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The importance of pre-thicket conifer plantations for nesting Hen Harriers *Circus cyaneus* in Ireland

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Hen Harriers C*ircus cyaneus* are threatened across much of their range and their conservation requires appropriate habitat management. The locations of 148 Hen Harrier nests found in the Republic of Ireland during national breeding surveys in 2000 and 2005 were used to assess nest-site selection. The distribution of these nests was compared to distributions of randomly located points to investigate selection at the scale of the nest-site and landscape. The main nesting habitats selected were pre-thicket stage of first and, particularly, second rotation plantations, mostly of exotic conifers. There was no evidence that the area of post-closure plantations negatively affected Hen Harrier nest distribution. There was a positive correlation across study areas 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. The overall effect of plantation forests on breeding Hen Harriers in Ireland therefore appears to be positive. However, this study did not consider the effects of plantation habitats on breeding success. Improved grassland was strongly avoided as a nesting habitat. Furthermore, after controlling for the influence of nesting habitat on nest location, landscapes with a high percentage cover of improved grassland were also avoided. Further agricultural intensification of grassland in areas where Hen Harriers breed is likely to have a negative impact on this species. These results are required for the development of management strategies for the conservation of this species.

Keywords: commercial forestry, conifer plantation, conservation, grassland, habitat selection, heath, raptors, second rotation, upland management.

The nominate race of Hen Harrier (C*ircus cyaneus cyaneus*) is distributed across much of Europe and Asia, with the conspecific Northern Harrier C*ircus cyaneus hudsonius* occurring across most of North America. Though previously widespread in Europe, it has suffered a large historical decline (Ferguson-Lees & Christie 2001) and is assessed as 'Depleted' by BirdLife International (2004). Hen Harriers are vulnerable across a large part of their European range; they are a Species of European Conservation Concern (BirdLife International 2004) and are included in Annex 1 of the EU Birds Directive (European Council Directive 79/409/EEC). This Directive obliges EU Member States to take measures to protect populations of Annex 1 species within their boundaries, including the establishment of Special Protection Areas (SPAs). The Hen Harrier is one of the bird species of greatest conservation concern in Ireland (Newton *et al.* 1999),

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where both historical and recent population declines have been linked to habitat loss and direct persecution (O'Flynn 1983, Norriss *et al.* 2002).

Hen Harriers are vulnerable to habitat loss, fragmentation and degradation (O'Flynn 1983, Bibby & Etheridge 1993), particularly where these involve changes in agricultural practice (Pain *et al.* 1997, Millon *et al.* 2002, Amar *et al.* 2005). Furthermore, the maturation of upland conifer plantations can limit the availability of suitable breeding and foraging sites for this species (O'Flynn 1983, Sim *et al.* 2001). Current conservation measures for Hen Harriers in many countries focus on habitat, and include regulation of agricultural regimes, management to improve the suitability of areas for Hen Harrier and preservation of existing suitable habitat. Such measures can be successful only when they are based on an understanding of the reasons for population decline and incorporate management regimes informed by knowledge of the species' ecological requirements.

In Northern Europe, the Hen Harrier breeds in open, upland habitats such as heather moor, bog, scrub, grasslands and young conifer plantations (Watson 1977, Cramp & Simmons 1980, Sim *et al.* 2001, Norriss *et al.* 2002). In recent decades, the suitability of many upland areas for Hen Harriers has been reduced by agricultural intensification (Shrubb 2003). Over the same period, large tracts of upland habitats in Ireland have been afforested (O'Leary *et al.* 2000). Hen Harriers nest and forage in young plantations, but this use declines following canopy closure (Madders 2003, Barton *et al.* 2006). The maturation of plantation forests therefore has the potential to impact negatively on Hen Harrier populations. Recent studies of breeding Hen Harriers in Ireland suggest that they also make extensive use of young second rotation plantations (Norriss *et al.* 2002, O'Donoghue 2004), a habitat only rarely reported to be used in Britain (Petty & Anderson 1986, Madders 2000). The period for which they use second rotation plantations is shorter than for first rotation plantations, possibly due to a paucity of prey in second rotation plantations immediately after clear-felling, and the more rapid closure of the second rotation canopies compared to those of first rotation plantings (Barton *et al.* 2006).

A complete survey (hereafter referred to as the 2000 survey) of the population of Hen Harriers in the Republic of Ireland was undertaken between 1998 and 2001 (Norriss *et al.* 2002) to inform the selection of the most suitable areas in which to establish Special Protection Areas (SPAs) for this species. This was followed in 2005 by a second survey, the results of which indicated that breeding numbers of Hen Harriers had increased slightly in the intervening period (Barton *et al.* 2006).

Management regimes for SPAs in Ireland have not yet been finalized, but to ensure that these designated areas remain suitable for Hen Harriers it is likely that changes in plantations and agricultural land-use within them will be restricted. Identification of appropriate restrictions on land use change requires a detailed understanding of Hen Harrier habitat requirements. The data generated by these two surveys provided the opportunity to assess the constraints imposed by the availability of suitable habitat on Hen Harrier populations, and inform conservation management decisions about suitable habitat type and suitable threshold levels for forest cover within SPAs. The objectives of this study were to assess (1) which habitats were preferred for nesting and which are avoided, (2) whether, in each of the main habitats selected for nesting, nests are located closer to or further from other habitats than expected, (3) the influence habitat composition at the landscape level has on nest-site selection, (4) whether changes in numbers of breeding Hen Harriers between the 2000 and 2005 surveys were related to changes in cover of the main habitats used for nesting, and (5) whether there is evidence for Hen Harrier nesting distribution being restricted by cover of unsuitable habitat for nesting and foraging.

