

Habitat use by Hen Harriers *Circus cyaneus* on Orkney: implications of land-use change for this declining population

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The use of habitats by hunting Hen Harriers *Circus cyaneus* just prior to the settlement period was investigated on Orkney, where numbers have declined by 70% over the last 20 years. Both males and females hunted over areas that were closer to subsequent breeding territories. Neither sex differed in the amount of time they hunted over areas dominated by either intensive pasture, moorland or rough grazing. However, male hunting was significantly related to the amount of unmanaged grass habitat with a litter layer. Female hunting was related negatively to vegetation height, and to the prevalence of both Heather *Calluna vulgaris* and managed grass; after controlling for these habitat features, female hunting also tended to be associated negatively with Common Starling *Sturnus vulgaris* abundance. Dramatic changes in land use on Orkney have occurred over the last 40 years, with increases in the amount of intensive pasture and decreases in the amount of rough grazing. These changes, coupled with a doubling in sheep *Ovis aries* densities over the last 20 years, are likely to have reduced the amount of unmanaged grass. These changes will have been detrimental to hunting male Harriers by reducing the amount of food they can supply to the females prior to egg laying and during the incubation period.

The decline of bird species in agricultural habitats has been well documented and has often been linked to intensification and changes in farming practices (Warner 1994, Aebischer *et al.* 2000, Donald *et al.* 2002). For some species there is increasing understanding of the processes by which birds are affected ecologically by agricultural change (Ormerod & Watkinson 2000). These processes vary between species but are generally associated with either decreases in food resources (Potts 1986, Campbell *et al.* 1997, Evans *et al.* 1997, Wilson *et al.* 1999), reduction in the quality of nesting habitat (Wilson *et al.* 1997, Chamberlain *et al.* 1999) or direct mortality of birds through harvesting processes (Green 1995, Arroyo *et al.* 2002).

In addition to its effects on birds, intensification may be responsible for a reduction in the abundance

of certain small mammal populations sharing these agricultural habitats (Gorman & Reynolds 1993; Harris *et al.* 1995, Arroyo *et al.* 2002). Although such declines are of interest in their own right, they may also have wider implications for other species using these farmland habitats. For example, predators that hunt these environments may suffer from a reduced prey base. Indeed, declines in small mammal abundance brought about through agricultural intensification have been suggested as an explanation for the declines of the Barn Owl *Tyto alba*, Short-eared Owl *Asio flammeus* and Weasel *Mustela nivalis* (Love *et al.* 2000, Gorman & Reynolds 1993, Tapper 1999). Species occupying higher trophic niches, such as raptors, are generally regarded as useful indicators of ecological change. However, with the exception of the effects of pesticides on Eurasian Sparrowhawks *Accipiter nisus* (Newton 1986, Sibly *et al.* 2000), the influence of agricultural intensification on these species has received relatively little attention in the UK. There are two main reasons for this; first, the majority of declines have been identified and

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quantified through the long-term data sets of the Common Birds Census (Fuller *et al.* 1995, Siriwardena *et al.* 1998), which operates at a spatial scale that is generally too small to provide good information for species with large home ranges that are relatively scarce, such as raptors (Marchant *et al.* 1990). Secondly, during the major period of agricultural change, many of the raptor species using lowland farm habitats – such as Eurasian Sparrowhawks and Common Buzzards *Buteo buteo* – were in the process of a population recovery following the end of widespread organochloride pesticide use and persecution (Newton 1986, Elliott & Avery 1991, Clements 2002). As a result, the effects of agricultural intensification on some of these species or populations may have been concealed.

One population of UK raptors for which there are long-term data and which has been largely unaffected by organochloride use (Hamerstrom 1986) or persecution (Meek *et al.* 1998) is the Hen Harrier *Circus cyaneus* on the Orkney Islands. Since the late 1970s there has been a pronounced decline in this population. Numbers of males and females in the population have declined by around 70% (Meek *et al.* 1998), and numbers of chicks produced have fallen, from an average of 60 chicks fledged per year in the 1970s, to an average of only 16 fledged per year in the 1990s (Amar *et al.* in press). There are no native mammalian predators on the Orkney Islands, and the Hen Harrier (hereafter Harrier) is a significant top predator in this environment.

