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Short communication

Influence of habitat on breeding performance of Hen Harriers *Circus cyaneus* in Orkney

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Declines of many bird populations have been linked to a reduction or degradation of their preferred habitats, leading to reductions in breeding productivity (Donazar *et al.* 1993, Tella *et al.* 1998, Robinson *et al.* 2001, Schmiegelow & Monkkonen 2002, Browne *et al.* 2004, Fernandez *et al.* 2004, Julliard *et al.* 2004). Although the precise mechanism linking habitat with productivity is often not understood, habitat may limit productivity when certain features are needed for nesting (e.g. Potts 1986, Bradbury & Bradter 2004), or are linked to prey abundance (e.g. Potts 1986, Tella *et al.* 1998, Benton *et al.* 2002). Where such declines occur, conservation measures aim to improve these habitats for the target species. However, it is important, before any habitat modification is to be implemented, to be able to predict the outcome of increasing preferred habitats on the breeding performance of the target species. When experimental manipulations of habitat are not feasible, one way to achieve this is to evaluate indirectly whether habitat influences breeding parameters, such as breeding density or performance.

The Hen Harrier *Circus cyaneus* is a medium-sized bird of prey, which in Britain nests mainly on moorland dominated by Heather *Calluna vulgaris* (Redpath *et al.* 1998, Sim *et al.* 2001). The Hen Harrier population on the Orkney Islands, situated off the north coast of Scotland, has undergone a pronounced decline since the late 1970s (Meek *et al.* 1998, Amar *et al.* 2005). Recent research has shown that the productivity of this population has declined, principally owing to a decrease in male breeding success driven by a decrease in polygynous breeding, and a decrease in the hatching success of secondary females (Amar *et al.* 2005). The most likely explanation for this reduced breeding success was a reduction in food supply, and indeed experimental provision of food increased the number of breeding females per male (Amar & Redpath 2002). Although Hen Harriers in Scotland breed almost always within heather (Redpath *et al.* 1998), additional research has suggested that males in Orkney showed a preference for hunting on rough unmanaged grass (hereafter, rough grass), probably as a consequence of the higher abundance of various important harrier prey species (such as pipits or voles) in this versus alternative habitats, such as heather or intensive pasture (Amar & Redpath 2005). Agricultural records indicate that rough grass has been lost at the expense of intensive pasture and also probably degraded through over-grazing by sheep, densities of which doubled between 1980 and 1998 (Amar & Redpath 2005).

In light of this past research, suggestions for the conservation management of the Hen Harriers on Orkney have focused on increasing the amount of rough grass (foraging habitat) in areas close to the heather moorland breeding areas (Amar & Redpath 2002, 2005, Amar *et al.* 2003b). To support these management actions further, we wanted to test the hypothesis that the availability of rough grassland close to nesting areas influenced breeding success of Hen Harriers.

For this purpose, we analyse long-term data for breeding success of Orkney Hen Harriers in relation to remotely sensed habitat data. We examine the associations between the amount of rough grass around nesting areas and various measures of breeding success. We predict that nesting areas with greatest access to rough grass will have the highest breeding performance.

METHODS

Breeding data

Location and breeding performance of Hen Harriers nesting on West Mainland, Orkney, were recorded each year between 1989 and 1997. The Orkney Islands are situated off the north coast of Scotland. The island of Mainland is the largest of the Orkney islands and the majority of Orkney's Hen Harriers nest on the west of Mainland. Nests are located in the complexes of hills, which are covered by heather-dominated vegetation. Potential nesting areas were visited at the start of the breeding season and attempts were made to locate all breeding birds. We defined a breeding attempt as a nest with a clutch. Although each year some nesting attempts may have been missed if they failed early in the incubation period, we believe

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that this is likely to be rare given observation intensity. Nests were visited around the time of expected hatch and occasionally throughout the nestling period. Brood size at ringing and fledging was recorded. If visits were made after broods had fledged, the number of young produced was estimated as the brood size at ringing or at the time of last visit if no chick remains were found in the nest. The location of each Harrier nest was recorded as a six-figure grid reference using 1 : 50 000 OS maps. Traditional nesting areas are used repeatedly year on year; these typically consist of a side of a valley or basin, and locations of these territories appear to have been very similar over the past 25 years (Amar & Redpath 2002). Each nest was assigned to one of these 52 individual nesting areas. There were on average four nesting attempts in each nesting area, ranging from one to 14 nesting attempts over the 9 years. In total, we used data from 210 nests over the 9 years, with an average of 23 nests (range 15–38 nests) per year. In common with the general pattern in Scotland (Redpath *et al.* 1998), all Harrier nests were found on heather-dominated moorland.