METHODS

The breeding population of Hen Harriers in the Republic of Ireland was estimated by the 2000 survey at 102–129 pairs, and by the 2005 survey at 132–153 pairs (Barton *et al.* 2006). The locations of 80 nests located during the 2000 survey and 68 nests located during the 2005 survey were used to assess habitat selection. These nests were located in six areas (Fig. 1), which each held more breeding Hen Harriers than any of the other areas covered by the surveys (Norriss *et al.* 2002, Barton *et al.* 2006), and were short-listed by the National Parks and Wildlife Service (NPWS) in 2002 as candidate Special Protection Areas (SPAs) for this species. They cover a total area of 2635 km^2 and in 2005 held just over 75% of the breeding Hen Harrier population in the Republic of Ireland

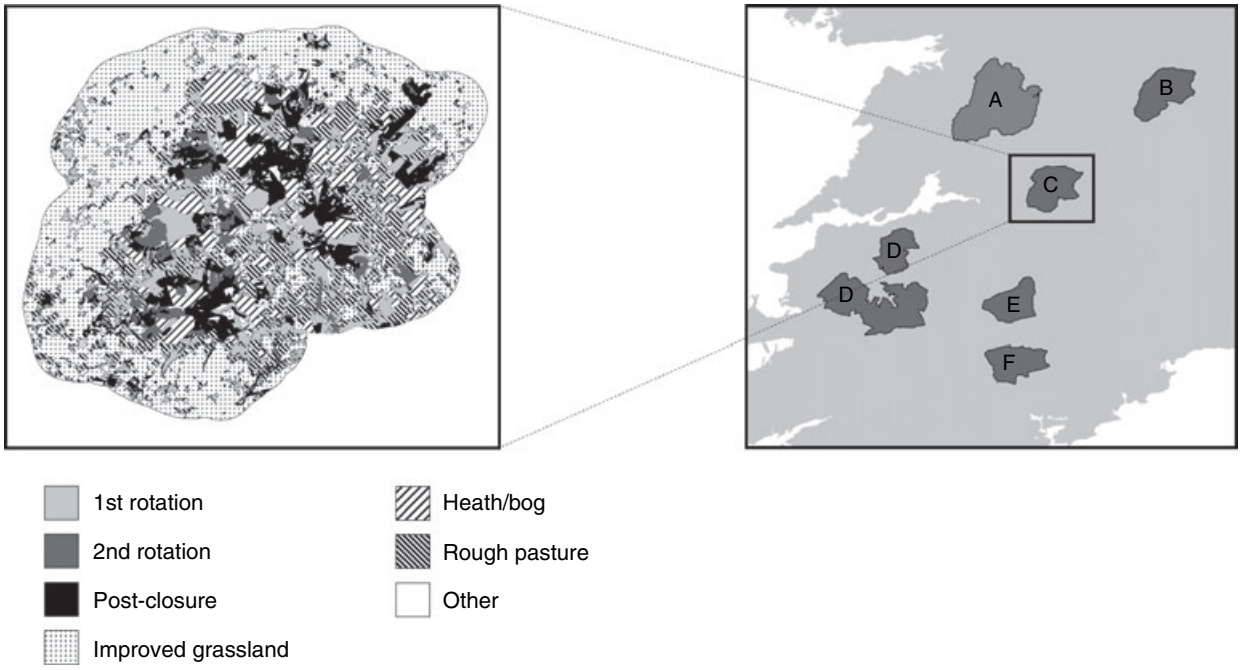

Figure 1. The right-hand panel shows the location of the six study areas in South-west Ireland: (A) Slieve Aughties (744 km^2); (B) Slieve Blooms (322 km^2); (C) Slieve Felims (279 km^2); (D) Mullaghareirks (798 km^2); (E) Ballyhouras (235 km^2) and (F) Nagles (258 km^2). The left-hand panel shows the distribution of habitat types in and within 2 km of area C in 2005.

(Barton *et al.* 2006). Cover of plantation forest in these areas during the period 2000–2005 was high (18–43%). All nest locations used in this study were accurate to within 100 m.

Habitat classification

Forested habitats were classified using (hierarchically and in the following order) the Coillte forest inventory, the Forest Service Grants Premiums database, and the FIPS (Forest Inventory Planning System) 1998 database. Open habitats were classified using National Parks and Wildlife Service Hen Harrier SPA habitat data and the Forest Service Forest Soils and land-cover dataset. Using ARCVIEW 3.3 GIS (Geographic Information System), digitized habitat maps of the six study areas were constructed for 2000 and 2005, each with a resolution of 30 m (the maximum pixel size of any of the parent datasets). All land within 2 km of the study areas was assigned to the following categories of open and forested habitat: pre-thicket first rotation plantations, pre-thicket second rotation plantations, post-closure first or second rotation plantations, improved grassland, heath/bog, rough grazing, and other. Details of each of these habitat categories are given in Table 1. Plantations were largely of conifers, particularly Sitka Spruce *Picea sitchensis*, Lodgepole Pine *Pinus contorta* and Larch *Larix* spp., though small areas of broadleaved plantation were also included.

Hen Harrier breeding locations and habitat availability

To investigate differences between actual nest locations and potentially available locations, we generated 100 sets each of three types of points to act as controls, for both the 2000 and 2005 surveys. We refer to these hereafter as random controls, nest habitat controls and improved grassland controls. Each of these controls consisted of 100 sets of n random points for each survey, with n being the number of nests found (80 in 2000, 68 in 2005).

