding success and habitat

The outcomes of 178 nests from the four study areas were recorded between 2007 and 2011. Table 2 gives the AICc scores, weights, deviance and ANODEV (r_d^2) values for the 6 nest survival models that were better (i.e. had a lower AICc score) than the null model, and for the null model itself. Parameter estimates and 95% confidence limits around these parameters are presented for the parameters of each of these models in Table 3. All six models that were better than the null model included study area, strongly indicating that this variable was related to nest success (Table 2). The top model, for which r_d^2 was 0.24, also included second rotation pre-thicket forest within 2 km and the interaction between this variable and study area. Parameter estimates for this interaction term indicate that second rotation pre-thicket forest at a landscape scale was negatively related to nest success in the Slieve Aughty Mountains, but there is no evidence of a similar relationship in the Ballyhouras (Table 3). Although the parameter estimate for the interaction between second rotation pre-thicket forest and study area for West Clare suggests that the same negative relationship might apply here, the confidence intervals for this estimate overlap with zero.

Table 2. Summary properties of MARK nest survival models with AICc scores lower than the null model (details of the latter are in the bottom row of the data). The explanatory variables included in each model are listed in the Formula column as follows: Area (3 level factor coding for study area); Year (5 level factor coding for study year); habitat variables ending in "_2km" coding for the proportion of land within 2km of the nest occupied by 2nd rotation pre-thicket (2ndr), non-foraging habitat (comprising intensively managed grassland and standing water) (Unsuitable), and foraging habitat (comprising heath/bog habitats, rough grazing and water) (Suitable). Where two variables are separated by an asterisk, the interaction between these variables was included in the model. Variables separated from one another by a plus sign indicate that only the main effects were included in the model. The other columns represent K (the number of parameters in the model), AICc, AIC weight (Wt), the cumulative AIC weight (Cum.Wt), residual deviance, and the pseudo-r^2 measure r_d^2.

Formula	K	AICc	Wt	Cum.Wt	Deviance	r_d^2
~Area * 2ndr_2km	6	506.0	0.37	0.37	494.0	0.24
~Year + Area*2ndr_2km	10	506.5	0.27	0.64	486.5	0.36
~Area + Suitable_2km	4	508.9	0.08	0.72	500.9	0.14
~Area	3	510.9	0.03	0.75	504.9	0.08
~Area + Unsuitable_2km	4	511.1	0.03	0.78	503.2	0.11
~Year + Area + Suitable_2km	8	511.4	0.02	0.80	495.4	0.22
~Area + 2ndr_2km	4	512.0	0.02	0.82	504.0	0.09
~1	1	512.3	0.02	0.84	510.3	0.00

Table 3. Parameter estimates, standard errors (se) and lower and upper confidence intervals (LCI and UCI, respectively) for the top model among nest survival models. See Table 3 for an explanation of codes in the Formula column. Level 1 of the three-level factor Area (as well as level 1 of the interaction between Area and 2ndr_2km) is incorporated within the intercept, as is standard practice in GLMs. Area level1 (incorporated in the intercept) is the Slieve Aughty Mountains, Area level2 is the Ballyhouras, and Area level3 is the Western study area.

	Estimate	se	LCI	UCI
(Intercept)	5.05	0.43	4.20	5.90
Area level2	-0.65	0.62	-1.86	0.56
Area level3	-0.20	0.50	-1.18	0.79
2ndr_2km	-9.15	3.06	-15.14	-3.16
Area level2:2ndr_2km	10.07	3.40	3.41	16.74
Area level3:2ndr_2km	-0.39	7.82	-15.72	14.94

Table 4. Total area of each study site, the proportion occupied by forest, and (separately for the whole of each study site, and for the proportion of the study site not covered by forest habitats) the proportion falling into five categories with respect to suitability for afforestation: 1. suitable open habitat cover > 50% and forest cover < 20%; 2. suitable open habitat cover > 50% and forest cover 20-40%; or suitable open habitat cover 30-50% and forest cover < 20%; 3. suitable open habitat cover 30-50%, forest cover 20-40%; 4. suitable open habitat cover<30%, forest cover >40%. The last category, titled "Most suitable for afforestation", comprises the total of the first three categories.

	Sl. Aughty Mts	Ballyhouras	Kerry
TOTAL AREA (km^2)	**674**	**319**	**106**
FORESTED AREA (%)	**49**	**48**	**75**
ENTIRE STUDY SITE			
Category 1 (%)	4	0	0
Category 2 (%)	19	17	0
Category 3 (%)	12	24	1
Category 4 (%)	64	58	99
Most suitable for afforestation (%)	**36**	**42**	**1**
ONLY NON-FOREST AREAS			
Category 1 (%)	8	1	0
Category 2 (%)	30	24	0
Category 3 (%)	17	29	4
Category 4 (%)	46	46	96
Most suitable for afforestation (%)	**54**	**54**	**4**

The above conclusions are nearly identical to those of a more detailed analysis of a subset of the same breeding data (covering the period from 2007 to 2009), which included data on open as well as forested habitats. This analysis forms the basis of a paper on Hen Harrier habitat and breeding success that has been accepted for publication by the academic journal *Ibis* (Appendix 5), and a COFORD Connects note on the use of forested landscapes by Hen Harriers in Ireland (Appendix 3).

Afforestation suitability

The overall area of each study site is shown in Figure 10, and the proportion of each site within each of the four suitability categories. If afforestation of habitats suitable to Hen Harriers was limited to areas where surrounding forest cover was less than 40% and combined cover of peatlands and rough grazing was greater than 30% (categories 1 – 3 in Figure 10), then 36% of the Slieve Aughty Mountains SPA, 42% of the Kerry part of the Stacks and Mullaghreirks SPA, and only 1% of the Ballyhouras would be potentially suitable for afforestation. For the Slieve Aughty Mountains, this is the area marked in green, yellow and orange in Figure 10c. Restricting consideration only to non-forested areas (as these are the only areas that are available to be afforested), this percentage increases to 54% for the Slieve Aughty Mountains and Kerry, and 4% for the Ballyhouras. This is illustrated in Figure 10d, in which only the areas not occupied by forest (represented in dark green) are considered in calculating the proportion of land suitable for afforestation. The reason for the very low value for the Ballyhouras is that forest cover in this area is higher than in any other area, and cover of open suitable habitats is very low.

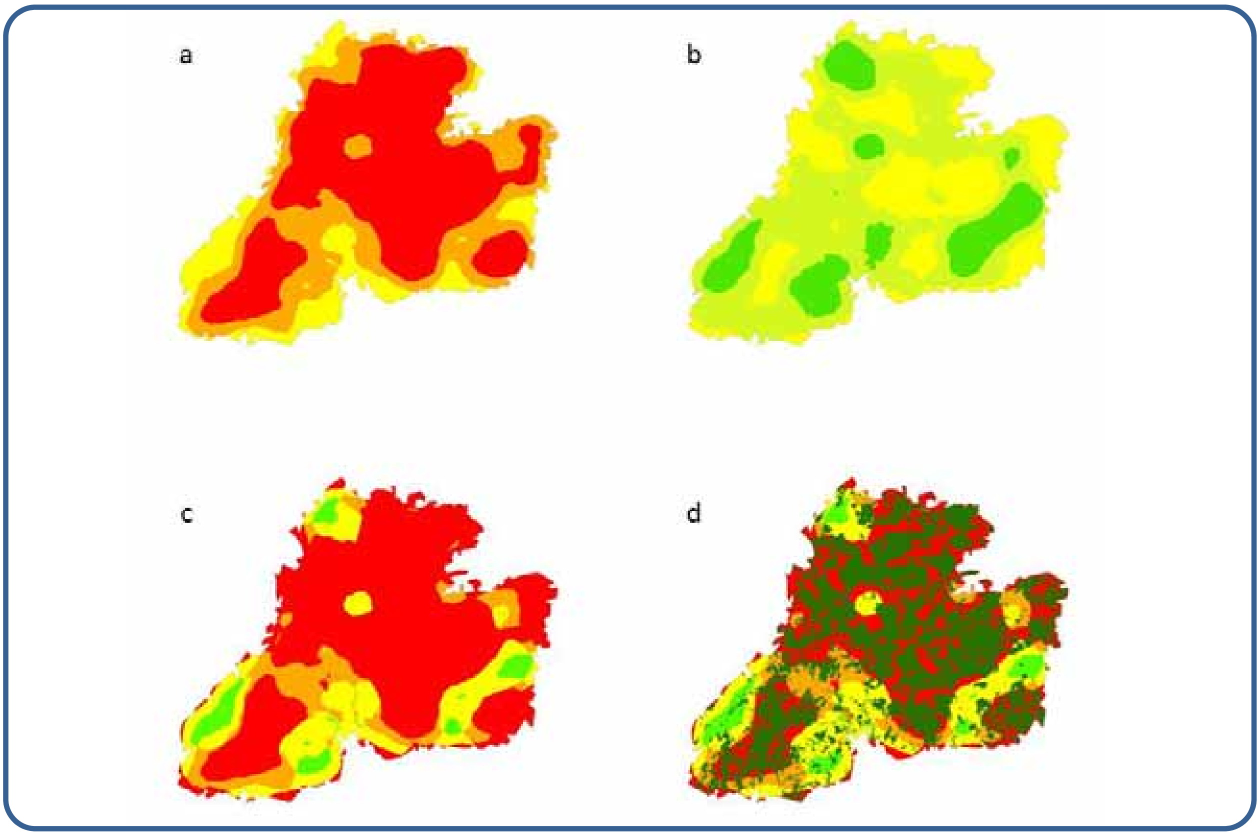

Figure 10. Maps of the Slieve Aughty Mountains Hen Harrier SPA, stratified according to a) percentage cover of forests within 2 km of each 10 x 10 metre cell (red: >40%; orange: 20% to 40%; yellow: <20%), b) availability of rough grazing and peatland habitats within 2 km of each 10 X 10 metre cell (darker green: >50%; light green: 30-50%; yellow: <30%), c) prioritisation index for afforestation (red: highest level of forest or lowest level of suitable open habitat; orange: intermediate level of both forest and open habitat; yellow: lowest level of forest or highest level of suitable open habitat (intermediate level of the other); green: lowest level of forest and highest level of suitable open habitat), and d) same as map c but with forested areas marked in dark green.

Discussion

Breeding success and habitat

The negative relationship between second rotation pre-thicket forests and Hen Harrier breeding success is notable, particularly because second rotation pre-thicket forest is a preferred habitat for nesting in Ireland (Wilson *et al.*, 2009). This suggests that Hen Harriers may be making suboptimal decisions regarding habitat selection in the landscapes available to them. Such a relationship could arise from a direct effect of second rotation pre-thicket forests on Hen Harriers. This could be the case if this habitat were associated either with unusually high abundance or activity of predators, or with unusually low abundance or availability of prey. Hen Harrier breeding success can be affected by availability of food both before and during the nest period (Amar and Redpath, 2002; Amar *et al.*, 2003; Amar *et al.*, 2005). If availability of prey was lower in pre-thicket second rotation forest than in alternative hunting habitats, Hen Harriers breeding in landscapes with a high proportion of this habitat could be disadvantaged. One way in which such an effect could come about is through the presence of brash (woody debris left after forest operations) in young second rotation forests, which might make access by harriers to prey more restricted than in other habitats. The observed area-specificity of the relationship might then be explained if the prey types available in the Slieve Aughty Mountains were better able to take advantage of the cover provided by this habitat, or if there were differences in the way this habitat was managed in this area relative to our other study areas.

Alternatively, second rotation pre-thicket forests could be associated with other landscape features or properties that have a negative impact on Hen Harrier breeding success. High levels of nest loss and predation have been associated with edge habitats (Weldon and Haddad, 2005; Hoover *et al.*, 2006; Pedersen *et al.*, 2009), and internal forest edges are likely to be more prominent in forests with high levels of second rotation pre-thicket forest. Also, the proportion of second rotation forest is highest in areas where plantation forests have been established for the greatest length of time. Such areas may support greater concentrations of nest predators such as foxes, corvids and mustelids, densities of which can be positively affected both by total area of forest and by the density of forest edge habitats (Chadwick *et al.*, 1997; Smedshaug *et al.*, 2002; Carey *et al.*, 2007). Pine Marten (*Martes martes*) is a forest mustelid that opportunistically preys on bird eggs and whose numbers have responded positively to the recent increase in Ireland's plantation forest cover. It is now most numerous in areas where suitable habitat such as conifer forest has existed for longest (National Parks and Wildlife Service, 2008). If nest success is affected by predators such as Pine Marten, this might help to explain the difference in the effect of second rotation pre-thicket forest between study areas, as the abundance of this species is probably higher in the Slieve Aughty Mountains than in our other study areas (O'Mahony *et al.* (2006); Declan O'Mahony pers. comm.).

Afforestation suitability

The management of habitats for Hen Harriers should aim to minimise fluctuation in the availability of pre-thicket forests over time, by ensuring a consistent matrix of different aged forest stands at the landscape level. Particularly in areas with high levels of forest cover, where second rotation pre-thicket forest often constitutes a large proportion of the suitable habitat available, this would help to minimise the length and severity of any 'bottle-necking' effect of periods where the landscape is dominated by closed canopy forest. Also, if second rotation pre-thicket forest can have a direct and negative impact on Hen Harrier breeding success, then maintaining a mix of age classes within forest estates in Hen Harrier areas would help to avoid periods in which cover of this habitat was particularly high.