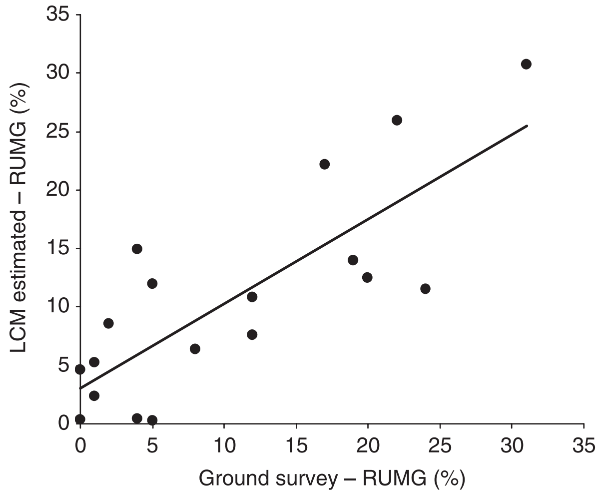

Figure 1. Relationship between the proportion of rough unmanaged grass (RUMG) in 18 1-km squares, as estimated from the digitized LCM 1990 map and from ground surveys. The trend line shows the fitted least-squares regression line (R^2 = 0.63).

Habitat data

Habitat data were obtained from the Land Cover Map of Great Britain 1990 (hereafter LCM) (Fuller *et al.* 1994a). This digitized map, which is based on a 25 × 25-m grid, categorized each grid square into its dominant cover type, out of a possible 25 cover types including 18 types of semi-natural vegetation. Data were incorporated into Arcview 3.12 [ArcView 3.12 (2003), ESRI], and analysed with Arcview Spatial Analyst 2.0a.

We first estimated the accuracy and relevance of the LCM 1990 data for their current use. To do this, we compared the amount of rough grass estimated from ground surveys within 18 1-km squares, conducted as part of another study (Amar & Redpath 2005), with habitat data in these same squares generated from LCM. Habitat surveys were conducted in summer (July and August) in either 1998 or 1999 and in spring (February and March) in either 1999 or 2000. In each square, two parallel 1-km transects were set up, each placed 250 m and 750 m away from one side of the square. Along each transect, 25 quadrats (25 × 25 cm) were placed at 40-m intervals, and the dominant vegetation type in each quadrat was recorded, giving information from 50 quadrats per square (for further details see Amar & Redpath 2005). LCM data were based on satellite images gathered during summer and winter and 88% of areas were classified using a combination of images taken over these two time periods (Fuller *et al.* 1994b). Therefore, we averaged the habitat data collected from transects during spring and summer to make the comparisons with the LCM data more realistic.

LCM has three different categories for rough grass habitats: grass heath (category 5), moorland grass (category 9) and rough/marsh grass (category 8). From the habitat survey, we compared the number of quadrats that were dominated by rough unmanaged grass (defined by a litter layer of dead grass adequate to conceal a moving vole; Amar & Redpath 2005) within each 1-km square, with the proportion of the different rough grass measures – on their own and in combinations – calculated from the LCM data. We found that categories 5 and 9 combined were most closely correlated with rough grass measures taken from the habitat survey (R^2 = 0.63, Fig. 1); given the amount of variation that was explained from this correlation, we believe that the use of categories 5 plus 9 is a valid representation of the relative amount of rough grass present in each area. Therefore, for the purpose of this study we used these two categories combined as our measure of rough grass. For analyses, we calculated the proportion of rough grass as the surface covered by this habitat type divided by total surface, after excluding areas covered by unidentified habitats.

To investigate the availability of rough grass habitat around nesting areas, we superimposed circles of 0.5, 1, 1.5 and 2 km in radius around each nest. The value of 2 km was chosen as the maximum distance, as Harriers are thought to spend the majority of time foraging within 2 km of nest-sites (Arroyo *et al.* 2004) and previous work has shown that habitat within 2 km of nest-sites influences the types of prey brought to nest-sites (Amar *et al.* 2004). Adjacent nesting areas, which were closer than 1 km apart, would therefore have overlapping circles at all radius sizes. This is entirely appropriate as Hen Harriers, males in particular, have overlapping foraging ranges (Arroyo *et al.* 2004). Using Arcview Spatial Analyst 2.0a we calculated the percentage of rough grass (as defined above) for each circle around each nest and used these data to calculate a mean value for each nesting area.