Points in random control sets were located randomly within the boundaries of the study areas. Within each random control set, points were distributed among study areas in the same numbers as were nests from the corresponding survey. Nest

Table 1. Categories of open and forested habitat used in this study.

Category	Fossitt Codes[a]	Description
Pre-thicket first rotation plantation	WD4	New forest plantations (planted on open habitats) still in pre-thicket growth stage (i.e. before the planted area is entirely covered by the forest canopy). All 1st rotation forest between 1–12 years of age was assigned to this category
Pre-thicket second rotation plantation	WD4	Pre-thicket forest established on previously forested land from which trees had been harvested. All commercial forests recorded as having been clearfelled 3–9 years previously, or originally planted 45 years previously, were assigned to this category
Post-closure plantation	WD4	Afforested land with closed canopy. All first rotation forest aged 13–42 years, and all second rotation forest aged 10 years or more, were assigned to this category
Improved grassland	GA1	Species poor grasslands, intensively managed for grazing. Land recorded as dry grassland in Forest Service land cover database
Heath/bog	HH1-2, PB2-4	Peatland habitats usually dominated by ericaceous shrubs or purple moor grass (*Mollinia caerulea*). Land classified as either 'Heath and Bog' in NPWS habitat database or as any 'Bog' or 'Heath' category in Forest Service land cover database
Rough pasture	GS4, HD1	Semi-improved grassland, grazed less intensively than improved grassland. Often incorporates areas of rushes, bracken and low shrubs. Land classified as rough pasture in NPWS habitat database or as wet grassland in Forest Service land cover database
Other	WS1, WS5, BL3, FL1-7	All land not fitting any of the above classifications. Main categories include extensive areas of scrub, recently clearfelled forest, built land and freshwater bodies

[a]Codes correspond to habitats described in Fossitt (2000).

habitat controls and improved grassland controls were generated to investigate nest-site selection at a landscape scale after accounting for variation due to nest habitat preferences and the distribution of improved grassland. Point locations in nest habitat control sets were generated as for random control sets but with the restriction that, within every set, each study area contained the same number of random points in each habitat as it did Hen Harrier nests. The points in improved grassland control sets were distributed in a similar way, but in addition to nest habitat, the potential locations of each point were constrained according to the proportion of the land within 2 km of the point occupied by improved grassland. Therefore, within each study area, every improved grassland control set contained the same number of points within each habitat and within each 10-percentile class of improved grassland as did the set of Hen Harrier nests in that study area.

To investigate habitat preferences at the nest-site scale, habitat at the site and distance to the nearest patch of each other habitat type was recorded for all nests and for each point in the random control sets. To investigate habitat composition around nests at a scale relevant to foraging Hen Harriers, we calculated the proportion of land occupied by each habitat within 2 km of all nests and each point in the three control sets. Arroyo *et al.* (2006) found that, although all breeding males in their study ranged up to 5 km from their nests, 60% of male foraging time was spent within 2 km of the nest. The average proportion of time spent by foraging females within this distance was greater than 90%.

Data analysis

All spatial analyses were carried out using ARCVIEW 3.3 and ARCMAP 9.2 GIS software. Random, nest habitat, and improved grassland control sets of points were generated using ARCVIEW Random Point Generator 1.27. The area of each habitat within 2 km of every point was derived by generating 2-km 'buffers' (fixed radius circles) around each point, and using the Tabulate Areas function of the Spatial Analyst extension in ARCVIEW 3.3 to calculate the area of each buffer occupied by the habitats it overlapped with.

The direction and strength of selection of individual habitats at both nest-site and landscape scales were assessed using one-tailed rank tests. To investigate habitat selection at the scale of the nest-site, the number of Hen Harrier nests occurring in each habitat was compared with the number of points from each of the 100 sets of random controls in that habitat. For example, if the number of nests in a habitat was the second highest

among the 101 sets (100 control sets plus 1 set of Hen Harrier nests), the one-tailed probability of randomly observing such a high value would be estimated as $P < 0.02$. In a similar manner, habitat selection at a landscape scale was assessed for each habitat by ranking the mean area of that habitat within 2 km of nest locations among the equivalent mean values for the 100 control sets.

Calculations of bootstrapped 95% confidence intervals for the mean proportions of nests occurring in different habitats, and mean area of habitat within 2 km of nests, were conducted in Microsoft EXCEL 2000. Bootstrapped samples were derived by drawing n values with replacement from the set of values representing n Hen Harrier pairs. This procedure was repeated 1000 times, and a count (for number of nests in each habitat) or mean (for area of habitat within 2 km) was derived from each set, for each habitat. The bootstrapped 95% confidence interval of these values was taken from the 50th and 951st ranked values of this set. Confidence intervals for the random, nest habitat and grassland control sets were estimated directly as the 5th and 96th ranked values (for proportions of points in different habitats) or means (for area of habitat within 2 km) of each of these control sets.