In even-aged stands, a mix of different ages can be achieved over time by bringing forward or delaying harvesting dates of particular stands, or by leaving some felled stands for a 'fallow' period of several years before they are planted. The latter option has the added benefit of extending the length of time that forested areas spend out of closed canopy stages, thereby increasing their overall value to Hen Harriers. The degree to which such measures could be employed depends to a large extent on commercial factors, but the 'fallowing' method described above is already being employed in several upland areas as part of an integrated strategy to reduce the incidence and intensity of pine weevil infestations (Dillon and Griffin, 2008). Also, a steady and predictable supply of timber, such as should result from a forest estate being managed to include a mix of different aged stands, is likely to be of greater economic use to the local forest industry than one in which demand varies widely between years.

It would certainly be desirable to achieve a mix of forest ages at the scale of an SPA. However, SPAs such as the Slieve Aughty Mountains are very large, with widely separated Hen Harrier territories that are unlikely to overlap in foraging range. It would therefore be prudent to ensure that a mix of different ages is also retained at a smaller scale. Finding the best scale at which to organise harvesting and replanting to achieve a balance of forest ages depends on balancing the potential benefits of a consistent mix of forest ages in all Hen Harrier territories with the increased difficulty of achieving this at small scales. Inevitably, availability of second rotation pre-thicket forest will fluctuate widely over time at the level of some Hen Harrier territories. However, this species is quite flexible in its breeding habits, with pairs capable of moving several kilometres between and even within seasons (Paul Troake and Barry O'Mahony, pers. comm.). Also, in less heavily afforested areas, breeding Hen Harriers are likely to be able to make greater use of alternative habitats when availability of second rotation forests is low.

The negative relationship between second rotation pre-thicket forests and Hen Harrier breeding success observed in the Slieve Aughty Mountains suggests that as well as ensuring a continued mix of growth stages in the forest estate over time, it would also be desirable to regulate expansion of forests in areas with Hen Harriers. This is especially so in the Slieve Aughty Mountains where this relationship has been observed, but possibly also elsewhere to ensure that levels of second rotation pre-thicket forest do not regularly reach the levels associated with the negative impacts on breeding success we observed.

At present, afforestation is regulated in Hen Harrier SPAs by applying an annual limit to each area, without regard for variation in existing levels of forest cover or other habitats within each SPA. The strategic approach to zoning SPAs according to their suitability for afforestation, demonstrated above, is one way of ensuring that habitat composition within SPAs is regulated on a scale appropriate to Hen Harriers. It is easy to implement on a case-by-case basis, and also to update, at least in terms of afforested areas. Updates of rough grassland and peatland habitats could be made according from aerial photographs or from satellite data, but it would require considerable effort to manually extract the relevant data from such sources (see discussion in Work Package 1). Coupled with the fact that such remote datasets are not updated on an annual basis, it is likely that zones would not be updated according to information pertaining to non-forest habitats much more frequently than once every five years.

Recommendation 5: The long-term influence of forested areas on Hen Harriers is likely to be optimised by minimising fluctuations in the availability of forest growth stages (such as pre-thicket, thicket and closed canopy forest) over time, by ensuring a consistent matrix of different aged forest stands is maintained at the landscape level. This would help to avoid 'bottleneck' effects due to periods when the cover of any one habitat was particularly high or low. We recommend a strategic approach to zoning SPAs according to their suitability for afforestation, as a means of ensuring that habitat composition within SPAs is regulated on a scale appropriate for Hen Harriers.

Work Package 3

Review remote tracking methodologies

Background

The majority of studies of habitat use by foraging Hen Harriers to date have used data collected by direct observation (Madders, 2003a; Amar and Redpath, 2005; Wilson *et al.*, 2009). This method is time consuming and subject to bias, as some areas are more easily watched than others, also direct observations do not generally allow observations of foraging birds to be associated with their nest. Remote tracking of Hen Harriers using satellite, GPS or radio tags would provide a far more efficient method of collecting detailed information on habitat use by Hen Harriers of the type required by Work Package 4 of this project (Hardey *et al.*, 2006). Conservation research, in particular, has benefitted from recent developments in remote tracking (Croxall *et al.*, 2005; Cooke, 2008; Catry *et al.*, 2011).

In the past it has not been possible to use these tracking methods on birds of the Hen Harrier's size due to weight constraints, however recent advances in these technologies render them now potentially more applicable to this study. Issues of tag size (tags should weigh no more than 3% of a bird's weight, which for Hen Harriers means about 10g), battery lifetime, positional accuracy, data retrieval and cost all had to be thoroughly investigated selecting which, if any, of these methodologies should be used in Work Package 4. A review of the available literature was therefore undertaken. However, because many relevant developments in this field were either too recent to have been published, or were ongoing, this literature review was complemented by an extensive search for non-published information, by directly contacting researchers, developers and end-users of remote-tracking technologies. The results of this Work Package were used to inform the methodologies employed in Work Package 4.

Methodology

In order to gather information for the review, and gain practical experience in trapping Harriers which will be essential to work on foraging ecology in Work Package 4 members of the project team visited and worked with Beatriz Arroyo of the Consejo Superior de Investigaciones Científicas, Spain, who had worked on Hen Harriers for several years. Project team members were trained by Beatriz Arroyo, Raul Alonso (BRINZAL Centro de Recupración de Rapaces Nocturnas, Madrid) and also Antonio Pinilla and Fergus Crystal (AMUS Centro de Recuperación de Fauna Protegida y Centro en Cria en Cautividad del Aguilucho Cenizo, Villafranca de los Barros). The team gathered information essential to reviewing remote tracking technologies and gained valuable experience in field techniques relevant in the capture of harrier species for remote tracking essential for Work Package 4 and for wing-tagging subsequently conducted as part of Work Package 5 (Figure 11 and Figure 12). This information transfer was invaluable to the success of the current project. Techniques learned included:

- Harrier trapping using decoys and a net
- Harrier trapping using pole traps
- Harness attachment
- Wing-tagging

Figure 11. Mark Wilson learning capture techniques for Montague's Harriers

An extensive review of literature, online information and existing relevant tracking technologies was also undertaken to inform Work Package 4. Over 400 papers using telemetry from recent years were reviewed and information collated on the type of telemetric technology used; species and size of study animals, weight of tag, method of tag attachment, lifetime of battery, accuracy of positional data, costs and requirements in terms of equipment and manpower, method of data retrieval, and any other relevant capabilities or limitations of the tracking system.

Figure 12. Training in attachment of VHF radio transmitter.

Results

Ecological studies employ a range of different types of tag in remote tracking of individual animals from simple VHF tags to complex Geolocators, with the specific tag dependant on the requirements of each study and the ability of the animal to carry the tag. Acoustic tags, specifically sonic and ultrasonic tags, are the preferred choice when studying aquatic organisms as these devices produce sound waves which propagate much more effectively than radio waves underwater. VHF (Very High Frequency Radio), which emits radio waves, is the most commonly used remote tracking technology for terrestrial animals (Sutherland *et al.*, 2004). The tag emits a relatively weak signal allowing it to be tracked until the animal is found and observations can commence. Accuracy in locating animals by triangulating the signal using multiple receivers can depend on topography and proximity of tags and receivers.

Satellite Platform Transmitter Terminals (PTT) are similar to VHF tags in that they both emit a radio signal. PTTs however emit a signal 100 or 200 times more powerful than VHF. This means the tag can be detected from anywhere on earth, however, if the satellites view of the tag is obstructed by topography, buildings, dense vegetation or by the Earth itself the signal will be blocked. Even in optimal conditions the accuracy of these devices is never less than 100m. These devices are also capable of transmitting data giving them a high power requirement and so size constraints are more severe (Keating *et al.*, 1991).

Passive Integrated Transponder (PIT) tags are microchip devices that can be scanned to reveal the identity of an individual animal and are most appropriate for studies of animal movement past a fixed point scanner (Dell'Omo *et al.*, 2000). These tags are not actively powered as they are powered by an interrogatory pulse of energy (acoustic or electrical) from an external receiver unit, however, they can only be detected within a range of a few centimetres limiting their usefulness to monitoring birds and fish in narrow rivers, or in the aquaculture industry. Because they do not require a battery they are the smallest remote tracking devices available.

Of all the technologies reviewed Global Positioning System (GPS) devices were the only ones with sufficient accuracy to provide the type of detailed information required when investigating Hen Harrier foraging habitat. GPS tags work by receiving signals from an array of satellites of known position. By measuring the time elapsed between transmission and reception of the signal from each satellite the distance between the satellite and the tag can be calculated. Signals from four or more satellites allow calculation of the tags position to within an accuracy of 10 metres or less, depending on whether or not additional measurements and corrections are undertaken to improve on basic GPS accuracy (Hulbert and French, 2001). The disadvantage of this tracking method is that it is not possible to retrieve data from the tag remotely as GPS tags only receive signals. Instead, the information must be stored on the tag until it can be physically retrieved and downloaded, or alternatively information can be sent remotely using satellite, mobile phone network, VHF or ‘Bluetooth’ radio frequencies.

Discussion

The findings of this literature review revealed that remote tracking of Hen Harriers using satellite, GPS or radio tags provides the most appropriate method of collecting detailed information on their habitat use. GPS engines requiring lower voltage and lower current, and powered by batteries of smaller size along with other advancements in miniaturisation have enabled the development of smaller GPS units. These recent advances render these devices potentially more applicable to this study than was previously the case due to the relatively small size of Hen Harriers. The results of this Work Package were used directly in Work Packages 4 and 5, and the literature review prepared as a manuscript for submission to *Irish Birds*.

Work Package 4

Hen Harrier foraging ecology

Background

The breeding success of many bird species, including Hen Harriers, can be affected by food availability, through its effects on probability of breeding, clutch size, reductions in the numbers of eggs and chicks prior to fledging, and nest success (Newton, 1979; Martin, 1987; Chamberlain *et al.*, 2009). Several studies from the island of Orkney have shown that Hen Harrier breeding success can be affected by availability of food, both before and during the nest period (Amar and Redpath, 2002; Amar *et al.*, 2003; Amar *et al.*, 2005). Food availability is in turn affected by habitat in two main ways. The type and quality of habitat in an area has a direct effect on the composition and numerical abundance of the prey that inhabit it, but habitat structure also has an important effect on how accessible these prey are to potential predators (Preston, 1990; Beier and Drennan, 1997). Investigating the association between land use and foraging activity is an important aspect of studies of raptor populations, particularly in landscapes such as the Irish uplands where habitats have been subject to large scale and profound anthropogenic change (Madders, 2000). The relative importance of different habitats in providing food for Hen Harrier adults and chicks during the breeding season has obvious implications for the management of land around their nests. It would be particularly useful to know the extent to which habitat composition at the landscape scale around the nest affects the ranging behaviour of hunting adults, the amount of foraging time taken up by travelling, and the rate at which parents can provision the nest. Without this information, the ability of researchers, legislators and managers to choose the best scale at which to consider the breeding ecology of Hen Harriers will be undermined.

Previous studies on habitat use by Hen Harriers have relied on data collected by direct observation by researchers in the field. Although widely used this method represents a very inefficient use of manpower, yielding very small amounts of data per unit effort as a day in the field may yield no more than a few minutes of foraging observations. It is also difficult to entirely eliminate habitat biases, as Hen Harriers are easier to observe in some habitats than in others. Finally, it is not generally possible to associate data collected from a foraging Hen Harrier by direct observation with a particular nest. These difficulties can be overcome by remote tracking methodologies, which allow the position of birds to be recorded without having to directly observe them. The remote-tracking method best suited to collecting data on foraging Hen Harriers is GPS tracking. Alternative remote-tracking technologies such as VHF (Very High Frequency radio) and satellite tracking are insufficiently accurate to resolve questions of habitat-use at a spatial resolution of 10s of metres (Work Package 3).

GPS is essentially an archival technology, meaning that the positional data collected is stored on the tag itself. Many GPS tags deployed on other species have incorporated other technologies such as satellite or GSM (Global System for Mobile communication), which allow the data to be remote downloaded from the tag. However, such combination tags are considerably heavier than stand-alone GPS units. The weight of remote-tracking equipment deployed on active birds is an important issue, both for the welfare of the birds (and, in the case of breeding Hen Harriers, of their partners and broods), and also the biological relevance of the data these tags collect (Calvo and Furness, 1992; Rodriguez *et al.*, 2009). Current recommendations state that this threshold should be between 3-5% of a bird's weight (see Work Package 3). Male Hen Harriers typically weigh around 350g, so to be within a threshold of 4% of body weight, the combined weight of equipment deployed should be no more than 14g. This effectively rules out GPS tags with the ability to remotely download data.

The aim of this Work Package was to develop a new system for retrieval of both tag and data without the need for recapturing adults and to use this system to collect foraging data on breeding Hen Harriers for investigation of the relationship between foraging and land use and habitat features. We relate these findings to the management of Hen Harrier breeding areas, providing recommendations aimed at maintaining or enhancing the value of landscapes for this species.