Recent research suggests that a decrease in food supply during the early breeding period is the most likely reason for this population's decline, and in particular the amount of food that males supply to their females during the prelaying period appears to be critical (Amar & Redpath 2002, Amar *et al.* 2003). One explanation for a decrease in the food supply for the Orkney Harriers is that agricultural intensification may have reduced the area of preferred hunting habitats and thus reduced the abundance of important prey species. Picozzi and Cuthbert (1982) observed that Harriers in Orkney hunted farmland and rough grazing in winter and Picozzi (1984) suggested that they hunted farmland and marshes adjacent to the moorland breeding areas in summer. However, these observations were not supported through any quantitative data.

In this paper we aim to identify at a broad scale whether certain habitats are important to male and female Harriers hunting in Orkney during the pre-breeding period. Furthermore, we also aim to test

whether the amount of time an area is hunted is associated with any measures of habitat characteristics or prey abundance. We predict that habitat use is likely to be related to the abundance of the important prey types, or of vegetation types that are correlated with prey abundance. Using agricultural records, we evaluate changes in land use on Orkney, and discuss the implications of these changes for Harriers. In light of these findings, management strategies that could be beneficial to Harriers are suggested.

METHODS

Selection of study areas

The use made by hunting Harriers of three main habitat types on West Mainland, Orkney, was investigated. These were as follows: (1) upland moorland, dominated by Heather *Calluna vulgaris*; (2) lowland rough grazing, principally a mixture of Heather and unmanaged grass, often located at the edges of moorland areas; and (3) intensive pasture, dominated by managed re-seeded grass species, heavily grazed by sheep and cattle. Areas of each habitat type were initially selected by eye on the ground; we then selected a square area dominated by this habitat type measuring 1 km² using an OS 1 : 25 000 map, re-orientating the square's position until it contained the maximum amount of this habitat, but still offering good views for observation (Fig. 1). Square selection was constrained by the limited availability of certain habitat types (principally the lowland rough grazing) and suitable topography for observations. If more than the required number of areas were located, the final decision on which square to use was made at random. We had no prior knowledge of Harrier hunting intensity in the study areas.

Quantifying habitat use by hunting Harriers

Data on Harrier foraging were collected just prior to Harrier settlement in spring 1999 and 2000, through watches of squares between 28 February and 29 March. Nine squares, three in each habitat type, were used in both years. Data in spring 2000 were also recorded from a further nine squares, again three in each habitat type. Overall therefore, data were collected from a total of 18 different squares, with six dominated by each habitat type.

The corners of each square were marked on the ground with coloured flags attached to bamboo