Overall differences in the composition of habitat around nests and control points were assessed by third order compositional analysis, as described by Aebischer *et al.* (1993), using the function 'compana' in library 'adehabitat' in R (R Development Core Team 2008). Differences between nests and controls were tested using Wilks' λ. To assess whether there was any evidence for avoidance of landscapes with high percentage cover of post-closure plantations, we calculated the proportion of points in the random, nest habitat and grassland control sets in each survey with higher values of post-closure plantation cover than the highest value for nests. We also calculated the proportion of nests, and points in the random, nest habitat and grassland control sets, with greater than 50% post-closure plantation cover. Changes between years in the number of Hen Harrier pairs breeding in each of the study areas were calculated from estimates of total numbers of breeding pairs in either survey given by Barton *et al.* (2006). The relationship between changes in the numbers of Hen Harriers and changes in habitat cover was assessed using non-parametric Kendall's τb correlations, estimated with SPSS 15.01.

RESULTS

Habitats selected for nest sites

Habitat composition, inferred from the distribution of random points between habitats, was significantly different between the six study areas in 2000 ($\chi^2 = 1272.7$, df = 30, $P < 0.001$) and in 2005 ($\chi^2 = 1319.5$, df = 30, $P < 0.001$). However, habitat selection did not differ between study sites in either survey year (Table 2, Fig. 2). Over 90% of nests in both years were located in four main habitats: pre-thicket first rotation plantations (40% in 2000; 16.2% in 2005), pre-thicket second rotation plantations (17.5% in 2000; 32.3% in 2005), post-closure plantations (22.5% in 2000; 22.1% in 2005), and heath/bog (11.3% in 2000; 22.1% in 2005), with the remaining nests located in rough pasture and other habitats. Pre-thicket second rotation plantation forest was the most strongly preferred nesting habitat (both years, $P < 0.01$), accounting for over five times more nests in 2000 than would be expected if nests were randomly located, and over seven times the number expected from random placement in 2005 (Fig. 3). Pre-thicket first rotation plantations were also selected (2000, $P < 0.01$; 2005, $P < 0.05$), but the difference between frequency of occurrence of nests and random points (between two and three times more nests than random points in both years) was not as marked as for pre-thicket second rotation plantations

Table 2. For each of seven habitat types, chi-squared scores and associated one-tailed *P*-values (at df = 5) for the distribution of nests and random controls between the six study areas (see Fig. 2).

Survey year	2000		2005	
Habitat	χ^2	*P*	χ^2	*P*
Pre-thicket first rotation plantation	4.1	0.56	6.0	0.12
Pre-thicket second rotation plantation	4.1	0.77	5.1	0.54
Post-closure plantation	0.0	0.77	0.0	0.65
Improved grassland	0.0	1.00	0.0	1.00
Heath/bog	13.1	0.07	13.3	0.06
Rough grazing	9.9	0.20	2.8	0.91
Other	6.7	0.46	5.7	0.57

The degree to which each habitat was positively selected or avoided did not differ significantly between study sites in either year.

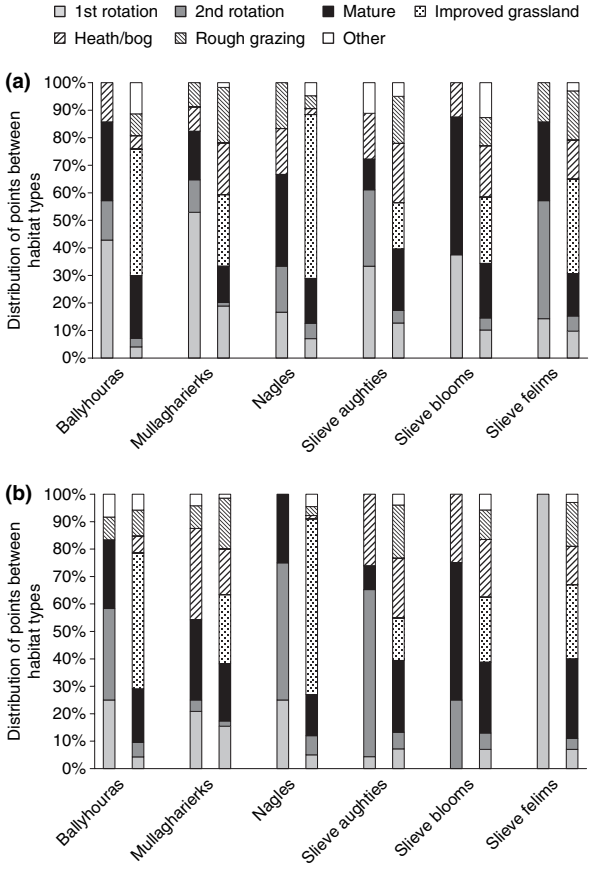

Figure 2. Distribution of nests (left-hand bar) and random points (right-hand bar) in different habitat types in each of the six study areas in (a) 2000 and (b) 2005. The numbers of nests in each study area included in analyses were as follows: Ballyhouras: 7 in 2000, 12 in 2005; Mullagharierks: 34 in 2000, 24 in 2005; Nagles: 6 in 2000, 4 in 2005; Slieve Aughties: 18 in 2000, 23 in 2005; Slieve Blooms: 8 in 2000, 4 in 2005; Slieve Felims: 7 in 2000, 1 in 2005.