Methodology

Trapping

Birds were trapped using a dho-gaza net (Clark, 1981) with a stuffed fox deployed in front of it. Nets were positioned between 30m and 120m from Hen Harrier nests, as agreed on a case-by-case basis with NPWS regional management staff. Trapping attempts focussed on breeding males from hatching until chicks were two weeks old, as at this time males are heavily invested in breeding attempts and responsible for providing the majority of food to females and chicks. Trapping attempts at nests after two weeks post-hatching focussed on females, as we were advised that males at older nests may be more inclined to desert their nests. Also, chicks at this age are able to thermoregulate independently (see analysis of camera footage data in Work Package 5), so the contribution of females to nest provisioning. Captured adults were removed from nets and fitted with GPS harness units described below before being released.

Tag and harness design

We used GiPSy2, a highly miniaturised GPS unit developed by Italian company TechnoSmArt, which was among the smallest units available at the time of this project. The efficiency of this tag was further increased by its use of sophisticated programming schedules which make the best possible use of the battery, so that a tag and battery weighing just over 9g can continue to function over a period of days or even weeks. GPS units were programmed with a two-part recording schedule, which consisted of a 16-hour period (from 0500hrs to 2100hrs, during which the 20 positions were recorded at a rate 1 per second during a single 20-second period every 5 minutes) and an 8-hour period (from 2100hrs to 0500hrs, during which between 1 and 20 positions were recorded every hour). GPS units operating on this schedule were able to record for periods of between 3 and 5 days. GPS units were attached to a 1.4g Holohil BD-2 VHF transmitter (which has an expected battery lifetime of 9 weeks), and two short sections of aquarium tubing (used to attach tags to the harness). These elements were attached to GPS units with tough, waterproof duct tape, which also served to protect tags from being damaged by birds.

GPS unit were deployed on Hen Harriers using a breast-strap harness designed to release the tag after it had finished collecting data. The harness holds the tag onto the back of the bird using four straps that are linked above the bird's sternum by a weak link (Figure 13). When the weak link breaks, all four strands of the harness are released simultaneously, freeing the tag.

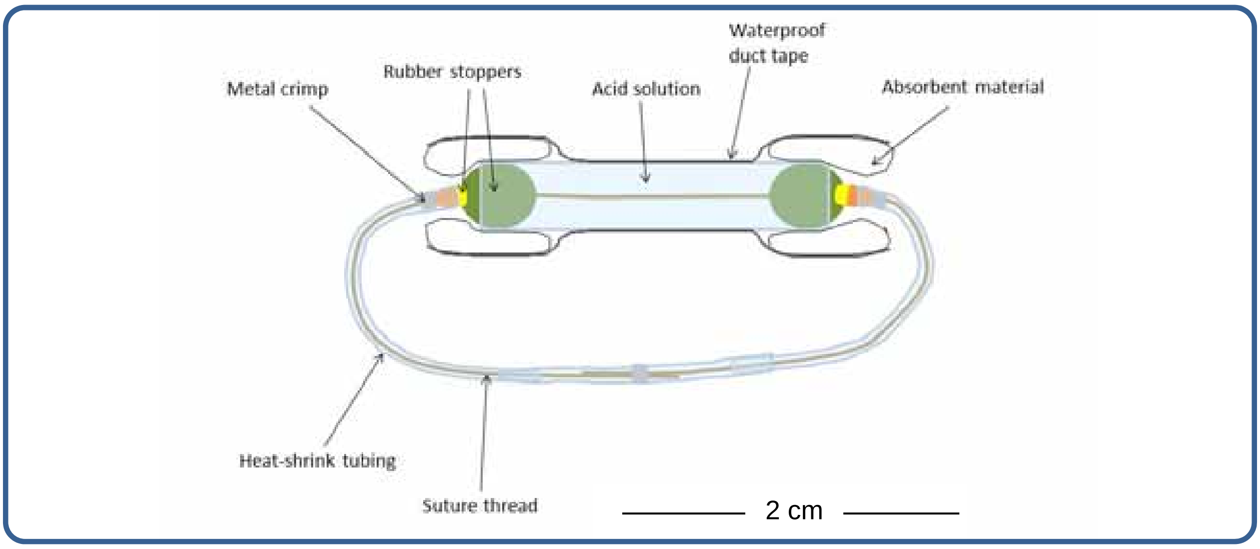

Figure 13. Structure of weak link in GPS harness. The acid solution is held around a section of the circular piece of suture thread by a short length of aquarium tubing, sealed at either end with rubber stoppers. Metal crimps hold the rubber stoppers in place, and also hold the ends of the suture together to close the circle.

Weak links consist of a length of catgut surgical suture thread that runs through a short section of 4mm aquarium plastic tubing with rubber stoppers in either end to make the space within the tubing watertight. In order to activate the weak link, a small amount of acid solution is injected into this space before the harness is deployed. Over a period of time determined by the temperature and concentration of the acid, it breaks down the suture thread running through the tubing until the suture loses its tensile strength and the weak link breaks. The acid is held within the tube by the rubber stoppers for the duration of its deployment so that it does not come into contact with the bird. Absorbent material held around the opening of the ends of the tube prevent acid contacting the bird during the short period between the link breaking and the harnesses falling away from the bird. The exposed section of suture (i.e. the suture thread not located within the aquarium tubing) is encased within 3mm diameter 2:1 heat-shrink tubing, in order to protect premature removal of the harness by birds (
Figure 13).

When GPS units had detached from the birds carrying them, they were retrieved by homing in on the VHF signal, from the transmitter attached to the tags, using a hand-held Yagi antenna. Tags were taken back to the lab, where positional data was downloaded from the GPS units using dedicated GiPSy 2 software.

Habitat digitisation

Vector layers of forest habitat were made available from Coillte and the FIPS (Forest Inventory Planning System) 1998 database. Open habitats were digitised using the ESRI ArcMap 10 software. Ordnance Survey orthophotographs, 6 inch maps and georeferenced Google Earth Satellite Images (dated 05/04/2006) were used as basemaps to create a digital map of open habitats. The "auto complete polygon" tool was used to prevent the creation of overlaps and gaps between adjacent fields as they were digitised. The open habitats were initially digitised as polygons, which were subsequently converted to polylines to represent field boundaries. This field boundary layer was then edited to remove duplicate boundaries created in the conversion process. Forest and open habitats were merged together to create a single land cover layer (Figure 14).

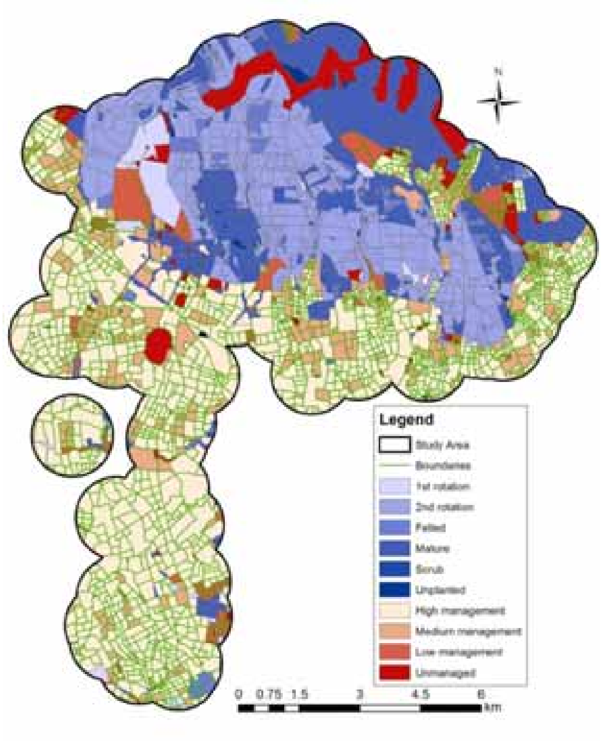

Figure 14. Categories and distribution of boundaries, forest and open habitats within the Ballyhouras study area, which comprised all areas within 1 km of Hen Harrier GPS tracks.

Habitat classification

Forest habitats were classified using the Coillte Inventory Database, Coillte Clearfell Management Database, Google Earth Satellite Imagery and the FIPS 1998 database (Work Package 1). Open habitats and hedgerows were classified using Google Earth Satellite Imagery and Ordnance Survey Orthophotographs. The study area comprised all land within 1km of any Hen Harrier tracks. Land within the study area was assigned to five classification categories of forest habitats (first rotation pre-thicket, second rotation pre-thicket, closed canopy, scrub and unplanted) and four categories of open habitats (high intensity managed grassland (HIMG), medium intensity managed grassland (MIMG), low intensity managed grassland (LIMG), and unmanaged habitat). Information pertaining to patchiness (the percentage of a forest block comprising open habitat) was added to the attribute table of forest habitat polygons. Patchiness, the proportion of a forest block comprising open habitat, was scaled from zero to 100, with the minimum values representing little or no open habitat. Open habitats were categorised as follows:

- HIMG – fields with a heterogeneous colour and obvious indications of managed patterning (Figure 15).
- MIMG – relatively homogeneous fields with some evidence of shading from non-grass vegetation (e.g. rushes, buttercups, etc.) (Figure 16).
- LIMG – fields with largely heterogeneous patterning, with no evidence of cultivation, some grass and evidence of scrub encroachment (Figure 17).
- Unmanaged Habitat – fields with no cultivated grasses and obvious scrub encroachment, or unenclosed peatland areas (Figure 18).

Figure 15. A typical example of High Intensity Managed Grasslands within the study area.

Figure 16. A typical example of Medium Intensity Managed Grasslands (centre) within the study area.

Figure 17. A typical example of Low Intensity Managed Grasslands within the study area.

Figure 18. A typical example of Unmanaged Habitat (centre) within the study area.

Data analysis

Hunting tracks were identified as those tracks with a speed greater than 2 ms^{-1}, for all, or a section of, the track. Speed was calculated by measuring the distance between subsequent points from point 14 to the final point in the hunting track. The speed measurement was taken from the 14^{th} point because there was an increase in the accuracy of positions recorded up to, but not after, this point. Analysis of habitat use was performed using the 20^{th} position in each hunting track. These points were extracted from the existing point shapefile by creating a structured query in the attribute table of the shapefile and exporting the selected features to a new shapefile.

All data analysis was carried out using ESRI ArcMap 10 GIS software. For boundary analysis, Hen Harrier tracks that did not intersect with a field boundary were omitted. Use of field boundaries was assessed by comparison of original tracks with 35 tracks sharing the same point of origin, but rotated at 10 degree intervals through 360 degrees. The tracks were rotated by spatially adjusting the position of the track in two dimensional space so that the first satellite location was moved to the x,y origin. The rotation algorithm was then applied and the newly oriented track was re-adjusted in two dimensional space, with the first satellite location returning to its original position and the remaining satellite locations moving to their new rotated positions. For every data point in each track, the distance from the nearest boundary was measured by creating a spatial join between the Hen Harrier track data and the boundary layer. The width of the nearest boundary was measured for each of the points used in the boundary analysis. Boundary width was measured using the ruler tool in Google Earth.

Habitat usage was assessed by comparing the hunting points with sets of random points generated using the Create Random Points tool in ArcMap. For each Hen Harrier satellite position, a set of 100 random points were generated within 1 km radius of the hunting position was generated, and another set of 100 points randomly distributed throughout the whole study area. Habitat information for each point was generated by creating a spatial join between the point data and the forest and open habitat layers. Each data point was classified according to the habitat information of the polygon with which it shared the same spatial location. When the distribution of Hen Harrier tracks between habitats differed from that of the random sets of points, the two-tailed statistical significance of this difference was estimated as twice the proportion of randomised runs showing more extreme 'avoidance' or 'preference'.

Results

Trapping

Twenty-seven capture attempts at 14 nests in 2010 and 2011 resulted in the successful capture of seven breeding adults; five males and two females. All birds were tagged (Figure 19) apart from one female caught accidentally while still on eggs, which was released immediately without being tagged. All birds were resighted subsequently in the nesting area, and of the six nests at which capture took place, nestlings successfully fledged from five (including one nest where both male and female were tagged). The male at the nest that failed had continued to provision the nest while he was carrying the tag, but a week after the tag had fallen off the male the female was injured on the nest (during what appeared to be an attempted nest predation event) and subsequently died. Our data therefore indicate that parental provisioning behaviour in male and female Hen Harriers in Ireland is not prevented by the stress of capture and tagging. However, at the five nests where males were caught there was a break in hunting and provisioning by the male after capture, typically 12-24 hours in length. The female that was tagged was back in the nesting area within 5 hours of being tagged, while the female that wasn't tagged after being captured was observed to return to the nest within 5 minutes of being released.

Figure 19. First Hen Harrier fitted with GPS tag, at Reynclamper in Slieve Aughties

System performance

In total, six birds were fitted with GPS tags; four in 2010 and two in 2011. The first two birds caught were males at Reynclamper in the Slieve Aughty Mountains, and Castlepook in the Ballyhouras. Both of these males fitted with harnesses that incorporated weak links with exposed sections of suture, and removed the harnesses within 12 hours (before returning to their nests) by biting through the suture. The data collected from these birds was therefore not useful for analysis of foraging behaviour. This problem was remedied by altering the design of the weak link so that the suture was protected by heat-shrink tubing (see above). All other tags were carried by birds until the weak link broke as it was designed to do. All birds were observed directly after their tags had dropped off, and none showed any signs of ill-effects, indicating that harnesses fell off cleanly as they were designed to do.