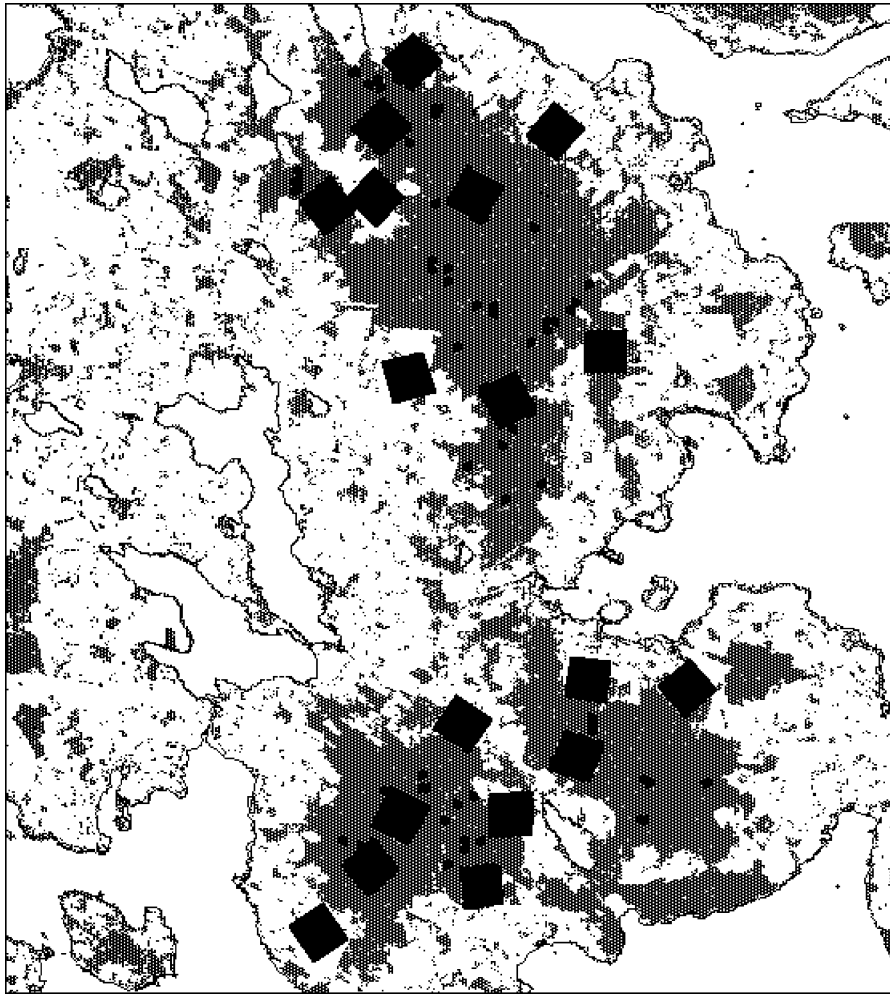


Figure 1. Map showing distribution of Hen Harrier nests on West Mainland, Orkney, in 1998–2000 and the locations of the 18 watch squares used in this study. Hatched areas are moorland and rough grazing habitats.

canes. All squares were chosen within 5 km of an active Harrier territory, the locations of which remain similar from year to year. The distances between the centre of a 'watch' square and the centre of male territories in the subsequent breeding season, within 5 km, were measured. A territory proximity index for each square was then calculated as the sum of the reciprocals of the squared distance to each territory. This measure was used to account for the possibility that Harriers in the spring may hunt nearer to their breeding grounds in anticipation of settling. The centre of a male's territory, rather than a nest-site, was chosen to allow for the fact that some males were polygynous and also because some males and many females on territories failed to breed at all (Amar *et al.* 2003).

Watches of squares were conducted from suitable locations that were close to the edge of a square and offered good views over the whole square. Each square was watched for a total of 10 h, comprising a number of watch sessions aimed to last around 3 h each, but their exact length was weather-dependent because watches were only conducted during times with little or no rain. During a watch session, squares were scanned continuously for hunting Harriers by using 10 × 42 binoculars. When an individual Harrier was spotted hunting in the square the following parameters were recorded: time spent in square, behaviour (hunting or other), age and sex. Harriers were classified as hunting if they were flying < 10 m from the ground (estimated visually). As Harriers tend to hunt by flying low and quartering across the

ground (Schipper *et al.* 1975), a height of 10 m was chosen as the criterion to exclude Harriers that may not have been actively searching for prey.

A tape recorder, set to run continuously for the duration of each foraging bout, was used to record the duration of hunting within a square. We recorded voice notes in real time and then timed these notes after a watch session was completed. Hunting Harriers were classified as either adult male, identified from their distinctive pale plumage, or as ringtails, which included females and immature males. Attempts were made to separate females from immature males, on the basis of size, as immature males are around 10% smaller than females (Cramp & Simmons 1980). Data on immature males were excluded from all analyses owing to the small sample size. Ringtails are hereafter referred to as females, although they may have included a small number of immature males.

Prey and vegetation measures

Vegetation and prey measures were recorded between the same dates that watches were conducted (i.e. 28 February–29 March). For squares observed in both years, vegetation measures were recorded only in the first year, and assumed not to have altered by the second year. Data on prey were recorded for each square watched in each year. Measures of avian prey species were recorded using line transects. Two parallel transects were performed at distances of 250 m and 750 m from a randomly selected side of each square. They were conducted between 06:00 and 09:00 h, as this period provided the highest repeatability in estimating passerine numbers, due to diurnal variation in detection rates (Thirgood *et al.* 1995). The numbers of individuals of each species seen within 200 m on either side of the transect line were recorded.

Vegetation measures and vole and lagomorph sign indices were recorded simultaneously. Quadrats, measuring 25 × 25 cm, were placed every 40 m along two transect lines within a square, again located 250 m and 750 m away from one side of a square, giving information from 50 quadrats per square. Vole abundance was indexed using the presence or absence of fresh droppings in each quadrat. Previous research showed that fresh vole droppings provided the most reliable index of relative vole abundance as estimated by simultaneous snap trapping (Oates 1996). The presence or absence of fresh lagomorph droppings was also recorded in each quadrat

and these were used as an index of lagomorph abundance. The dominant type of vegetation in each quadrat was recorded and the highest live point of this vegetation type measured. Each dominant vegetation type was recorded to species level, except for grasses, which were classified categorically as either managed or unmanaged. Unmanaged grass was defined by a build up of dead vegetation forming a mat under the living vegetation, adequate to conceal a moving vole (Hewson 1982).