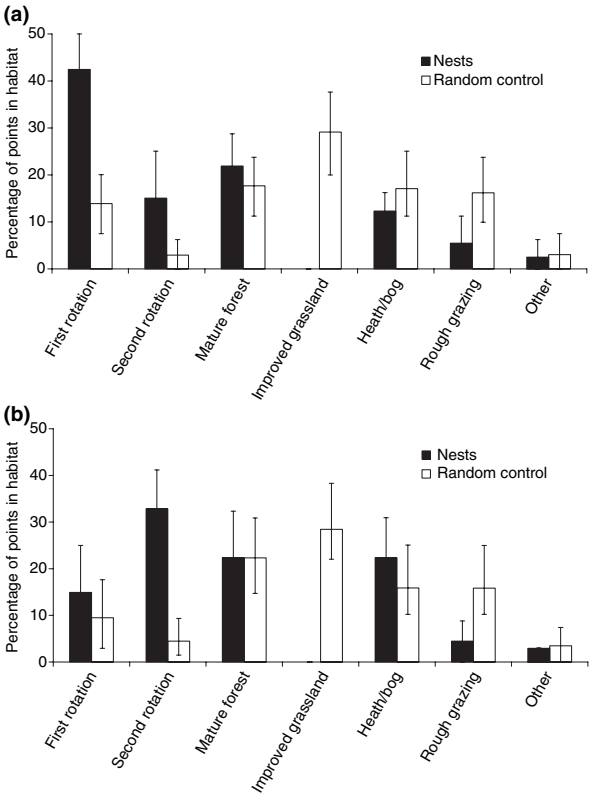

Figure 3. Distribution between habitat types of (a) 80 nests and 8000 random points for the 2000 survey and (b) 68 nests and 6800 random points for the 2005 survey. Error bars show 95% confidence intervals for these proportions.

(Fig. 3). The frequencies with which nests were located in post-closure plantation forest and heath/bog were not significantly different from random in either year (Fig. 3).

Improved grassland was the most strongly avoided habitat (both years, $P < 0.01$), with no nests being located in this habitat in either year, despite it occupying over 25% of the study areas (Fig. 3). Nests were located approximately three times less frequently in rough grazing than were random points, indicating that this habitat is also avoided (2000, $P < 0.01$; 2005, $P < 0.02$). Where written descriptions of habitat accompanied the precise nest-site locations given in the survey, nests located in rough grazing were commonly associated with localized areas of gorse (*Ulex* spp.), willow (*Salix* spp.) or other low shrubs.

Distance from nests to nearest habitat patch

For nests and random points in each of the four main nesting habitats, the average distance to the nearest patch of each habitat is given in Table 3. Nests in pre-thicket first rotation plantations were further from rough grazing than expected at random in both surveys. In 2005, they were also further from improved grassland and closer to pre-thicket second rotation forest than expected. Nests in pre-thicket second rotation plantations were further than expected from rough grazing and pre-thicket first rotation plantations in 2000. Nests in post-closure plantations were closer than expected to areas of heath/bog in both surveys. Similarly, heath/bog nests were closer than expected to areas of post-closure plantations in both surveys, and

Table 3. For each of the four main habitats used for nesting, average distances in metres from nests and random controls situated in that habitat to the nearest area of each other habitat type in 2000 and 2005.

	Nest site habitat											
	First rotation plantation			Second rotation plantation			Post-closure plantation			Heath/bog		
Nearest habitat patch 2000	Nests	Random	*P*	Nests	Random	*P*	Nests	Random	*P*	Nests	Random	*P*
First rotation plantation				654.5	378.7	+**	476.5	489.6	ns	351.2	466.1	ns
Second rotation plantation	985.1	1066.1	ns				739.9	777.1	ns	753.5	1068.1	ns
Post-closure plantation	438.0	458.8	ns	200.1	266.3	ns				250.1	447.8	−*
Improved grassland	600.4	535.1	ns	943.9	709.7	ns	991.5	782.2	ns	838.6	734.8	ns
Heath/bog	285.9	342.7	ns	312.7	426.4	−*	339.4	434.1	−*			
Rough grazing	464.8	369.1	+*	744.9	462.7	+**	702.4	638.0	ns	563.8	467.3	ns
Other	624.3	600.5	ns	407.7	384.1	ns	296.5	371.0	ns	454.7	592.0	ns
Nearest habitat patch 2005												
First rotation plantation				702.6	592.5	ns	582.7	674.3	ns	367.3	514.3	−*
Second rotation plantation	791.0	1082.9	−*				485.8	714.1	ns	980.1	1090.5	ns
Post-closure plantation	303.1	306.5	ns	143.2	156.2	ns				196.2	332.3	−*
Improved grassland	748.3	457.5	+*	1270.0	1078.7	ns	699.7	760.5	ns	1003.4	781.1	ns
Heath/bog	296.3	436.7	−*	498.4	503.2	ns	292.0	503.9	−**			
Rough grazing	686.2	381.1	+*	802.6	701.3	ns	637.1	613.7	ns	634.8	512.6	ns
Other	507.9	547.6	ns	337.6	336.5	ns	414.1	379.1	ns	522.0	523.4	ns

Direction ('+' or '–') and significance level (*$P < 0.05$, **$P < 0.01$) of differences between nests and random controls was assessed using one-tailed rank tests.

were also closer to pre-thicket first rotation plantations in 2005.

Habitat composition within 2 km of nests

In both years, habitat composition within 2 km of Hen Harrier nests differed significantly from that around random control points (2000: Wilks' $\lambda = 0.50$, $P < 0.001$; 2005: Wilks' $\lambda = 0.17$, $P < 0.001$). The average area of habitat within 2 km of Hen Harrier nests differed from random for all habitats (Fig. 4). Cover of the following habitats was greater around nests than around random controls: pre-thicket first rotation plantations (2000, $P < 0.01$; 2005, $P < 0.03$), pre-thicket second rotation plantations (both years, $P < 0.01$), post-closure plantations (both years, $P < 0.01$), heath/bog (both years, $P < 0.01$), and other (2000, $P < 0.04$; 2005, $P < 0.01$). Cover of improved grassland (both years, $P < 0.01$) and rough pasture (both years, $P < 0.01$) was lower than expected.