One of the six tags was not subsequently found after it had fallen off, despite an extensive search for it. It is possible that the VHF transmitter failed on this tag, or that it fell off in a position from which the VHF signal could not be effectively detected. The five other tags were all found within 24 hours of searching for them. The three tags from which useful data were collected were all deployed on birds breeding in the Ballyhouras. These were a female at Castlepook territory tagged in 2010 (15,955 positions recorded over 4.1 days), a male at Ballintlea tagged in 2011 (5,902 positions recorded over 1.3 days) and a male at Streamhill tagged in 2011 (11,563 positions recorded over 2.9 days). From these positions, a total of 293 Hen Harrier hunting tracks were identified for using in foraging habitat analyses.

Habitat use

One hundred and eighty-nine hunting tracks occurred in forest habitats, as opposed to 104 hunting tracks recorded in open habitats (

Figure 20). The maximum distance any bird was recorded from its nest was 11.4km for the Streamhill male, 2.6km for the Ballintlea male, and 7.5km for the Castlepook female. Twenty-two percent of hunting tracks were within 1km of the focal nest, 49% were within 2km and 89% were within 5km. Within each of these three distance bands, the nest the spread of hunting points between open and forested habitats was very similar (Figure 21).

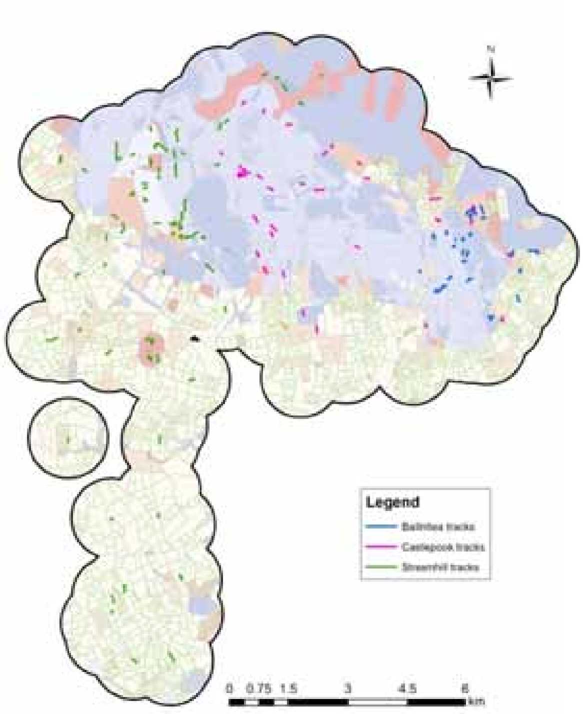

Figure 20. Positions of hunting tracks for Castlepook female 2010 (pink), Ballintlea male 2011 (yellow) and Streamhill male 2011 (green).

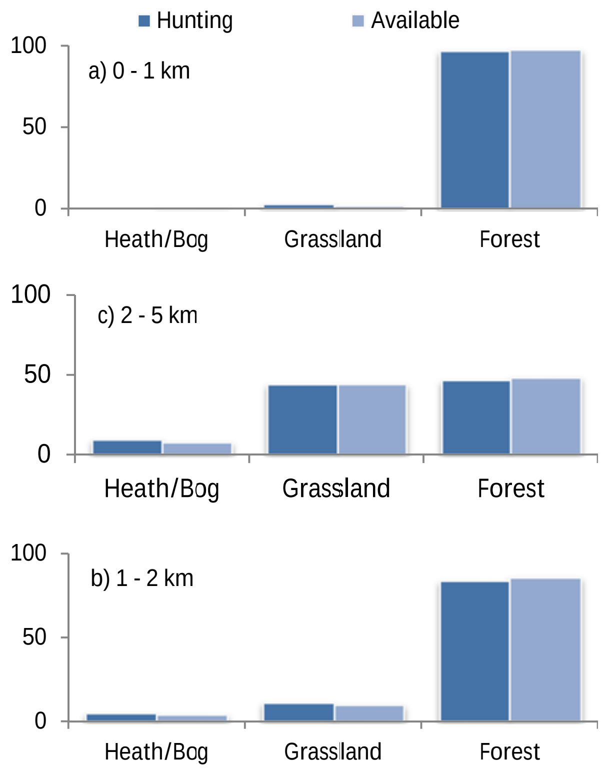

Figure 21. Habitat used by foraging adult Hen Harriers at a) up to 1km from the nest site (n=65), b) between 1 km and 2 km from the nest site (n=80) and c) between 2km and 5km from the nest site (n=116).

Seventy-two percent of hunting tracks in forest habitats occurred in areas of second rotation pre-thicket forest, which was a greater proportion than expected by random chance either within 1km (2-tailed randomisation test P<0.01) or across all forest habitats in the entire study area (2-tailed randomisation test P<0.01) (Figure 22). By contrast, the proportion of hunting tracks located in closed canopy forest (16.4%) was significantly less than the proportion expected from random chance within 1km (2-tailed randomisation test P<0.01), or across the entire study area (2-tailed randomisation test P<0.05). Of those Hen Harrier tracks that occurred in closed canopy forest habitats, a higher proportion occurred in stands with patchiness of at least 10% than would be expected by random chance (Figure 23). In relation to forest age, foraging Hen Harriers appeared to avoid stands that were less than 3 and greater than 15 years old, with the strongest preference shown for forests between 6 and 11 years of age (Figure 24).

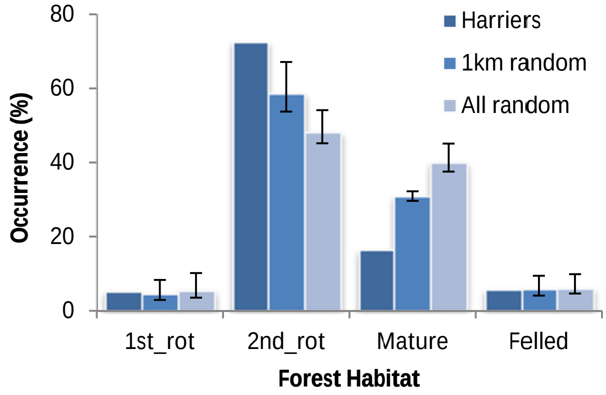

Figure 22. Percentage occurrence of Hen Harriers, random points located within 1km and random points within the entire study area in forested habitat, with 95% confidence interval error bars.

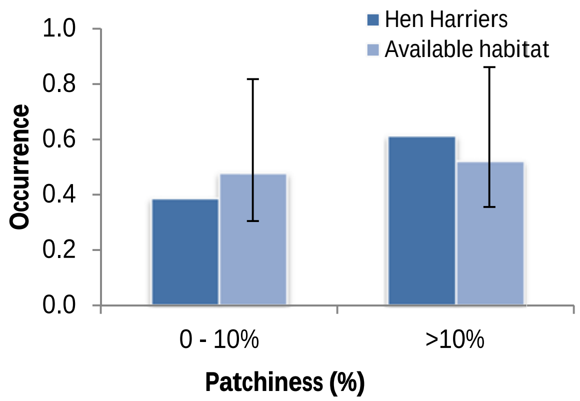

Figure 23. Distribution of Hen Harrier hunting tracks in closed canopy forest between two categories of patchiness.

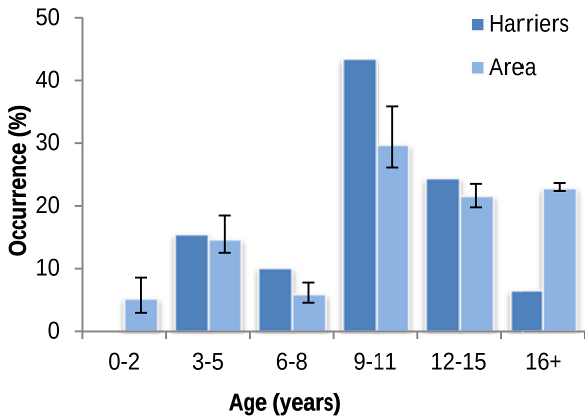

Figure 24. Distribution of Hen Harrier hunting tracks in forest between different age categories, relative to the availability of habitat in each category.

In open habitats, 34.6% of hunting tracks were located in HIMG, 25.7% within MIMG, 25.7% within LIMG, and 13.8% within unmanaged habitat (Figure 25). The percentage of hunting points is lower in in HIMG, and higher in the other habitats, than would be expected by random chance within the whole study area (at which scale these differences are significant; 2-tailed randomisation tests P<0.01) and also within 1km (at which scale these differences are not significant).

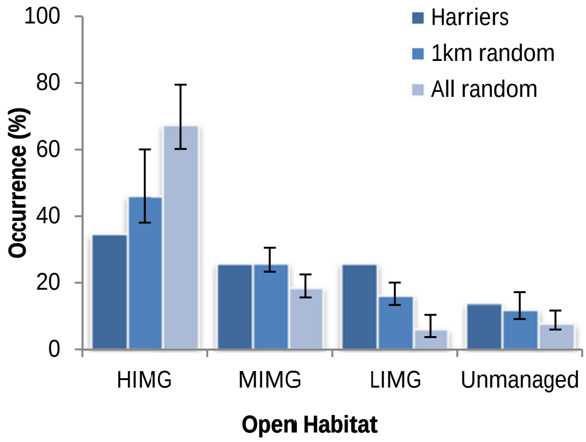

Figure 25. Percentage occurrence of Hen Harriers, random points located within 1km and random points within the entire study area in open habitat, with 95% confidence interval error bars.

Forty nine Hen Harrier hunting tracks in non-forested habitats intersected one or more field boundaries. The average distance from a boundary of all points in these tracks was calculated to be 20.9m. This figure is significantly lower than the average distance from boundaries of all points in rotated tracks (30.6m, 2-tailed randomisation test P<0.03), suggesting that Hen Harriers flying in the vicinity of boundaries tend to follow them. Within 1km of the 49 hunting tracks that intersected boundaries, there is significant preference for boundaries between 3-4m in width (2-tailed randomisation test P<0.05) and significant avoidance of boundaries between 7-8m in width (2-tailed randomisation test P<0.05, Figure 26).

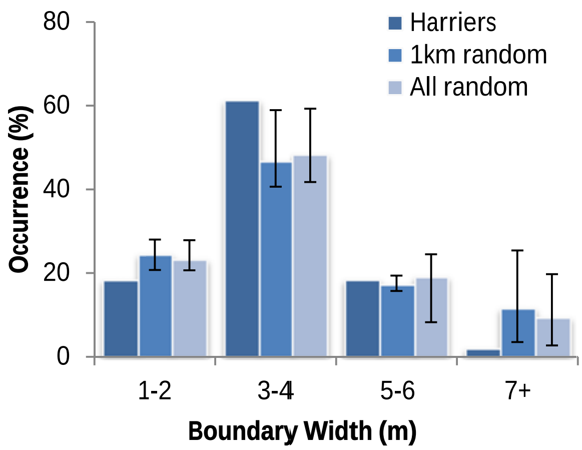

Figure 26. Distribution of Hen Harrier occurrences and random points between width classes of the nearest boundary.

Discussion

Tagging methodology

Twenty-six percent of trapping attempts were successful. This is slightly lower than the equivalent rate of 38% experienced by researchers during the nesting period in a Scottish project, using a variety of similar methods to those used in this study (Amar *et al.*, 2003). One of the differences between the two studies that might account for this difference in trapping efficiency is the distance from nests at which trapping attempts took place. An initial condition of NPWS licenses was that trapping attempts be carried out at no less than 100m distance, with this distance being reduced to a minimum of between 30 and 40 metres in individual cases after approval by NPWS regional management staff. In contrast, the standard trapping protocol used in Scotland was to set up the decoy 5m from active nests. Such a short distance would not have been practical during our capture attempts on males, as approaching the nest so closely would typically have drawn the attention of brooding females, which we were trying to avoid. However, being able to deploy trapping equipment at shorter distances than we were previously allowed could, especially in trapping attempts aimed at capturing females, have increased trapping success. Other factors which may have contributed to differences in trapping success experienced in the two studies include techniques used (in the Scottish study, which took predominantly in open, moorland habitats, pole traps and noose bonnets were used) and the fact that many of the unsuccessful trapping attempts in the current study were repeat attempts at nests where trapping had previously been unsuccessful. The difference in response to trapping between males and females observed in this study closely mirrors the experience of researchers in the Scottish study, with females returning to parental duties within a few hours, and males observed to resume provisioning the day following capture.

The novel harness design used in this study allowed GPS data to be collected from birds as small as male Hen Harriers, which weigh only 350g. Improvements made to the harness during the study successfully prevented the harness being removed prematurely by the subject birds. One of the six tags we deployed was not retrieved, and there is always likely to be a small risk of tag loss due to VHF signal failure, signal curtailment due to position of the tag after harness detachment, or to study animals leaving the study area before harness detachment. Changes to improve the reliability of the system may be possible in the future, particularly to reduce variability in the time taken for harnesses to detach, and to increase the strength and longevity of the VHF beacon which is used to retrieve the tag. Nevertheless, this system has the potential to be adapted to a wide range of different contexts, thereby extending the possibility of applying to the accuracy of GPS technology to the study of more species and ecological situations than might otherwise be possible.