Hen Harrier diet

The main prey types in the Harrier diet were estimated from pellets. At the start of the watches the largest communal roost on West Mainland (containing 3–17 individuals, K. Fairclough pers. comm.) was cleared of pellets. At the end of the watch period, pellets were again collected. This was conducted in both years and a total of 98 pellets were found, which yielded 138 identified items in all. Items in pellets were identified to species level where possible. Rabbits *Oryctolagus cuniculus* and Brown Hares *Lepus europaeus* were classified together as lagomorphs, because lagomorph hair can usually be separated to species only at the microstructural level (Wolfe & Long 1997). For further details of methods used in the pellet analysis, see Clarke *et al.* (1997).

Changes in land use

Seven parishes (regional areas of different sizes) on West Mainland, Orkney, have breeding Hen Harriers: Birsay, Harray, Evie, Rendall, Firth, Orphir and Stenness. For these parishes, data from the annual June Agricultural Census from 1960 until 1998 were used to assess changes in land use. For each parish, we recorded the total area of land from which records were taken, the area under intensive pasture, the area under rough grazing and the total number of sheep. Densities of sheep were then calculated per hectare.

Statistical analysis

All statistical analyses were performed using SAS, version 6.12 (SAS Institute 1990). Because some squares had repeated observations in the different years, data on hunting and prey types were analysed using generalized linear mixed models (GLMM), with the non-independent effect of individual squares specified as a random term in the model. These models

were implemented in SAS using the GLIMMIX macro (Littell *et al.* 1996). The data on time spent hunting in squares were best described by a gamma distribution and these models were therefore fitted with a gamma error structure and a log link function. The properties of the gamma distribution mean that zero figures cannot be accommodated; therefore, half the smallest value of the response variable was added to each observation. This value was chosen because analyses were conducted with a log link function, such that values at the lower end of the range would have had a disproportionate effect. We examined hunting by males and females separately in all analyses.

First, we examined whether a square's proximity to Harrier territories had an influence on the amount of time it was hunted. Differences in hunting time between the three habitat types were then explored. Finally, owing to the relatively small number of squares sampled for hunting, and the relatively large number of possible explanatory variables, we constructed models using a two-step approach. We first constructed a habitat model exploring the variation in hunting, using the four habitat measures (the three vegetation types dominating over 10% of the quadrats, and the mean vegetation height). We used a backward elimination procedure, dropping the least significant term in the subsequent model until only terms significant at the 10% level, using SAS type III analysis, remained. We then entered estimates of abundance for the four most important prey types in turn and examined whether any were significant in the model, again using type III analysis. Denominator degrees of freedom in these models were estimated, using Satterthwaite's formula (Littell *et al.* 1996). Pair-wise comparisons were conducted in the GLMM using the difference in least square means (DLSM).

GLMMs were used to examine differences in the abundance of prey types between squares; we looked for any differences between years first, and then differences between habitat type, controlling for any significant year effects. Because vegetation data were only collected once from each square, comparisons of unmanaged grass between habitat types did not require the use of mixed models. Instead, data were analysed with a general linear model (GLM).

RESULTS

Harrier diet and prey abundance in the different habitat types

In early spring, the four most numerous prey types accounted for 48% of all the prey items identified in the pellets. These were Orkney Voles *Microtus arvalis orcadensis*, lagomorphs, Common Snipe *Gallinago gallinago* and Common Starlings *Sturnus vulgaris*, which accounted for 18, 14, 10 and 6% of items, respectively.