In both years, habitat composition within 2 km of Hen Harrier nests differed from that around nest habitat control points (2000: Wilks' $\lambda = 0.68$, $P < 0.001$; 2005: Wilks' $\lambda = 0.55$, $P < 0.001$). However, differences in the cover of individual habitats were less marked than that between nests and random controls (Fig. 4). Area of improved grassland around nests was smaller than around nest habitat controls in both years (both years, $P < 0.01$). Area of heath/bog within 2 km of nests was greater than around nest habitat controls in 2000 ($P < 0.03$), and areas of both pre-thicket second rotation ($P < 0.03$) and post-closure plantations ($P < 0.02$) within 2 km of nests were greater than around nest habitat controls in 2005.

Composition of habitat within 2 km differed between Hen Harrier nests and improved grassland control points in 2005 (Wilks' $\lambda = 0.77$, $P = 0.01$) but not in 2000 (Wilks' $\lambda = 0.87$, $P = 0.08$). Differences in the cover of individual habitats between Hen Harrier nests and improved grassland control sets were smaller than those between nests and the other control sets (Fig. 4). The area within 2 km of Hen Harrier nests did not differ significantly from the area around improved grassland controls for any habitat variable in 2000. In 2005, the area of post-closure plantations was greater around nests than around improved grassland controls ($P < 0.04$), and the area of improved grassland was smaller ($P < 0.05$).

The maximum level of post-closure plantation cover within 2 km of any of the nests was

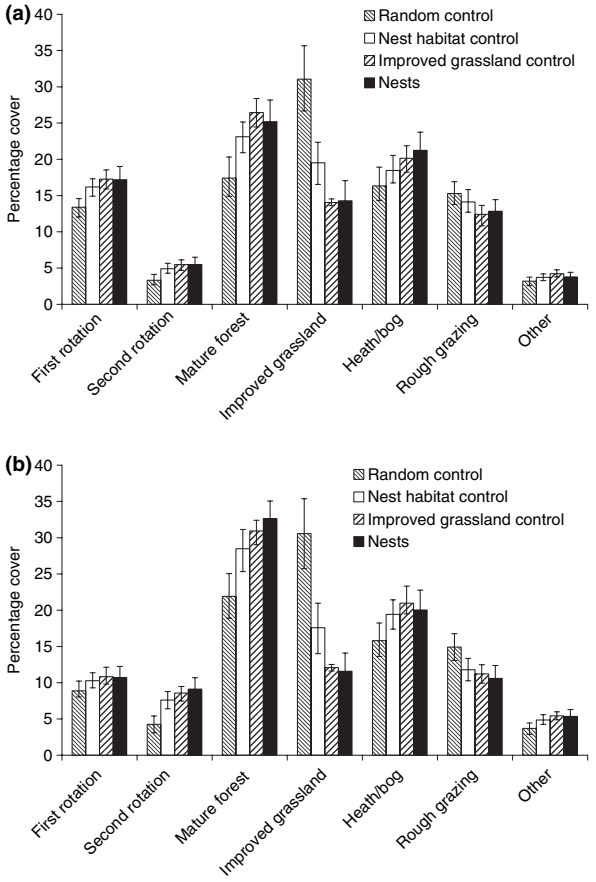

Figure 4. Habitat composition of area within 2 km of random controls, nest habitat controls, improved grassland controls and nests in (a) 2000 survey and (b) 2005 survey. Error bars show 95% confidence intervals of means.

68.5% in the 2000 survey and 62.5% in the 2005 survey. For each survey period, these values were exceeded by less than 1% of the values for post-closure plantation cover within 2 km of each of the random, nest habitat and improved grassland controls. In 2000, the percentage of points with greater than 50% post-closure plantation cover within 2 km was 8.3% for nests, 5.2% for random controls, 6.3% for nest habitat controls, and 6.8% for improved grassland controls. In 2005 the percentage of points with greater than 50% post-closure plantation cover within 2 km was 7.5% for nests, 4.1% for random points, 6.4% for nest habitat controls and 8.0% for improved grassland controls. Thus, there was no indication that Hen Harriers avoided placing their nests in areas with high cover of post-closure plantations.

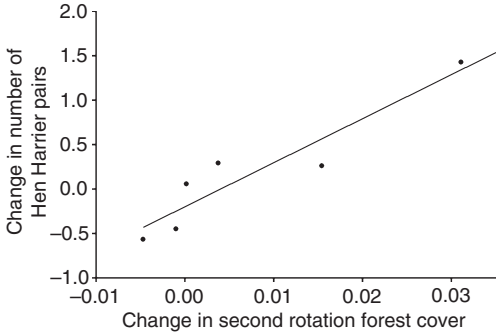

Figure 5. The proportional difference in the number of breeding Hen Harriers in study areas between 2000 and 2005, plotted against the proportional change in percentage cover of pre-thicket second rotation plantations during this period. These two variables are positively correlated with one another (Kendall's $\tau b = 0.73$, $n = 6$, one-tailed $P = 0.02$).

Changes in numbers of breeding Hen Harriers

The change in the number of breeding Hen Harrier pairs in the six study areas between the 2000 and 2005 surveys was positively correlated with the change in the proportion of pre-thicket second rotation plantations within 2 km (Fig. 5). The proportional change between years in area within 2 km was not correlated with changes in the number of breeding Hen Harriers for any of the other habitats.