Statistical analysis

Statistical analyses were carried out in SAS version 9.0 (SAS Institute 1999). We examined the breeding performance of each nesting area in relation to the percentage of surrounding rough grass at each of the four different radii (0.5, 1.0, 1.5 and 2.0 km) using a General Linear Model (GLM). We examined the following breeding parameters: hatching success (whether a clutch hatched or not); breeding success (whether young were produced from a breeding attempt); fledging success (for clutches which hatched, whether the nest fledged any young); productivity (number of young produced from each breeding attempt, from 0 to 5); fledged brood size (for nests which fledged young, the number of young fledged). We analysed data at the level of the nesting area. For binomial measures such as hatching success, breeding success and fledging success, the total number of positive attempts for each nesting area was used as the numerator, with the number of attempts (hatching success, breeding success) or the number of hatched clutches (fledging success) as the denominator in a GLM, with a binomial error structure and a logit link function. For measures such as productivity and fledged brood size, we used the total young produced in each nesting territory with the log of the number of nesting attempts (productivity) or successful broods (fledged brood size) as an offset in a GLM, fitted with a Poisson-specified error structure and a log link function. Models with Poisson error structures were corrected for overdispersion. We examined the influence of habitat at four different radii on our breeding performance measures. The rough grass measures at the different radii were not independent. However, our interest lay in examining the differences in the strengths of these relationships as a means to examine which might be the most appropriate spatial scale. Therefore, whilst we acknowledge there is multiple testing, Bonferroni corrections were not considered appropriate to these analyses.

Table 1. Results from general linear models, modelling the influence of the proportion of rough grass around nesting areas, at four different radii, on various breeding parameters.

				Percentage rough grass (mean ± se)	
Radii (km)	*df*	χ^2/F	*P*	Above average	Below average
Hatching success					
0.5	1, 50	2.48	0.11	10.0 ± 1.8	5.4 ± 1.6
1.0	**1, 50**	**6.04**	**0.01**	**10.5 ± 1.1**	**6.7 ± 1.0**
1.5	**1, 50**	**6.38**	**0.01**	**10.6 ± 0.9**	**8.1 ± 0.7**
2.0	**1, 50**	**4.75**	**0.02**	**10.5 ± 0.7**	**9.2 ± 0.6**
Breeding success					
0.5	**1, 49**	**4.55**	**0.03**	**10.8 ± 2.3**	**5.7 ± 1.1**
1.0	**1, 49**	**7.98**	**0.004**	**11.1 ± 1.4**	**6.9 ± 0.8**
1.5	**1, 49**	**9.51**	**0.002**	**10.8 ± 1.1**	**8.1 ± 0.6**
2.0	**1, 49**	**7.45**	**0.006**	**10.6 ± 0.8**	**9.1 ± 0.5**
Productivity					
0.5	1, 49	0.80	0.37	9.8 ± 2.3	6.5 ± 1.3
1.0	**1, 49**	**4.48**	**0.03**	**10.4 ± 1.4**	**7.4 ± 0.8**
1.5	**1, 49**	**6.90**	**0.01**	**10.3 ± 1.0**	**8.5 ± 0.6**
2.0	**1, 49**	**5.50**	**0.02**	**10.4 ± 0.8**	**9.3 ± 0.5**
Fledging success					
0.5	1, 37	1.58	0.20	10.8 ± 2.1	6.6 ± 1.6
1.0	1, 37	2.28	0.13	10.3 ± 1.3	7.5 ± 1.1
1.5	1, 37	2.92	0.08	10.4 ± 0.9	8.2 ± 0.7
2.0	1, 37	1.75	0.18	10.4 ± 0.8	9.3 ± 0.5
Fledged brood size					
0.5	1, 33	1.26	0.26	8.2 ± 2.0	11.0 ± 2.2
1.0	1, 33	0.15	0.70	10.2 ± 1.6	9.0 ± 1.3
1.5	1, 33	1.18	0.28	10.8 ± 1.4	9.1 ± 0.9
2.0	1, 33	0.81	0.37	10.8 ± 1.1	9.6 ± 0.6

χ^2 values are given for binomial data, *F* test statistics are given for count data. Significant results are displayed in bold type. The percentages of rough grass surrounding nesting areas, which were above or below the average for each response variable, are presented.

RESULTS

From a total of 210 clutches found during 1989–1997, 93 successfully hatched. We had information for 79 of these broods, of which 16 failed, with the rest fledging at least one young. This represents an apparent hatching success rate of 44% and a fledging success rate of 80% from the clutches that hatched. Each breeding attempt (including failed attempts) produced an average of 0.68 chicks. At the level of the nesting area, average hatching success was 49%, and fledging success from those that hatched clutches averaged 76%.