The abundance of all important prey species in the squares, except voles, varied between years (lagomorphs: $F_{1,16} = 8.87$, $P = 0.01$; Starling: $F_{1,7} = 36.2$, $P < 0.001$; Snipe: $F_{1,8} = 6.59$, $P = 0.03$; whereas for Voles: $F_{1,10} = 0.68$, $P = 0.42$). Abundance of these important prey species also varied between the habitat types (Table 1). Vole signs were encountered significantly less in intensive pasture than on either moorland or rough grazing (DLSM: $P = 0.01$ and 0.05 , respectively). By contrast, lagomorph signs were encountered more often on intensive pasture than on moorland (DLSM: $P = 0.01$). Starling abundance was significantly higher on intensive pasture than on either moorland or rough grazing (DLSM: $P < 0.001$, $P < 0.001$, respectively). More Snipe were found on

Table 1. Abundance of main prey types and unmanaged grass within squares of the three habitat types. Vole and Rabbit estimates are the number of quadrats with positive signs out of 50 quadrats surveyed in each square. Avian abundance measures are the number of individuals counted per two 1-km transects. Unmanaged grass data are presented as the percentage of quadrats dominated by unmanaged grass from the 50 measures made. Data are presented as means \pm 1 se. Test statistics for prey species are from a GLMM, controlling for any significant year effect. Test statistics of unmanaged grass are from a GLM.

Variable	Intensive pasture	Moorland	Rough grazing	df	F	P
Voles signs	0.44 \pm 0.24	2.89 \pm 0.72	1.78 \pm 0.52	2,13	4.03	0.04
Lagomorph signs	3 \pm 0.82	0.67 \pm 0.33	1.22 \pm 0.47	2,18	4.18	0.03
Starlings	25.22 \pm 6.95	1.33 \pm 0.99	2.56 \pm 0.88	2,15	11.09	0.001
Snipe	2.89 \pm 0.95	1 \pm 0.41	4.56 \pm 1.04	2,23	4.41	0.02
Unmanaged grass	5.34 \pm 2.72	3 \pm 1.34	23 \pm 3.04	2,15	19.45	0.001

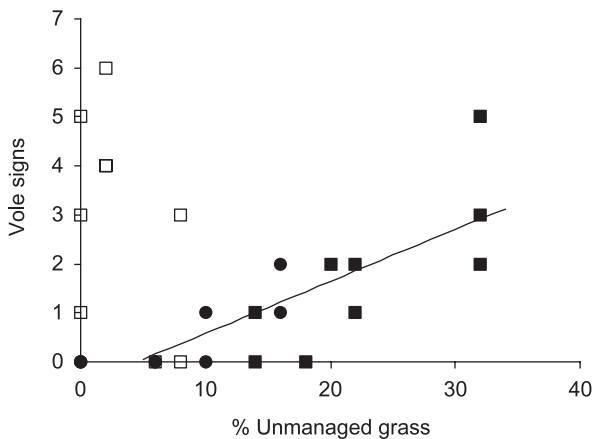


Figure 2. Relationship between percentages of unmanaged grass-dominated quadrats and estimated vole abundance (fresh vole droppings per 50 quadrats) in the three habitat types (intensive pasture (●) moorland (□) and rough grazing (■)). The trendline shown is a linear regression for intensive pasture and rough grazing only.

lowland rough grazing than on moorland (DLSM: $P = 0.007$) and although not significant, there were generally more on intensive pasture than on moorland (DLSM: $P = 0.06$).

The abundance of two of the important prey species was correlated with the amount of unmanaged grass. Within farmland and rough grazing, there was a significant positive relationship between the proportion of unmanaged grass and vole signs ($F_{1,3} = 25.11$, $P = 0.01$; Fig. 2). In moorland no such relationship existed as vole signs were commonly seen in rank Heather habitats. There was also a positive correlation between unmanaged grass and Snipe abundance when data from all habitat types were pooled ($F_{1,12} = 10.89$, $P = 0.006$). Rough grazing habitats had significantly more unmanaged grass than the other habitats (Table 1).

Habitat use by hunting Harriers

There was a positive association between hunting and territory proximity, for both males ($F_{1,19} = 7.26$, $P = 0.01$) and females ($F_{1,18} = 5.70$, $P = 0.02$). In other words, the closer squares were to the breeding areas the more they were hunted. Therefore, to control for this we fitted territory proximity as a permanent fixed effect in all subsequent models.