Foraging habitats

One must be cautious about generalising from the GPS data collected in this Work Package, as it derives from only three birds, all of which were using the same study area. However, some patterns about use of habitat by these birds are evident. Ranging distances of these birds, even over the short periods of time over which they were tracked, were notably larger than ranging distances of VHF-tracked birds in Scotland (Arroyo *et al.*, 2006). During four days of tracking, the maximum distance from the nest travelled by the GPS-tracked female was 7.5 km (compared to 4 km in Scotland), while during a similar period of data collection the maximum distance from the nest of either of the two males was 11.4 km (compared to 9 km in Scotland). This difference may be because Irish Hen Harriers (at least in the Ballyhouras) have to forage over larger areas in order to provision their broods (despite the fact that brood sizes of Hen Harriers in Ireland are typically smaller than those of Hen Harriers in Britain). This suggests that Hen Harriers in Ireland may be constrained in their breeding behaviour and success by the availability of prey. There is a relative lack of (particularly microtine) small mammals in Ireland, which are present in greater diversity and abundance in most parts of Britain. However, it is worth noting that the breeding seasons of 2010 and 2011, during which these data were collected, both followed unusually severe winters during which mortality of many resident upland passerines was high. As small birds comprise a large proportion of the diet of Hen Harriers during the breeding season (O'Donoghue, 2010), depleted populations of resident passerines during the spring following these winters may have forced Hen Harriers to travel further for food than they would otherwise. Another possibility is that at least part of the difference in ranging behaviour is due to detection biases in the VHF study. The likelihood of picking up a signal from a Hen Harrier carrying a VHF transmitter decreases with the distance between the (manually operated) receiver and the Hen Harrier. The majority of time spent searching for VHF signals is focussed on the area around the nest, because this is where birds spent most of their time, and so where they are most likely to be found. In VHF studies, birds are therefore less likely to be detected the further from the nest they are hunting. No such potential bias exists in GPS studies, as data collection does not depend on birds being within range of fixed or manually operated receivers.

Despite the large distances travelled by hunting Hen Harriers, the majority of foraging was concentrated relatively close to the nest, as one would expect with central-place foragers like breeding Hen Harriers. Over 50% of all GPS registrations consistent with hunting behaviour were within 2 km of the focal nest. Moreover, because the area within a certain radius of the nest increases as the square of this distance, the concentration of hunting behaviour was more than 10 times higher within 1 km of the nest than it was between 2 and 5 km from the nest. Another interesting feature of Hen Harrier hunting behaviour is the apparent lack of overlap in hunting range between neighbouring birds. In 2010, the territories to the east of the nest of the Castlepook female (represented by the pink dots in Figure 20), including Ballintlea, were unoccupied, but Streamhill immediately to the west held the only other Hen Harrier to breed successfully in the Ballyhouras that year. In 2011, birds bred in all three of these territories. The overlap between the activity of birds at Castlepook and Streamhill was much smaller than between the Castlepook and Ballintlea, despite the fact that the two nests of the former pair were only 1.6 km apart, which was almost 5 times closer than the nests of the latter pair, which were 7.7 km apart. This is because the Castlepook female foraged almost entirely in the unoccupied area to the east of her nest, suggesting that foraging behaviour can be affected by neighbouring pairs.

The greater use of forest habitats than non-forest habitats by foraging birds may, at least in part, be explained by the greater availability of the former in the area around nest sites. These were all located in second rotation pre-thicket forests, and surrounded mainly by this and other forest habitats. However, the fact that two-thirds of hunting tracks occurred in forest habitats, and that all of these nests successfully fledged chicks, suggests that breeding Hen Harriers can rely to a large extent on forest habitats for hunting. This is good news, as in areas like the Ballyhouras, most Hen Harriers do not have access to large areas of rough grassland, scrub or peatland habitats.

Within forest habitats, the selection of second rotation pre-thicket forest and avoidance of closed canopy forest ties in well with what has been observed of Hen Harrier use of forest habitats in observational studies (Madders, 2003b; O'Donoghue, 2004). The age range of young forest habitats most intensively used was from 6-11 year old, but Figure 25 also shows that foraging also occurs in forests between 12 and 15 years old. This is older than the areas considered as being ‘useful’ to Hen Harriers by many analyses up until now, and has positive implications for the long-term value of forested areas for Hen Harriers, as it means they will be able to forage in these areas for a greater proportion of the time than would otherwise be the case. There is some evidence to suggest that when Hen Harriers forage over stands of closed canopy forest, they tend to select ‘patchier’ stands that incorporate a greater proportion of open habitats or failed/poorly grown forest than would be expected by random chance. Although such stands may not be particularly valuable from a commercial forestry point of view, due to slower timber growth rates or poor timber quality, their value for Hen Harriers and other species may be higher (Iremonger *et al.*, 2007).

Recommendation 6: The use by Hen Harriers of different forest ages revealed by GPS tracking data shows that forest areas being managed for Hen Harriers should aim for as high a proportion of forest as possible within the 6-11 year old age range (bearing in mind the requirement for minimising fluctuations in the availability of different growth stages). However, forests as old as 12-15 years are still more useful than older age classes as foraging habitat. We recommend maintaining as high a proportion of forest as possible across the 6-15 year age range, in Hen Harrier SPAs.

Areas of intensively managed farmland appear to be avoided by Hen Harriers, probably because of the low densities of prey. Previous studies have shown that densities of songbirds in grassland areas are negatively related to the intensity of agricultural management (Wilson *et al.*, 2012), and small mammal abundance in grassland is related to height and diversity of vegetation (Kate O'Flaherty, unpublished data). Of the less intensively managed habitat types, LIMG seemed to be the most strongly preferred, even though shrub cover (and therefore prey abundance) was likely to be higher in Unmanaged Habitat. This may suggest that Hen Harrier preferences among non-forest habitats are determined by compromises between prey abundance and availability. If so, then a similar explanation may underlie the distribution of Hen Harriers in non-forest habitats between different boundary widths. Birds showed the greatest preference for boundaries between 3-4m in width, apparently avoiding very narrow or very wide boundaries. This may be because boundaries of medium width hold high densities of prey abundance than narrower boundaries (i.e. 1-2m), but are not so overgrown as to greatly limit the accessibility of these prey to Hen Harriers.

The results of this Work Package will be prepared as a manuscript for submission to *Bird Study*.

Recommendation 7: Foraging Hen Harriers showed the greatest preference for boundaries between 3m and 4m wide, apparently avoiding very narrow or very wide boundaries. Boundaries of this size typically correspond to old townland boundaries. We recommend maintenance of appropriate sized field boundaries and activities which result in destruction or deterioration of these boundaries should be avoided in areas used by foraging Hen Harriers.

Work Package 5

Hen Harrier breeding success

Background

The protection of Hen Harriers in Ireland is principally by means of designation of Special Protection Areas, which are managed to ensure that suitable habitat is provided for Hen Harriers. In order to successfully coordinate Hen Harrier conservation with other land uses we need to understand the factors that contribute to breeding success in this species, and how these are related to habitat management.

Declines in Hen Harrier populations throughout Europe have been associated with anthropogenic impacts including habitat loss and persecution (Watson, 1977; Etheridge *et al.*, 1997; Amar *et al.*, 2003). The use of different forested and non-forested habitats during the breeding season by Hen Harrier has been the subject of investigation in recent times, particularly in Scotland and Wales (Meek *et al.*, 1998; Thirgood *et al.*, 2003; Amar and Redpath, 2005; Sim *et al.*, 2007). Many studies have investigated the possible reasons and mechanisms for declining Hen Harrier populations

Prior to the mid-20th century, the typical breeding habitats of Hen Harriers were open moorland, bog, areas of scrub and rough pasture in the uplands (Redpath *et al.*, 1998; Sim *et al.*, 2001; Norriss *et al.*, 2002). In many upland areas now occupied by Hen Harriers, the extent of such habitats has been reduced by agricultural intensification and afforestation. The ground vegetation of young plantations provides suitable nesting and foraging habitat for Hen Harriers (O'Flynn, 1983; Redpath *et al.*, 1998; Madders, 2000) allowing populations to persist in these areas. However, while Hen Harriers nest and forage in young plantations, they do not use this habitat as extensively following canopy closure, and the maturation of upland conifer plantations may limit the availability of suitable breeding and foraging sites (Petty and Anderson, 1986; O'Donoghue, 2004; Sim *et al.*, 2007). Furthermore, although Hen Harriers appear to have adapted to forested areas to a remarkable degree, at least in some parts of their range, degradation of preferred habitat may have a negative effect on breeding performance of Hen Harriers, ultimately limiting productivity (Amar *et al.*, 2007b). Restocked plantation forest has only become widely available to Hen Harriers in Ireland in recent decades, and so the preferences expressed in relation to this habitat, in terms of nest site selection, may not be entirely adaptive or translate into high breeding success.

The aim of this Work Package was to investigate the breeding biology of Hen Harriers in Ireland, and examine factors that influence breeding success, to inform conservation management, particularly in Special Protection Areas.

Methodology

Data on breeding Hen Harriers were collected at four study sites (Slieve Aughty Mountains, West Clare, Kerry and Ballyhoura Mountains) in the south of Ireland between 2007 and 2011 (Figure 27). The study sites in the Slieve Aughty Mountains and in Kerry are designated Hen Harrier SPAs, while the other two study sites hold relatively dense concentrations of breeding Hen Harriers (Barton *et al.*, 2006). The four study areas include a matrix of different habitat types including first and second rotation conifer plantations.

Figure 27. Study areas in Slieve Aughty Mountains, West Clare, Kerry and Ballyhoura Mountains.

Due to variation in available manpower, data was collected in Kerry only during the first three years of the study when Barry O'Donoghue (NPWS) was collecting data for his PhD study, which comprised part of this Work Package. In addition to manpower funded by the current project, National Parks and Wildlife Service provided supplementary funding each year in support of fieldwork on this project, and also employed a fieldworker to assist with data collection.

Data were collected during the breeding season between April and August each year. Territories were located by vantage point watches early in the breeding season at each study area. Nest locations were identified, typically between April and June, by observing the behaviour of territorial pairs before and during nest-building and laying, and by tracking females back to the nest after they had accepted food-passes from males during incubation and brooding. Nest visits were then undertaken (under licence from National Parks and Wildlife Service) to gather information on breeding biology. This included:

- Timing of breeding (first egg, hatch and fledge dates).
- Clutch size.
- Brood size.
- Nest failure (timing, cause) or success.
- Number of fledged young.

Initial visits were made to nests to identify breeding attempt status and nest contents, with a final visit to ring and wing-tag chicks when they were approximately four weeks old. Nest visits were not conducted where this was deemed to pose too great a risk to the success of the breeding attempt, either by drawing the attention of potential predators to the nest, or by facilitating access to the nest by predators though trampling of surrounding vegetation. Fieldwork continued until early August, with all nests being monitored until they had either failed or fledged. Nest cameras were also installed at a subset of nests to supplement data acquired by visual observation in study sites (Figure 28). Hen Harrier pellets were collected from winter roost sites and nest sites during the course of the study. During the summer of 2008 these were analysed by a student employed on a summer bursary to identify prey items and describe the Hen Harrier's diet.

Only nests with known breeding outcomes were used in the calculations. Three main measures of the breeding success of the population were calculated. Fledged brood size was calculated as the average number of young fledged from successful nests. Breeding productivity was calculated as the average number fledged across all nests. Finally, nest success rate was calculated as the percentage of nests that fledged at least one young. The Mayfield method was also used to calculate daily survival rates, and to estimate success rates of nests in this study (Mayfield, 1975). The effects of year and study area on success rate (the probability of nests fledging one or more young) were also investigated.

Figure 28. Fieldworkers checking live footage from a camera deployed at a Hen Harrier nest.

Habitat assessments were carried out for all nests in the weeks following fledging. Habitat data were derived from digitised forest inventory information held by the Forest Service for privately owned forests, and by Coillte for state owned forests. Non-forest habitat data was derived from habitat maps of our study areas compiled by NPWS. We verified this information using aerial photographs and field-based ground-truthing. Each nest was classified into one of six habitat categories:

- First-rotation pre-thicket forest
- Second rotation pre-thicket forest
- Closed canopy forest
- Improved grassland
- Heath/bog
- Rough grazing/Scrub

In order to conduct analysis of breeding success in relation to habitat at the landscape scale, the proportion of land within 2 km of each nest falling into each of seven categories (the six habitats listed, and a miscellaneous category comprising all other habitats) was calculated.