We found a significant positive association between the proportion of rough grass surrounding a nesting area and the probability of hatching, breeding success and productivity (Table 1). Furthermore, this was true for all four radii examined, with the exception of the effect of rough grass on hatching success and productivity at the smallest radius. In contrast, there was no detectable effect of rough grass on fledging success (whether young fledged if the clutch hatched) or fledged brood size (number of young in successful broods; Table 1).

The actual differences in the amount of rough grass between nesting areas with above or below average breeding success were relatively small (Table 1). For example, the average percentage of rough grass (± 1 se) within 2 km of nesting areas with above average measures of breeding success was 10.6 ± 0.8%, whereas nests with below average measures had 9.1 ± 0.5%, which represents around a 19-ha difference.

DISCUSSION

Results from this study show that breeding attempts in nesting areas surrounded by higher proportions of rough grass had greater probability of success and fledged overall more nestlings, mainly because of a higher probability of reaching the hatching stage. These results concur with the low hatching success observed in the study population in recent years, and confirm those of previous studies, which suggested that the critical stage of food limitation for this population is the early breeding period (Amar & Redpath 2002, Amar *et al.* 2005). Additionally, our results confirm that rough grass is a critical habitat for Orkney Hen Harriers, providing the necessary food during the incubation period. We know from previous research that Orkney Harriers selectively hunt areas with more rough grass in both spring and summer (Amar *et al.* 2003a, Amar & Redpath 2005). This hunting preference is most probably due to the fact that the abundance of many of their important prey items, e.g. Orkney Voles *Microtus arvalis orcadensis*, Snipe *Gallinago gallinago* and Meadow Pipits *Anthus pratensis*, is positively correlated with rough grass abundance (Amar 2001, Amar & Redpath 2005). It is also possible that prey are not only more abundant, but also more available, as suggested by another study which found that prey capture rates relative to encounter rates by hunting Hen Harriers varied between habitats managed differently (Redpath *et al.* 2002). For example, high densities of Orkney Voles can occur in pure stands of heather in Orkney. However, their tunnels are often hidden by thick layers of heather roots and moss, presumably making them less available to hunting Harriers (Amar & Redpath 2005). Regardless of whether it is availability or abundance of prey that is important, it is clear from the results that the amount of rough grass available to Harriers in Orkney improves their breeding performance. Our results thus confirm the link between food limitation, preferred hunting habitat and breeding performance.

We considered the relationship between breeding success and the proportion of rough grass in circles up to a 2-km radius around nests. The relationships between rough grass and hatching success, breeding success and productivity were significant for all radii above 0.5 km. Thus, as long as sufficiently good foraging habitat is created within 2 km of nest-sites, it is not necessary to establish such areas particularly close to nest-sites. Preliminary data from radiotracked birds suggest that breeding Harriers forage mainly within 2 km of the nest (Arroyo *et al.* 2004), and habitat within 2 km of Hen Harrier nests has been shown to influence the prey types delivered to the nest (Amar *et al.* 2004), further confirming that this may be a good operational distance for implementing management schemes to create foraging habitat for Harriers.

Although the association of breeding success and rough grass abundance is most logically explained through greater access to the preferred hunting habitat, we cannot rule out other factors causing this relationship. For example, this same association would be found if birds with inherently lower breeding success, such as younger less experienced birds or secondary females within polygynous harems, settled in areas with less rough grass around them. However, even if that were the case, this would suggest that the more dominant birds are selecting the more grassy areas, indicating that there are fitness benefits associated with these habitats.

Our analyses revealed that creating rough grass habitat should have a direct effect on increasing Harrier breeding success (which is the main goal in the management of the Orkney Hen Harrier population), and provided some indication on the distances from the nest at which to implement management. Results from this study therefore support the proposed management plans to improve the breeding success of Hen Harriers on Orkney by increasing the amount of rough grass around nesting areas. This management is now underway, through the Orkney Hen Harrier Scheme (www.snh.org.uk/pdfs/about/orkneyHH.pdf) launched in 2002 by Scottish Natural Heritage, the statutory body for conservation in Scotland. Under this scheme, payments for the creation and maintenance of rough grassland are available to farmers managing land adjacent to the three moorland blocks used by nesting Hen Harriers on Orkney's West Mainland. Logically, the total amount of foraging habitat created, the location of these areas and, ultimately, the benefits to the Hen Harrier population will depend on the uptake of the scheme. However, our results suggest that even a relatively small uptake should benefit the Harrier population, given the comparatively small differences in rough grass cover around comparatively successful versus unsuccessful nesting areas. This work indicates the sensitivity of Hen Harriers on Orkney to rough grassland and as such suggests they may act as an indicator of the value of this habitat to biodiversity more generally.

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