Males did not differ in the amount of time they hunted the three habitat types ($F_{2,16} = 2.28$, $P = 0.13$). However, pair-wise comparisons suggested that males tended to hunt lowland rough grazing more than

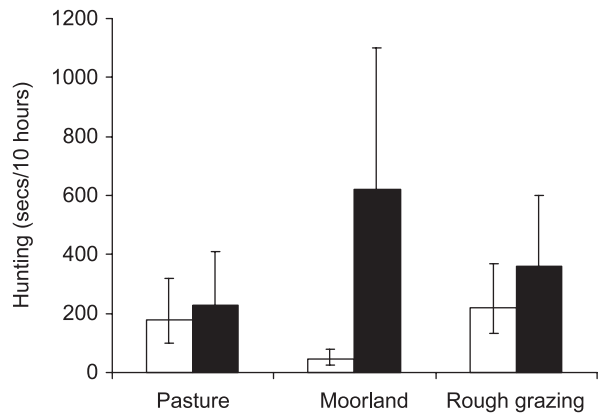


Figure 3. Hunting by male (clear bars) and female (filled bars) Harriers in spring in the three habitat types. Data are mean model estimates after controlling for distance from breeding territories, which was set at a constant of the mean index (1.57). Data are presented ± 1 se.

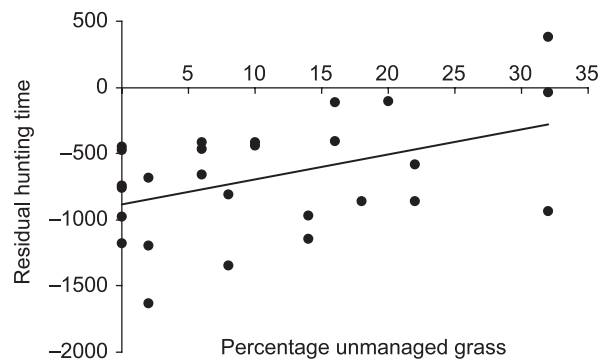


Figure 4. Residuals of the amount of time male Harriers hunted an area (seconds/10 h) and the percentage of quadrats dominated by unmanaged grass after controlling for the significant relationship between hunting and territory proximity. The trendline shown is a linear regression.

moorland (DLSM: $P = 0.053$; Fig. 3). There was a positive relationship between the amount of time a square was hunted by males and the amount of unmanaged grass within a square (Fig. 4); after controlling for this, hunting was not found to correlate with any of the prey measures (Table 2).

Females, similarly, did not differ in the amount of time they hunted over the three habitat types ($F_{2,16} = 0.62$, $P = 0.54$; Fig. 3). Female hunting was found to be correlated negatively with vegetation height and managed grass prevalence, and to be marginally negatively correlated with Heather prevalence ($F_{1,13} = 3.12$, $P = 0.10$). After controlling for all these habitat variables, female hunting was also

Table 2. Generalized linear mixed models (GLMM) examining hunting time for male and female Harriers. Figures in bold are for the significant habitat variables of the final fitted habitat model for each sex. Values for the non-significant terms are the values obtained when the terms were added alone in the model containing territory proximity and the significant habitat variables. The final habitat model also includes square as a random term, estimates of which were 0.658 ± 0.47 for males and 0.468 ± 0.39 for females.

Variable	Male				Female			
	Estimate	df	F	P	Estimate	df	F	P
Territory proximity	0.658	1,15	10.42	0.005	0.598	1,16	4.91	0.041
Habitat variables								
Unmanaged grass	0.138	1,14	8.79	0.010	0.023	1,13	0.07	0.79
Managed grass	0.009	1,18	0.19	0.66	-0.137	1,13	6.62	0.02
Heather	-0.04	1,19	2.35	0.14	-0.083	1,13	3.12	0.10
Vegetation height	-0.036	1,18	0.02	0.87	-0.109	1,14	4.30	0.05
Prey variables								
Vole	0.022	1,22	0.03	0.86	-0.085	1,21	0.30	0.59
Lagomorph	0.077	1,23	0.43	0.51	0.013	1,21	0.01	0.91
Starling	-0.004	1,16	0.09	0.76	-0.028	1,14	3.66	0.07
Snipe	-0.028	1,14	0.12	0.73	0.109	1,18	1.75	0.20

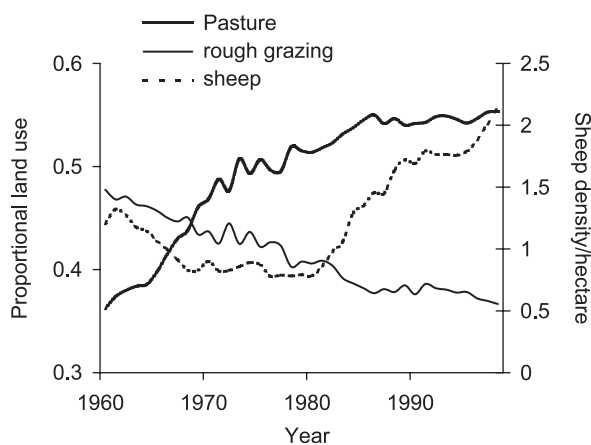


Figure 5. Proportion of land under intensive pasture and under rough grazing and the density of sheep in Orkney from 1960 to 1998. Data are mean values from the seven parishes on West Mainland that have breeding Hen Harriers.

found to be marginally negatively related to Starling abundance ($P = 0.07$; Table 2).