In order to gather data on parental behaviour of female Hen Harriers cameras were deployed at 27 nests in Kerry, the Ballyhouras, West Clare and the Slieve Aughty mountains between 2008 and 2010. This resulted in usable data from 16 nests (in the Ballyhouras, West Clare and the Slieve Aughty mountains), with 11 cameras producing no data either due to the field of view being too narrow, the lens being out of focus or the image produced being too dark to view activity. The cameras operated under a Video Motion Detection (VMD) facility which recorded images when activity occurred at the nest. Information on attendance, incubation/brooding and provisioning activity were the principal data extracted while other information, such as prey type, size, male attendance and interesting events were also noted. Attendance, incubation/brooding and provisioning behaviour of the female was analysed in relation to variation with chick age and time of day. The reliability of the camera system and its implications for interpretation of the data were also investigated by determining any illogical time sequences, for example, gaps in footage that were greater than 30 minutes with a large change in orientation of the female or an illogical behaviour pattern.

The wing-tagging scheme initiated in 2006 by the Irish Raptor Study Group (IRSG) and National Parks & Wildlife Service (NPWS) was expanded significantly during this project. Wing tags were made from PVC nylon and were attached to the birds by fastening the tag through the patagium (between wrist and shoulder). Several morphometric measurements (weight, wing length, tarsus length and width) were recorded from each nestling. The colour of the right wing-tag was specific to the study area (Kerry = Red, Ballyhoura = Yellow, West Clare = Green, Slieve Aughty Mountains = Black), while the colour of the left wing-tag represented the year of tagging (2007 = Red, 2008 = Green, 2009 = Yellow, 2010 = Black, 2011 = Orange). In addition, an individual alphanumeric identifier was included on each tag to facilitate identification of individual birds. Posters were used to advertise the colour scheme and solicit feedback of sightings from the general public, and details of the scheme were also submitted to the European colour-ring Birding website (http://www.cr-birding.be).

Results

Breeding Biology

Almost two hundred Hen Harrier nests were monitored during the five years of this study, the annual number located in each study area declining over this time (Table 5). The success rate of these nests remained relatively consistent over the course of the study in all areas except in West Clare (where it declined) (Figure 29), and the number of young produced by successful nests remained consistent over time (Figure 30). The annual number of juvenile Hen Harriers produced by the three main study areas ranged from 21 to 61, and showed a slightly decreasing trend over time, with 38 fledged in 2007, 61 in 2008, 35 in 2009, 21 in 2010 and 25 in 2011. The average number of juveniles fledged from all successful and unsuccessful nests (productivity) during this study was 1.4 ± 0.3, and productivity over the course of the 5 year study period was 1.9 in West Clare, 1.3 in the Ballyhouras and 1.0 in the Slieve Aughty Mountains, showing a decline over the duration of the study in West Clare only.

Table 5. Number of nests included in the analysis in each study area during each of the five years.

YEAR	2007	2008	2009	2010	2011
Sli Aughty Mts	9	12	12	8	7
West Clare	10	12	10	9	7
Ballyhouras	11	14	9	7	6
Kerry	15	22	16	-	-
TOTAL	**45**	**60**	**47**	**24**	**20**

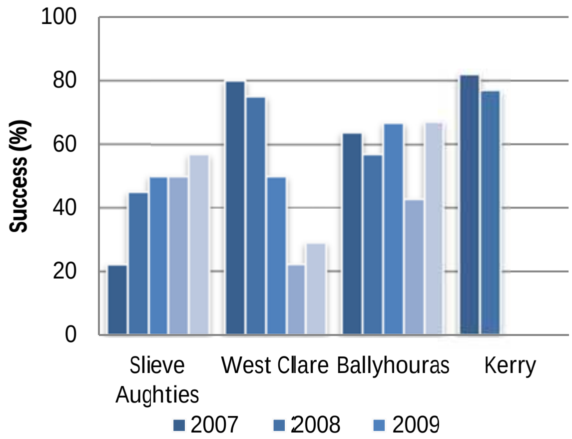

Figure 29. Percent of Hen Harrier nests that produced fully fledged young in each study year in each of the study areas.

Figure 30. Mean (±se) number of juvenile Hen Harriers produced in each study area by successful nests in each study year in each of the study areas.

Breeding Success in Different Habitats

The outcomes of 140 nests from the four study areas were recorded between 2007 and 2009 for analysis of the relationship between breeding habitat and breeding success. Seventy percent of the variation in overall breeding productivity was explained by nest success. Nest success was found to differ significantly between study areas. Neither nest success nor fledged brood size was related to total forest cover, or to percentage cover of closed canopy forest in the landscape. The proportion of second rotation pre-thicket forest in the landscape around Hen Harrier nests was negatively related to nest success in the Slieve Aughty mountains, but there was no evidence of a similar relationship in other study areas.

Diet

Almost 900 Hen Harrier pellets were analysed during this project and the majority contained just one prey item. In addition, prey remains and direct observations were included in prey analysis. Nest camera footage was not included in dietary analysis due to the poor quality of images for this purpose. Hen Harriers were found to have a diverse diet, which varies between areas and seasons, and includes small mammals, birds, amphibians and reptiles. Of these prey items 78% were birds and the remainder mammalian prey. 78% of the bird prey items taken by Hen Harriers were passerines.

Wing-tagging

One hundred and seventy juvenile Hen Harriers were tagged using colour-coded wing-tags during this study in the three study areas (Figure 31). Forty were tagged in 2007, 69 in 2008, 25 in 2009, 20 in 2010 and 16 in 2011. Forty eight percent of tagged nestlings were male and 52% were female. Very few tagged birds were recorded during subsequent breeding seasons. One bird tagged in the Slieve Aughty Mountains in 2008 is known to have over-wintered in Galway in 2008 and 2009, and to have returned to the Slieve Aughty Mountains to breed in 2010 and 2011. Two Hen Harriers tagged in the Ballyhouras were subsequently recorded (separately) in the Slieve Aughty Mountains and the Ballyhouras, though neither was recorded to have bred. A Hen Harrier wing tagged in Kerry in 2010 was sighted in South Wexford in the autumn of 2011. Tagged birds have been recorded more frequently at communal winter roosts than they have during the breeding season (O'Donoghue, 2010).

Figure 31. Hen Harrier chick carrying a custom made wing-tag.

Parental Behaviour

Data collected using nest cameras revealed a highly significant difference between females in nest attendance (H=182.48; df=4, P<0.001) and incubation/brooding (H=167.59; df=4, P<0.001) over time (Figure 32). A highly significant difference in provisioning rate was also found between females following hatching (H=36.76; df=11, P<0.001) by females as chicks increased in age (Figure 33). The main trends observed in the data on daily provision rate were a low provisioning rate early in the day followed by a steady increase over the course of the day and a gradual decline towards dusk.

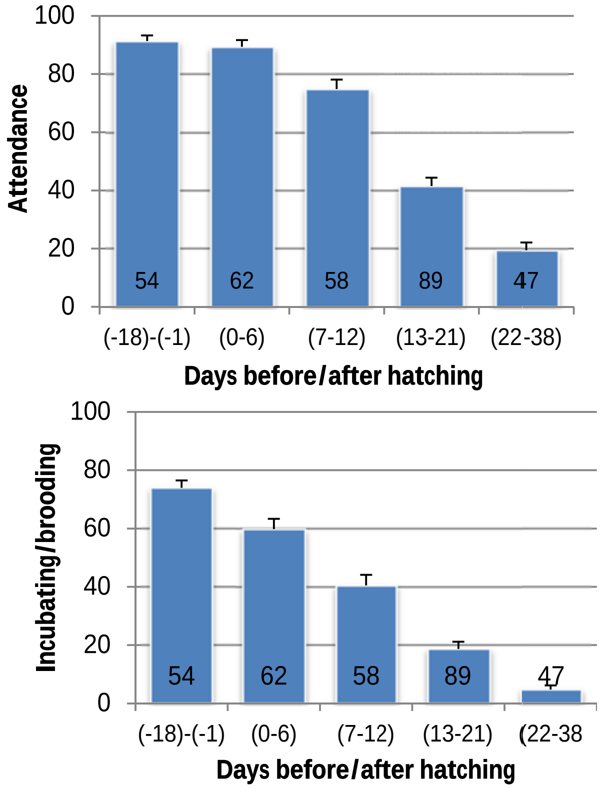

Figure 32. Mean (±se) proportion of time spent in attendance by the female (top) and incubating/brooding (bottom) with increasing chick age. Values in columns indicate sample size (number of nesting days).

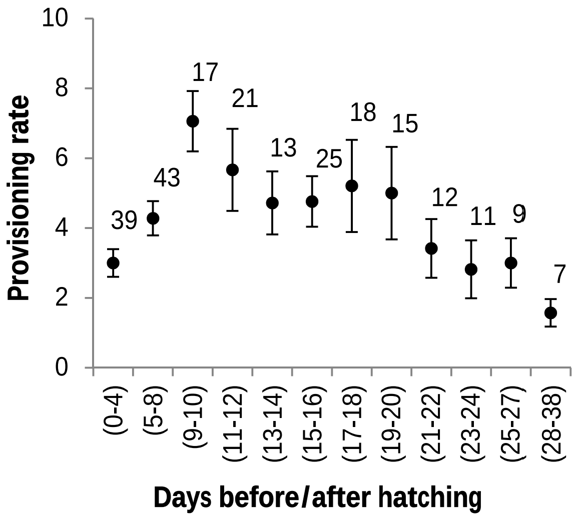

Figure 33. Mean (±se) provisioning rate of the female with increasing chick age. Values above error bars indicate sample size (number of nesting days).

Camera footage provided limited data on prey identification due the inadequate quality of images recorded as a result of low camera magnification, location/distance of the camera from the nest cup and female or vegetation blocking view of feeding events. Of those prey items (48%) that were identified 36% were small passerine (including 1 coal tit, 1 chaffinch, 1 pipit), 9.9% were medium passerine (Including 1 blackbird, 1 thrush) and 2.13 % were small mammals.

The installation of nest cameras at Hen Harrier nests has provided empirical data on parental behaviour activities at the nests of Hen Harrier with minimal disturbance. The nest cameras also captured other interesting events including siblicide by the older chick of the younger chick at a nest with just two chicks, the predation of a nest by a fox (Figure 34) and a female Hen Harrier defending a nest against a kestrel (Figure 35).

Figure 34. Fox at Hen Harrier nest.

Figure 35. Adult female Hen Harrier defending the nest against a Kestrel.

Effects of Fieldwork on Breeding Success

This project involved visits by fieldworkers to nests over a 5 year period to collect information on breeding biology, to ring and wing-tag nestlings, to deploy cameras at nests and GPS tags on adult Hen Harriers. Given the vulnerable status of this species in

Ireland we conducted a study to check that our research activities did not have a significant impact on the birds.

The data used in these analyses were derived from 60 visited and 28 unvisited nests found during between 2008 and 2010. All unvisited nests included in this analysis were found and known to be active during the period when visited nests in that study area were being visited for the first time. When they were first located nests were rated for risk relating to disturbance and predation. Nests in visited and unvisited groups had a similar spread of risk ratings assigned to them. Nest cameras were deployed at 24 of the visited nests. We used a method called 'logistic exposure modelling' a variant of Generalised Linear Modelling (GLM) that allows for testing of the effects of fieldwork activities on nest success (the probability of nests successfully fledging at least one chick) while controlling for the number of observation days at each nest (Schaffer, 2004). As well as the two research-related variables 'Visited' and 'Camera', we also tested for effects of 'Year' and 'Region' on nest success using GLM.

At the 60 visited nests the average success rate was 63%, while at the 28 unvisited nests the success rate was 50%. This difference was not statistically significant, nor was there any statistically significant effect of 'Region' (Table 6). Of the 24 nests where cameras were deployed, 13 (54%) were successful. Neither 'Camera' nor 'Region' was retained in the final model, but 'Year' was (Table 7).

Table 6. Final model selected for nest success of visited and unvisited nests from 2008 – 2010. Region was not included in the final model. Null deviance 119.07 on 87 degrees of freedom, residual deviance 140.36 on 84 degrees of freedom. AIC = 148.36.

	Estimate	se	z value	Pr(>|z|)
Intercept	4.8606	0.2638	18.426	<2e-16
Visited	0.7376	0.3919	1.882	0.0598
Year 2009	0.4534	0.4758	0.953	0.3406
Year 2010	-0.9028	0.4435	-2.036	0.0418

Table 7. Models for nest success for nests with and without nest cameras during the breeding seasons of 2008 and 2010. Neither region nor presence of camera was included in the final model: a. model with presence of camera included. Null deviance 119.07 on 87 degrees of freedom, residual deviance 143.38 on 84 degrees of freedom. AIC = 151.38; b. model with presence of camera deleted from model. Null deviance 119.07 on 87 degrees of freedom, residual deviance 144.03 on 85 degrees of freedom. AIC = 150.03.

a.	Estimate	se	z value	Pr(>|z|)
Intercept	4.6625	0.2581	18.064	<2e-16
Camera	0.3388	0.4303	0.787	0.4310
Year 2009	0.1472	0.4452	0.331	0.7408
Year 2010	-1.1813	0.4723	-2.501	0.0124

b.	Estimate	se	z value	Pr(>|z|)
Intercept	4.7202	0.2463	19.167	<2e-16
Year 2009	0.1702	0.4444	0.383	0.7017
Year 2010	-0.9968	0.4405	-2.263	0.0237

In 2010, four breeding adults (three males and one female) at four nests were captured in order to fit them with GPS/VHF harness backpack-style harnesses. All of these birds continued to provision nests after being released, and three of the four nests fledged successfully. The other nest failed more than three weeks after deployment of the GPS tag on the male bird at this nest, about a week after the female at this nest was fatally injured at the nest, possibly by a predator.