DISCUSSION

Selection for nesting habitat

Pre-thicket plantation forest was more strongly selected by Hen Harriers in both survey years than any other habitat. The vegetation in pre-thicket first rotation plantations generally resembled that of the planting habitat, but was taller and with a greater prevalence of low shrubs (Wilson *et al.* 2006). Such differences in vegetation may be due to lower grazing intensities in afforested sites and, in the case of habitats with high soil moisture content, to draining of the site prior to planting with trees (Buscardo *et al.* 2008). Studies in Scotland (Redpath *et al.* 1998) and France (Cormier *et al.* 2008) have shown that nesting Hen Harriers select sites with taller vegetation, and with greater than average cover of heather species.

Selection for pre-thicket second rotation plantations was even stronger than for pre-thicket first

rotation plantations. In fact, in the 2005 survey, nests were more frequently situated in pre-thicket second rotation plantations than in any other habitat, despite the fact that second rotation forest represented less than 5% of all study areas. The recovery of vegetation in clear-felled sites tends to be rapid, so that within a few years of planting with trees, vegetation in field and shrub layers is abundant (Cooper *et al.* 2008), providing plentiful cover for ground-nesting birds typically associated with open habitats (Bibby *et al.* 1985, Burton 2007). In addition to these elements of vegetation, pre-thicket second rotation plantation habitat incorporates a substantial volume of brash (tree branches left on site after timber harvesting), which in Ireland is typically distributed in linear mounds called 'wind rows'. The combination of brash and growing vegetation can restrict mammalian access to some areas of young second rotation plantations (Truscott *et al.* 2004), which is another reason why this habitat might be favoured by Hen Harriers.

In most parts of Great Britain, heather-dominated habitats have been shown to be the most important for nesting and foraging Hen Harriers (Redpath *et al.* 1998, 2002, Amar & Redpath 2005, Sim *et al.* 2007). In contrast, we did not find that heath/bog was selected for nest-site location. Many Irish peatland habitats are overgrazed (MacGowan & Doyle 1996, McKee *et al.* 1998), which could reduce their usefulness to Hen Harriers by decreasing cover for nesting (Redpath *et al.* 1998) and lowering prey densities (Madders 2000). At least part of the reason that pre-thicket plantation habitats are so strongly selected by Hen Harriers in Ireland may be the lower grazing pressure they experience compared with the surrounding open habitats.

In both years, the numbers of Hen Harrier located in areas of heath/bog and post-closure forest were not significantly different from random expectation. It is probable that, within both of these habitats, nest selection operated at a smaller scale than could be resolved by datasets used in this analysis. The notes of recorders in the survey indicate that nests located in post-closure plantations were often in patches where tree growth was slower than in the surrounding plantation, or had been set back by disease or fire. Similarly, nests located in heath/bog were often associated with patches of scrub, or with nearby forest plantations. The average distance between nests located in heath/bog and the nearest patch of post-closure plantation was smaller than expected at random. The same association also held for nests situated in post-closure plantations, which in both years were closer to heath/bog than expected at random. This suggests that areas close to an edge between these two habitats may be attractive to breeding Hen Harriers. This could be because the typical vegetation at edges between post-closure forest and heath/bog is good for nesting, or because the proximity of tall trees enables adults to conceal their entrance to and exit from nest-sites, while the proximity of heath/bog affords adults with an area to forage within easy access of the nest. Although improved grassland was the most abundant habitat in the study areas in both survey periods, occupying almost 30% of the study areas, no nests were situated in this habitat. This habitat contains very little suitable cover for nests, and areas dominated by improved grassland tend to be at lower altitude and have higher levels of human activity than areas of other upland habitats. Rough grazing was not so comprehensively avoided, but a far smaller proportion of nests were situated in this habitat than the equivalent proportion of random points. Rough grazing habitat is typically dominated by graminoid vegetation, and consequently does not provide much shelter or concealment for nest-sites, although several studies have found that it is a preferred habitat for foraging (Amar & Redpath 2005, Barton *et al.* 2006, Amar *et al.* 2007). Hen Harrier nests have been recorded in areas dominated by rushes or grasses, but this species generally prefers areas with higher levels of shrub cover (Redpath *et al.* 1998, Cormier *et al.* 2008). Where written descriptions of habitat accompanied the nest-site locations given in either survey, nests located in rough pasture were frequently described as being associated with localized areas of gorse (*Ulex* spp.), willow (*Salix* spp.) or other low shrubs.

Selection at the landscape level

Habitat within 2 km of nests differed from that expected if nest-sites were selected at random with respect to habitat. The areas of post-closure plantation, heath/bog and other habitat within 2 km of nests are significantly greater than random in both surveys, though numbers of nests situated in these habitats were not significantly different from random. However, all habitats holding a greater or smaller proportion of nests than expected

at random also differed significantly from random with respect to area within 2 km of the nest. This is to be expected, for two reasons. First, the patch of habitat occupied by a point contributes to the total area within 2 km. In the case of large patches of habitat, this contribution may be large. Secondly, the distribution of habitat patches throughout the study areas was not random, the levels of cover of certain habitats tending to be higher in some areas and lower in others (Fig. 1). Thus, a point falling in heath/bog was more likely to have a high level of heath/bog cover around it than a point falling in another habitat. This means that it was not possible to completely separate the influence of nest-site selection on the basis of nesting habitat from that of selection operating at a wider, landscape scale. Hen Harriers may nest in a patch of pre-thicket second rotation plantation because of the opportunities it affords for shelter and concealment of their nests, because it is advantageous to nest in landscapes that contain relatively high levels of second rotation plantation cover around them, or for a combination of these factors. However, differences between nests and nest habitat controls indicate that at least a component of nest-site selection was based on landscape scale factors.