Change in land use

The total area covered by the agricultural records in the seven parishes averaged 232 km² annually and did not vary greatly between years (range 224–239 km²). Between 1960 and 1998, the proportion of land under intensive pasture increased from 36% to 54% (Fig. 5). Over this same period, the amount of land under rough grazing declined by 11%,

equivalent to a loss of around 22 km². In addition, numbers of sheep remained relatively constant from 1960 to 1980 and then increased sharply. The mean stocking density between 1960 and 1980 was 0.95 sheep per hectare, but by 1998 it had reached 2.14 sheep per hectare (Fig. 5).

DISCUSSION

Factors affecting habitat use by hunting Hen Harriers

Male Hen Harriers hunted over areas where unmanaged grass was most abundant and this habitat was important for some of the main prey species. Vole abundance was related positively to the percentage of unmanaged grass in both lowland rough grazing and intensive pasture. Similar relationships between unmanaged grass (i.e. with a litter layer) and vole abundance were found by Palmer (2002). In our study, no such relationship existed for moorland-dominated habitats, and this was probably due to the fact that vole signs often appeared within thick Heather. Presumably voles were able to use the Heather as cover and forage on the grasses within the moorland sward, behaviour which may have reduced their availability to foraging Harriers. Snipe were also associated with unmanaged grass. Therefore, the preference for areas with more unmanaged grass may well indicate selection of areas with a greater availability of these important prey types.

Female Harriers hunted areas with shorter vegetation and this could reflect a selection for areas where prey were more available, as was suggested by Martin (1987) and Simmons (2000). This result, however, appears to contradict the findings of Schipper *et al.* (1975), who suggested that females tended to hunt in areas with taller vegetation than did males. However, the ranges of vegetation heights and prey species differed between the two studies, and so may not be directly comparable. The negative relationship between female hunting and Starling abundance might be due to Starling flocking behaviour (Cramp & Perrins 1994), because flocking individuals might be more able than solitary individuals to detect hunting Harriers, and so decrease their likelihood of capture (Kenward 1978). Starlings were more abundant on intensive pasture, which also had more managed grass, but the negative relationship between Starling abundance and hunting was not linked to these factors: even after controlling for the effect of habitat, including managed grass prevalence, this negative relationship still remained.

Both male and female hunting was associated positively with the proximity to Harrier territories. So Harriers were apparently constrained in their hunting by the location of these nesting areas, despite the fact that birds were not regularly seen on territories. Recent research has shown that habitat characteristics around Harrier nest-sites (at the 1-km radii) can have a strong influence on breeding performance (Amar *et al.* 2002). Therefore, although nest-sites are unlikely to be limited on Orkney, there might well be strong competition between birds to secure the best quality nesting sites. Thus birds may hunt nearer to potential nesting areas to ensure that they have the opportunity to settle on good territories when settlement eventually occurs.

Changes in land use and implications for Hen Harriers

Since 1960, the proportion of land under intensive pasture has increased at the expense of rough grazing. These changes in land use are likely to have been detrimental to Harriers. Previous research has shown that the breeding performance of this Harrier population is limited by the amount of food that males can supply to their females during the prelaying period (Amar & Redpath 2002, Amar *et al.* 2003). Male Harriers hunted areas with more unmanaged grass, and the increases in intensive pasture and

decreases in rough grazing are likely to have reduced the total amount of this habitat. Females may also have suffered from the increase in intensive pasture, because hunting by females was associated negatively with managed grass and Starling abundance, two features that are indicative of intensive pasture.