These data confirm that our fieldwork did not have a noticeable impact on overall Hen Harrier breeding success. The absence of an effect of fieldwork should be considered in the context of the study, which involved highly trained, experienced staff adhering to detailed fieldwork protocols that ensured that the welfare of birds was the main priority.

Discussion

The number of nestling Hen Harriers produced each year by the three main study areas ranged from 21 to 61 during the period 2007-2011, and showed a slightly decreasing trend over time. Although the objective of this study was not to census the Hen Harrier population in our study areas, the data does suggest that, at least in some parts of their range, Hen Harrier numbers in Ireland are decreasing and that low levels of breeding success may be a contributing factor in this decline. Our data supports previous studies on Hen Harriers in other parts of their range, which show that nest success is a more important determinant of Hen Harrier breeding success in different years than the size of broods produced (Etheridge *et al.*, 1997; Whitfield and FIelding, 2009).

The average number of juveniles fledged from all successful and unsuccessful nests (productivity) during this study was low (1.4 ± 0.3), but in keeping with productivity of Hen Harriers reported from other parts of their range (England, 2008). Productivity over the course of the 5 year study period was 1.9 in West Clare, 1.3 in the Ballyhouras and 1.0 in the Slieve Aughty Mountains, and showed a decline in West Clare only. Declining populations are associated with much lower productivity rates (Amar *et al.*, 2007b). However, the average of 2.4 (± 0.2) chicks were fledged per successful breeding attempt, is lower than reported in the UK, where successful Hen Harrier nests have been observed to fledge an average of more than 3 chicks (Fielding *et al.*, 2011). Although the productivity of Irish Hen Harriers in this study was not very high, it was above the theoretical threshold for stable or increasing populations identified by a recent study of Hen Harriers in the UK (Fielding *et al.*, 2011), suggesting that it is sufficient to allow Hen Harrier populations in these areas to remain stable, in the absence of negative effects of dispersal or poor survival rates. Although this study did not provide detailed data on juvenile survival, dispersal and subsequent recruitment to the breeding population, return rates of tagged individuals were very low indicating that further work in this area is necessary.

Our research on Hen Harrier foraging ecology, undertaken for Work Package 2 of this project (Wilson *et al.*, 2009), and research conducted in parts of western Scotland (Haworth and Fielding, 2009) have shown that Hen Harriers select recently planted forest habitat, in areas including second rotation forests and those with closed canopies, for nesting, and actively avoid landscapes with high proportions of intensively farmed pasture during nest site selection. The negative relationship between second rotation pre-thicket forests and Hen Harrier breeding success therefore suggests that Hen Harriers may be making suboptimal decisions regarding habitat selection in the landscapes available to them. Such a relationship could arise from a direct effect of second rotation pre-thicket forests on Hen Harriers. This could be the case if this habitat were associated either with unusually high abundance or activity of predators, or with unusually low abundance or availability of prey. Hen Harrier breeding success can be affected by availability of food both before and during the nest period (Amar and Redpath, 2002; Amar *et al.*, 2003; Amar and Redpath, 2005). If availability of prey was lower in pre-thicket second rotation than in alternative hunting habitats, Hen Harriers breeding in landscapes with a high proportion of this habitat could be disadvantaged. One way in which such an effect could come about is through the presence of brash (woody debris left after forest operations) in young second rotation forests, which might make access by harriers to prey more restricted than in other habitats. The observed area-specificity of the relationship might then be explained if the prey types available in the Slieve Aughty Mountains were better able to take advantage of the cover provided by this habitat, or if there were differences in the way this habitat was managed in this area relative to our other study areas.

Recommendation 8: Hen Harriers actively select recently planted forest habitats, both for nesting and foraging. Second rotation pre-thicket forests were selected for nesting, while landscapes with high proportions of intensively farmed pasture were avoided. These factors need to be taken into account by conservation management plans.

Alternatively, second rotation pre-thicket forests could be associated with other landscape features or properties that have a negative impact on Hen Harrier breeding success. High levels of nest loss and predation have been associated with edge habitats (Weldon and Haddad, 2005; Hoover *et al.*, 2006; Pedersen *et al.*, 2009), and internal forest edges are likely to be more prominent in forests with high levels of second rotation pre-thicket. Also, the proportion of second rotation forest is highest in areas where plantation forests have been established for the greatest length of time. Such areas may support greater concentrations of nest predators such as foxes, corvids and mustelids, densities of which can be positively affected both by total area of forest and by the density of forest edge habitats (Chadwick *et al.*, 1997; Smedshaug *et al.*, 2002; Carey *et al.*, 2007). Pine Marten (*Martes martes*) is a forest mustelid that opportunistically preys on bird eggs and whose numbers have responded positively to the recent increase in Ireland's plantation forest cover. It is now most numerous in areas where suitable habitat such as conifer forest has existed for longer (National Parks and Wildlife Service, 2008). If nest success is affected by predators such as Pine Marten, this might help to explain the difference in the effect of second rotation pre-thicket between study areas, as the abundance of this species is probably higher in the Slieve Aughty Mountains than in our other study areas (O'Mahony *et al.* (2006), Declan O'Mahony pers. comm.).

Recommendation 9: We recommend that land use planning and management ensure the right mix of habitats for Hen Harriers in SPAs.

The installation of nest cameras at Hen Harrier nests enabled the monitoring of nest attendance and behaviour with minimal disturbance to the nest site during critical periods of the breeding season, provided savings in resources and reduced the potential for observer bias in results. In general evidence suggests that cameras have minimal disruption to the nest site or parental behaviour (Thompson *et al.*, 1999; Peietz and Granfors, 2000; Sabine *et al.*, 2005). Analysis of nest camera footage showed significant changes in female attendance and incubation/brooding with chick age which generally decreased through the breeding season. As the demands of the eggs and chicks change, the time activity budgets of the parents are also adjusted so that a trade-off was reached between attending and incubating/brooding at the nest and foraging away from the nest (Palmer *et al.*, 2001; Redpath *et al.*, 2002b). The results of this study showed that the female Hen Harrier does not leave the nest prior to hatching. During this time she relies on the male to provision her (Amar and Redpath, 2002; Hardy *et al.*, 2006). This changes just after hatching when the chicks become dependent on attendance and brooding behaviour of the female (Redpath *et al.*, 2002a). As the chicks grow, their food requirements are also likely to increase and therefore the female hunts more frequently once the chicks are at this stage and as their physiological demands increase. The low provisioning rate seen later in the season may be due to the chicks increased independence where they spend more time away from the centre of the nest and therefore the camera may not record all prey events as feeding takes place outside the immediate nest area as well as growth of vegetation blocking view of feeding activities. Time of day also had a significant influence on attendance and incubation/brooding by females as chicks age increased. No significant variation in attendance and incubation/brooding activity was seen over the course of the day early in the breeding season, which is related to the fact that females are either incubating the eggs (as heat is required for embryonic development) or brooding the nestlings (due to thermoregulation requirements).

Recommendation 10: Further work on Hen Harrier ecology should focus on investigations of habitat quality, the interaction between breeding sites and roosting sites, the fate of fledged young in Ireland, the source of our national breeding population and the potential compatibility between Hen Harrier breeding ecology and further land-use development and climate change.

The findings of this Work Package on breeding biology of Hen Harriers have been reported in a PhD thesis (O'Donoghue, 2010), at a number of conferences and in peer reviewed publications. A paper in *Irish Birds* in 2008 (Appendix 2) reported on the basic breeding biology as determined during the first two years of the study (Irwin *et al.*, 2008). A subsequent paper in *Irish Birds* (Appendix 4) provided a more complete review of the breeding biology of Hen Harriers over the 5 years of the study and described patterns and trends between areas and across years (Irwin *et al.*, 2011). A paper on parental behaviour of female Hen Harriers has been prepared for submission to *Bird Study* by Nora Lewon. A paper addressing the relationship between habitat and breeding success has been accepted for publication in *Ibis* (Wilson *et al.* 2012). Papers on movements using the wing-tagging data and on the diet of Hen Harriers in Ireland are currently being prepared (O'Donoghue *et al.*, In Prep).

Implications for policy and practice

This study constitutes a step change in the level of study on Hen Harriers in Ireland, involving several novel elements such as the collection of information on parental behaviour using nest cameras, and the collection for the first time of movement data on foraging Hen Harriers using GPS. Our results show that Hen Harriers show a preference for forested habitats in several contexts, including nest-site selection and foraging, and we have identified a number of important gaps in our knowledge. In particular, these include habitat-specific variation in predator and prey populations, and the relationship between breeding population fluctuations and Hen Harrier movements and survival outside of the breeding season. It is worth noting that, despite the wide range of field activities carried out on breeding Hen Harriers, including visits to nests, deployment of nest cameras, capture and GPS-tagging of adults, and wing-tagging and ringing of juveniles, no negative effects of fieldwork on nest success of birds were found over the whole duration of the study. Given that the restrictions associated with the licenses under which this work was carried out sometimes reduced the effectiveness of the work, particularly in relation to capture of adults for GPS tagging, it may be possible make changes to the way that fieldwork is regulated that improve the quality of science it is possible to carry out on Hen Harriers in Ireland without compromising its conservation status.

In order for effects of habitat change on Hen Harriers to be effectively monitored, up to date information must be collected on both Hen Harriers and habitat. The national surveys of Hen Harriers that have been carried out every five years since 2000 (Norriss *et al.* 2002, Barton *et al.* 2006, Ruddock *et al.* 2012) provide good overall information about changes in population size and distribution. However, at present there is no systematic collection of data on habitats that Hen Harriers use that would allow changes in Hen Harrier population parameters to be assessed in the context of habitat change. Detailed information on the composition and age of most forests is regularly updated in the inventories held by Coillte and Forest Service (albeit with a time lag). However, the only regularly updated dataset that holds information on non-forest habitats is CORINE, which does not discriminate between different Irish upland habitats effectively enough to be very useful for any study of Hen Harrier ecology. Because the majority of Hen Harrier pairs breed in areas with mosaics of forest and non-forest habitats, a more holistic approach is needed to monitoring and managing these areas for Hen Harriers. Establishing a habitat dataset of open habitats in Ireland that can be compiled and, crucially, updated in an automated manner (from aerial photographs, satellite imagery and other remote sensing datasets) would go a long way to enabling such an approach.

More research is needed to better understand the nature of the relationship between second rotation pre-thicket forests and Hen Harrier breeding success observed in the Slieve Aughties – both to determine what factors are responsible for it, and to test whether and to what extent it is representative of the value of forest habitats in the wider landscape. Particularly worthy of further investigation is the potential for this relationship to be mediated by variation in prey availability and/or predator activity associated with second rotation pre-thicket forests. Both of these factors, in particular the latter, are more generally worthy of study, as they affect many species other than Hen Harriers, and there has been relatively little study on them in an Irish context to date.

In order for further afforestation to be permitted within Hen Harrier SPAs the licensing authority needs to be satisfied that such planting will not lead to an overall deterioration of the SPA or to any areas within it. When planning for further afforestation in SPAs, as well as in other areas with breeding Hen Harriers, it therefore makes sense to ensure that such land use change happens in areas where it is unlikely to tip landscape configuration into an unfavourable state for this species. To this end, a strategic zoning of SPAs according to the thresholds of forest and other suitable habitat cover could help to minimise the risk of negative impacts of afforestation. Such zones would be based on the ability of landscapes to accommodate further afforestation while remaining favourable to Hen Harriers, and should be updated regularly to reflect on-going changes in land use.

Within SPAs and other areas managed for Hen Harrier conservation, activities such as forest establishment and wind farm development are strictly regulated. The statutory instrument describing the SPA also lists some agricultural activities, such as the 'improvement' of heath or bog, which are cited as requiring the consent of the Minister for Arts, Heritage and the Gaeltacht before being undertaken in these areas. However, 'agricultural improvement' of grassland areas is not currently included among these activities, despite evidence that it is has the potential to be detrimental to Hen Harriers. We have confirmed the findings of other studies that have shown that Hen Harriers show strong avoidance of intensively managed agricultural land. This was apparent at both local and wider landscape scales, in nest-site selection and in habitat use by foraging birds. The National Parks and Wildlife Service's Farm Plan Scheme, of which there is significant uptake throughout the Hen Harrier SPA Network, is currently used as a means of limiting agricultural improvement of grassland habitats within SPAs. However, this scheme does not apply to any areas with Hen Harriers outside of SPAs, and other financial incentives (such as farm area-based payments, which may require clearance of scrub in order for an area on a farm to be eligible) may actively encourage farmers to decrease the quality for Hen Harriers of the habitats they manage. Finding ways to limit the degree to which agricultural intensification is permitted in upland areas occupied by Hen Harriers, would help to ensure that the value of such areas for this species is not degraded.