Differences in habitat within 2 km between nests and controls were much less for nest habitat controls than for random controls because the points in each nest habitat control set were distributed among the seven habitats in the same proportions as were Hen Harrier nests. However, despite the fact that none of the points in nest habitat controls was located in improved grassland, the biggest difference between nests and nest habitat controls was in the cover of this habitat. After controlling for the influences of both nesting habitat and improved grassland, habitat composition within 2 km of the nests did not differ greatly from that around improved grassland controls. This suggests that most variation in Hen Harrier nest-site location can be explained in terms of selection of preferred nesting habitats and avoidance of landscapes with a high proportion of improved grassland.

Male Hen Harriers typically range over distances of several kilometres from the nest during the breeding season, but the intensity of foraging activity is much greater within 2 km of the nest than beyond this distance (Madders 2003, Arroyo *et al.* 2006). Selection of nest-sites situated in landscapes with low levels of improved grassland cover could therefore be due to avoidance of areas with low foraging profitability. Previous studies found that improved grassland is used infrequently by hunting Hen Harriers (Madders 2000, O'Donoghue 2004, Barton *et al.* 2006) and that the density of prey species in agricultural land is negatively related to the intensity of farming (Butet & Leroux 2001, Vanhinsbergh & Chamberlain 2001). Alternatively, the lack of cover that makes improved grassland unsuitable as a nesting habitat could also render nearby patches of potentially suitable nesting habitat less attractive by making it harder for adults to approach the nest without being observed by potential nest predators and humans.

There was no evidence that Hen Harriers in either survey avoided nesting in areas with high post-closure plantation cover. Indeed, a higher level of post-closure forest cover around nests was one of only two significant differences in habitat cover between nests and improved grassland controls. This indicates that, at least at recent levels and configurations of plantation cover, post-closure plantation forest did not greatly limit the distribution of breeding Hen Harriers within the main parts of their Irish range.

CONCLUSIONS

The extent to which Hen Harriers use pre-thicket second rotation plantation forest has important consequences for the long-term impact of afforestation of open upland habitats on this species. The area most similar to Ireland with respect to the nature and extent of its upland plantation forests is Great Britain, where Hen Harriers are also traditionally regarded as birds of open upland habitats such as moorland and bog. Several British studies have shown that Hen Harriers make extensive use of first rotation conifer plantations at the pre-thicket stage (Redpath *et al.* 1998, Madders 2000). Some researchers have suggested that the recent recovery of Hen Harrier numbers in some parts of Britain is partly due to the nesting and foraging opportunities afforded them by new conifer plantations (Avery & Leslie 1990), and also to the lower levels of persecution experienced by birds breeding in forest plantations (Etheridge *et al.* 1997, Green & Etheridge 1999). However, regardless of how valuable young plantations in their first rotation are to Hen Harriers, afforestation of upland habitats will result in a net loss of habitat if this species does not make use of second rotation

plantations. Although recent studies in Britain have reported Hen Harriers foraging in second rotation forest (Madders 2000, Sim *et al.* 2007), nesting in this habitat is reported as being sporadic (Petty & Anderson 1986, Madders 2000), Sim *et al.* (2001) concluding that second rotation plantation forest appears to be 'largely unsuitable' for nesting. In the USA, reforestation is considered to be one of the factors contributing to a recent decline in Northern Harrier populations (Serrentino 1992, MacWhirter & Bildstein 1996). In Ireland, however, pre-thicket second rotation plantation forest is not only the most commonly used nesting habitat, but is positively correlated with changes in breeding Hen Harrier numbers over time. Coupled with the lack of evidence for any negative impact of post-closure forest cover on Hen Harrier distribution within these areas, this gives some reason to be optimistic about the long-term effects of afforestation on this species, at least in Ireland.

However, such optimism should be tempered with caution. Whereas some aspects of nest-site selection exhibited by this species are adaptive (Simmons & Smith 1985), the fact that Hen Harriers prefer to nest in pre-thicket second rotation plantations does not necessarily mean that this habitat is good for Hen Harriers. Restocked plantation forest has only become widely available to Hen Harriers in Ireland in the past few decades, so the breeding preferences expressed in relation to this habitat may not be entirely adaptive. For instance, if predation pressure in second rotation plantations is higher than in alternative nesting habitats, a preference for nesting in restock may place Hen Harriers in an 'ecological trap' (Robertson & Hutto 2007). Similarly, the fact that Hen Harriers show no avoidance of landscapes with a high proportion of post-closure plantations does not mean that their breeding success in such landscapes is comparable to that in more open areas. Further information on breeding success in relation to habitat is necessary to decide whether the influence of forestry on breeding Hen Harriers is as positive as the distribution of breeding pairs suggests.

However, there is clear evidence that Hen Harriers in Ireland avoid agriculturally improved land, at both site and landscape levels. Intensification of agricultural management within areas that hold breeding Hen Harriers is likely to be associated with decreases in the numbers of this and other upland species (Pain *et al.* 1997), and should be avoided. Where the possibility exists for increasing shrub cover and reducing grazing pressure in upland areas, this might provide opportunities to improve the suitability of these areas for breeding Hen Harriers.

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