Although much of the land-use change in Orkney had occurred prior to the start of the major decline in the Harrier population in the late 1970s, the pasture and other habitats that were present may still have been of sufficient quality to offer reasonable hunting opportunities. However, at the start of the 1980s, the stocking density of sheep increased greatly in the seven parishes in this study and indeed throughout Orkney (Fuller & Gough 1999). High densities of grazers can change the sward structure by keeping the grass very short, making it difficult for voles to survive (Glue 1967). Indeed, this increase in grazing pressure is likely to have reduced the quality of all habitats. It has been shown previously that reducing sheep numbers can increase cover and vole densities in a range of habitats (Hewson 1982, Hill *et al.* 1992). Increases in sheep densities may also affect numbers of potential avian prey through various mechanisms (Fuller & Gough 1999). Unfortunately, the June Agricultural Census provides no information about sheep distribution across different vegetation types and land-use classes.

We found that rabbits were an important prey item on Orkney, but mainly young individuals, below about 277 g (Amar *et al.* 2003). Rabbits may now form a larger part of the diet in the spring than previously, but through necessity rather than through choice. In the early 1960s, E. Balfour (unpubl. data) collected a total of 38 pellets during the prelaying periods of 1961 and 1962, and found that voles formed 78% of the identified items and only one of the pellets contained rabbit remains. We collected 115 pellets in Orkney during the prelaying periods (April and May) in 1998 and 1999 and found that 29% contained voles, and 19% contained rabbit remains. So these limited data suggest that there may have been a shift toward rabbits between these two periods, presumably because voles became scarcer and rabbits more common. Glue (1967) found a similar result in Barn Owls *Tyto alba*: when increased grazing reduced the amount of thick mat vegetation and decreased Short-tailed Vole *Microtus agrestis* abundance, there was a corresponding reduction of this prey in the Owls' diet.

Conservation management

Changes in farming practices that have caused declines in common species such as granivorous birds or small mammals have the potential to affect predatory species that hunt on farmland. Habitat use by Hen Harriers in Orkney may not be typical of most of the UK population, which forage in upland areas dominated by Heather moorland and rough grazing. However, findings from this study suggest some factors that might influence Hen Harriers in these other environments if overgrazing causes large-scale habitat changes, and also on how best to manage these habitats for their benefit. In addition, these findings may help to elucidate the causes for the declines of other raptors which use farmland habitats. For example, the Common Kestrel *Falco tinnunculus* declined by 30% between 1994 and 2000 in the UK (Gregory *et al.* 2002), and voles form an important part of its diet (Village 1990). Loss of unmanaged grassland is likely to be as detrimental to Kestrels as it has been for Hen Harriers in Orkney.

The overall conclusion that male Hen Harriers used areas of unmanaged grass suggests that the species would benefit from the creation of more of this habitat, and from the higher number of voles and other prey species that it supports. Increasing unmanaged grass among intensive pastures on Orkney may be the quickest and most convenient way to proceed, as this would entail only the removal of livestock. Previous studies suggest that these set-aside lands might be colonized by voles within 2 years (Churchfield *et al.* 1997, Tattersall *et al.* 2000). It may also be advantageous if these habitats were created on areas directly bordering the moorland, because both males and females hunted in areas that were closer to their breeding grounds. Furthermore, moorland areas had higher vole densities than did intensive pasture, allowing rapid colonization from adjacent habitat, although field margins within farmland habitats are also known to have high numbers of voles (Gorman & Reynolds 1993). By locating these areas next to Heather-dominated vegetation, Meadow Pipit *Anthus pratensis* densities on the moorland margins might also be increased (Smith *et al.* 2001), which may produce benefits later in the season when they are an important prey species (Burthe-Wood 2000, Amar 2001).

Alternatively, we could try to manage the moorland in Orkney for Harriers; increasing grazing pressure on moorland could in the long term increase the ratio of grasses to Heather (Welch 1986). This is

likely to benefit Harriers and increase their densities, because Harrier densities are related to Meadow Pipit abundance, which in turn is positively related to the grass-to-Heather ratio (Smith *et al.* 2001). In the short term, however, increased grazing may decrease the quality of this moorland habitat for voles and Meadow Pipits (Hill *et al.* 1992, Hope *et al.* 1996). However, the area of moorland on Orkney has already been considerably reduced over recent decades (Bennett 1986), and any further loss of this habitat could mean that nesting areas might become limiting for the Harriers. Furthermore, the conversion of this habitat type from a Heather-dominated mosaic to a more grass-dominated habitat is perhaps also undesirable, and one that could have unforeseen consequences for other biodiversity sharing this habitat.

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