The GPS data is useful in indicating the value of certain habitats for foraging – particularly scrub, second rotation forest, and patchy closed canopy forest. The association of foraging Hen Harriers with hedgerows and with farmland managed at low intensity suggests a benefit of shrub-rich habitats, but the apparent avoidance of hedgerows greater than 5m wide and entirely unmanaged land suggests that unchecked development of scrub may not be in this species best interests. Neither the preference shown for young second-rotation forests, nor the avoidance of areas in the first few years after clearfelling were surprising. However, the use of forests up to 15 years old suggests that this restock may continue to be useful for Hen Harriers for longer than was previously thought to be the case. In the case of Hen Harriers foraging in closed canopy forest, there is little evidence from the GPS tracking data for a preference for stands with patchy growth. However, this is perhaps because patchiness levels corresponding to more than 50% open habitat (due to large scale failure of young trees, or sometimes to disease or fire) are seen less often in the Ballyhouras than in other parts of the country such as the Slieve Aughty mountains and West Clare. More generally, the fact that all three Hen Harriers from which GPS data were collected were tracked in the Ballyhouras means that caution should be exercised in generalising from this data to Hen Harriers in other areas. Tracking of Hen Harriers in additional areas would surely yield better information on foraging preferences in a wider spectrum of habitats and landscapes.

This study also highlights the potential for remote tracking to generate useful data on Hen Harriers, and there are at least two ways in which such technologies could play a useful role in advancing Hen Harrier conservation in the future. The accurate positional data that can be collected using GPS tags makes this technology well-suited to tracking the movements of Hen Harriers breeding near wind farms, in order to evaluate the risk of turbines having a negative through either collision or habitat displacement. Satellite tags based on systems such as ARGOS were not suitable for use in this study due to the lack of positional accuracy relative to GPS, but the ability to retrieve data from such tags remotely, irrespective of location, makes them perfectly suited to collecting data from juvenile birds in the period between fledging and the subsequent breeding season. The very low re-sighting rates on breeding grounds of birds tagged as nestlings reported in this study suggest that recruitment of young birds into breeding populations may be low enough to pose a threat to the stability of Irish Hen Harrier populations. Information about the post-fledging movements and eventual fates of young birds could be crucial in helping to identify the extent and causes of such a problem.

Conclusions and recommendations

The implementation of an effective conservation strategy for Hen Harriers in Ireland is reliant on up-to-date information and scientific knowledge of Hen Harrier populations and the habitat composition of the areas that they inhabit across all stages of their life cycle. Three National Hen Harrier surveys have been undertaken, the first in 2000, the second in 2005 and the most recent in 2010, to obtain a reliable estimate of the size and distribution of the Irish Hen Harrier breeding population. The output from the first Work Package of the current project was a GIS database which brings together all of the relevant information on habitat composition of Hen Harrier SPAs in Ireland. This was used in the analysis of Hen Harrier habitat preferences in the current project and provides a useful tool and reference point against which the effects on Hen Harriers of land use changes such as agricultural improvement afforestation and felling can be assessed, in order to inform forest policy and strategic planning in the SPAs.

Although the aim of the present study was not to census Hen Harrier populations in our study areas we did aim to study the breeding biology of as many nests as possible in each study area during each of the five study years. Our data suggest a decrease in breeding numbers of Hen Harriers in our study areas in the south-west of Ireland during this time. Although the breeding productivity of these nests (the numbers of chicks produced) was technically above the threshold for stable or increasing populations, the decline in the numbers of adult pairs breeding each year resulted in a decrease in the number of young Hen Harriers produced in Ireland in recent years. The lack of evidence for successful recruitment of young birds into the breeding population over the course of this project indicates that a combination of low breeding output and poor juvenile survival may be important factors in the observed declines in Hen Harrier populations. There is scope to develop this work further through investigation of the factors affecting juvenile survival, post-fledging movement and subsequent recruitment to the breeding population. This can be achieved through continuation of the wing-tagging scheme that is currently in place. Satellite tagging of juvenile birds would also offer a useful insight into the factors determining survival and recruitment of young Hen Harriers into the breeding population.

Historic fluctuations in Hen Harrier populations have been related to land use change, and particularly to a reduction in the extent of traditional breeding habitats such as moorland and bog. During the latter part of the twentieth century, the uplands of Ireland have undergone a period of intense afforestation. Hen Harrier populations in Ireland appear to have adapted well to this change, responding to the decline in suitable open habitats by making increased use of young forests. Many of these forests have now matured and are entering the second forest rotation representing a further large-scale change in these upland areas. The present study revealed that the main nesting habitats selected by Hen Harriers in the uplands of Ireland were young forests, of both first and second rotations, with no evidence that the area of closed canopy forest negatively affected Hen Harrier distribution. Landscapes with a high percentage cover of agriculturally improved land were avoided both as nest sites and at landscape level. Intensification of agricultural management within areas that hold breeding Hen Harriers should therefore be avoided. Where it is possible to increase shrub cover and reducing grazing pressure in intensively managed farmland near Hen Harrier breeding areas this may improve the value of such habitats for this species. However, data collected using GPS tagging of foraging Hen Harriers suggest that, in grassland areas, abandonment of agricultural land is unlikely to favour Hen Harriers, the strongest preferences shown by foraging birds being for areas with farmed at low intensity, with moderate levels of shrub cover.

The presence of breeding Hen Harriers in Ireland's newly forested landscapes does not guarantee their persistence in these areas. We found that breeding success was not related to total forest cover in the landscape, or to the proportion of mature forest in the landscape, but at nests in the Slieve Aughty Mountains high cover of second rotation pre-thicket forest was associated with low levels of breeding success. This may be due to factors, unique to this site, related to predation, disturbance or prey availability, and indicates that habitat composition may play a role in determining Hen Harrier breeding success. Land use changes taking place in areas studied during this time (and, bearing in mind the potential for lagged population responses to ecological change, in the preceding period) include agricultural intensification and changes in the extent and composition of the forest estate. Both of these activities are on-going and, at least until their effects on Hen Harriers are better understood, should be regulated in areas where this species breeds in order to limit their potential to negatively influence Hen Harriers. The management of habitats for Hen Harriers should aim to ensure a consistent matrix of different aged forest stands at the landscape level in order to minimise variation in percentage cover and availability of different age classes across the forest cycle. Particularly in areas with high levels of forest cover, where second rotation pre-thicket forest often constitutes a large proportion of the suitable habitat available, this would help to minimise the length and severity of any 'bottle-necking' effect of periods where the landscape is dominated by closed canopy forest.

We make the following key recommendations, subject to the limitations of this project:

1. Felling and replanting are not currently grant-aided in Ireland, and though the former takes place under license from the Forest Service, neither of these activities is formally recorded by the Irish State. All felling and replanting in Ireland should be formally recorded within six months in a national GIS database. This might be achieved by increasing the frequency of FIPS updates, and broadening their remit to include establishment of second rotation forests as well as new plantings.
2. The quality and frequency of updating of data on non-forest habitats is in even greater need of improvement. Two actions that would be helpful in this regard would be to establish a system whereby landcover data can be updated regularly (preferably in an automated manner, using remote sensing datasets), and to explore the possibility of using CSO data on farm surveys as a proxy for land use data.
3. In addition to developing a land cover dataset for Ireland, we recommend a study aimed at calibrating CORINE data to facilitate its use in studies of birds in Ireland, possibly using data from the CBS (Countryside Bird Survey).
4. Hen Harrier conservation would benefit from a socioeconomic study of the benefits of complying with EU regulations to ensure that land uses are compatible with Hen Harrier conservation.
5. The long-term influence of forested areas on Hen Harriers is likely to be optimised by minimising fluctuations in the availability of forest growth stages (such as pre-thicket, thicket and closed canopy forest) over time, by ensuring a consistent matrix of different aged forest stands is maintained at the landscape level. This would help to avoid ‘bottleneck’ effects due to periods when the cover of any one habitat was particularly high or low. We recommend a strategic approach to zoning SPAs according to their suitability for afforestation, as a means of ensuring that habitat composition within SPAs is regulated on a scale appropriate for Hen Harriers.
6. The use by Hen Harriers of different forest ages revealed by GPS tracking data shows that forest areas being managed for Hen Harriers should aim for as high a proportion of forest as possible within the 6-11 year old age range (bearing in mind the requirement for minimising fluctuations in the availability of different growth stages). However, forests as old as 12-15 years are still more useful than older age classes as foraging habitat. We recommend maintaining as high a proportion of forest as possible across the 6-15 year age range, in Hen Harrier SPAs.
7. Foraging Hen Harriers showed the greatest preference for boundaries between 3m and 4m wide, apparently avoiding very narrow or very wide boundaries. Boundaries of this size typically correspond to old townland boundaries. We recommend maintenance of appropriate sized field boundaries and activities which result in destruction or deterioration of these boundaries should be avoided in areas used by foraging Hen Harriers.
8. Hen Harriers actively select recently planted forest habitats, both for nesting and foraging. Second rotation pre-thicket forests were selected for nesting, while landscapes with high proportions of intensively farmed pasture were avoided. These factors need to be taken into account by conservation management plans.
9. We recommend that land use planning and management ensure the right mix of habitats for Hen Harriers in SPAs.
10. Further work on Hen Harrier ecology should focus on investigations of habitat quality, the interaction between breeding sites and roosting sites, the fate of fledged young in Ireland, the source of our national breeding population and the potential compatibility between Hen Harrier breeding ecology and further land-use development and climate change.
11. We recommend building on this project through further research projects to answer these critical questions for this Annex 1 species.

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Full list of outputs from the project

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Irwin, S., Wilson, M.W, Kelly, T.C., O'Donoghue, B., O'Mahony, B., Oliver, G., Cullen, C., O'Donoghue, T. and O'Halloran, J. 2008. Aspects of the breeding biology of Hen Harriers *Circus cyaneus* in Ireland. Irish Birds. Vol 8: 331-334. (Appendix 2).

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Wilson, M.W., Irwin, S., Norriss, D.W., Newton, S.F., Collins, K., Kelly, T.C. and O'Halloran, J. 2009. The importance of pre-thicket conifer plantations for nesting Hen Harriers *Circus cyaneus* in Ireland. Ibis. Vol 151: 332-343. (Appendix 1).

Papers in preparation

O'Connell, S., Wilson, M.W., Dell'Omo, G., Irwin, S. and O'Halloran, J. *In prep.* Review of remote tracking methodologies. Irish Birds.

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O'Donoghue, B. G., O'Donoghue, T.A., O'Halloran, J., Kelly, T.C. and O'Connell, S. *In* prep. Diet of Hen Harrier (*Circus cyaneus*) in Ireland.

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Input to policy and practice development

Wilson, M., Irwin, S., O'Donoghue, B., Kelly, T. and O'Halloran, J. 2010. The use of forested landscapes by Hen Harriers in Ireland. COFORD Connects, Environment No. 10. (Appendix 3).

Theses

O'Donoghue, B. 2010. Hen Harrier (*Circus cyaneus*) ecology and requirements for conservation. PhD Thesis, University College Cork.

Inputs to curriculum development and teaching

Wilson, M.W. 2007. Hen Harrier and Forestry. Biodiversity Components of Forestry Certificate Course, UCC.

Wilson, M.W. 2008. Habitat requirements of Hen Harriers in Ireland. 'Early Start' class in Zoology Department, UCC.

Internet presence

A project website has been published at: www.ucc.ie/en/planforbio/Projects/HENHARRIER/

This project is also mentioned on a number of other websites including:

- www.nature.ie
- www.npws.ie
- www.noticenature.ie
- www.clarebirdwatching.ie
- www.sligobirding.com

The Hen Harrier was featured as '*Species of the month*' on the noticenature.ie website in July 2008.

Other activities

An episode of *Living the Wildlife* in May 2009 featured a piece on Hen Harrier Research in Ireland with Tim and Barry O'Donoghue. Filming for RTE's EcoEye series was undertaken on two occasions during the 2009 breeding season and will be aired in January 2009. The programme includes contributions from several project members, including John O'Halloran, Barry O'Mahony and Mark Wilson and focuses on the breeding ecology of Hen Harrier in afforested landscapes in Ireland. Along with project outputs such as COFORD connects, will bring information from the project to a wide public audience.

Appendices

Appendix 1

Wilson, M.W., Irwin, S., Norriss, D.W., Newton, S.F., Collins, K., Kelly, T.C. and O'Halloran, J. 2009. The importance of pre-thicket conifer plantations for nesting Hen Harriers *Circus cyaneus* in Ireland. Ibis. Vol 151: 332-343.

Appendix 2

Irwin, S., Wilson, M.W, Kelly, T.C., O'Donoghue, B., O'Mahony, B., Oliver, G., Cullen, C., O'Donoghue, T. and O'Halloran, J. 2008. Aspects of the breeding biology of Hen Harriers *Circus cyaneus* in Ireland. Irish Birds. Vol 8: 331-334.

Appendix 3

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Appendix 4

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Appendix 5

Wilson, M. W., O'Donoghue, B., O'Mahony, B., Cullen, C., O'Donoghue, T., Oliver, G., Ryan, B., Troake, P., Irwin, S., Kelly, T.C., Rotella, J.J. and O'Halloran, J. 2012. Mismatches between breeding success and habitat preferences in Hen Harriers *Circus cyaneus* breeding in forested landscapes. Ibis. Vol X: XX-XX.

PDFs of these documents are available for download at www.ucc.ie/en/planforbio/Outputs