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HABITAT USE AND RANGE MANAGEMENT ON PRIORITY AREAS FOR HEN HARRIERS: 2003 REPORT

REPORT TO SCOTTISH NATURAL HERITAGE

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BACKGROUND

The hen harrier *Circus cyaneus* is listed on Annex 1 of the EU Birds Directive (EEC/79/409). As a signatory to the Directive the UK government is obliged to set up a series of Special Protection Areas (SPAs) in those areas that are most important for the species, and to maintain the species in a favourable demographic status. Scotland holds the majority of the UK hen harrier population and a series of Scottish SPAs have been established or proposed.

Knowledge of the spatial and habitat use of breeding harriers is fundamental to the effective management and protection of the species. Yet relatively little is known about harrier ranging behaviour or habitat preferences, hindering development of effective habitat and site management for breeding harriers.

By the use of modelling and analyses of harrier habitat selection, conclusions can be drawn about how to optimally manage habitat to benefit hen harriers. This project focuses especially on supporting Natural Care (an SNH conservation management programme for moorland areas), by providing recommendations for habitat management, appropriate targets for hen harrier numbers and productivity, and assessments of the success of the Natural Care programme on hen harrier SPAs.

The primary objective of this project, therefore, is to improve our understanding of the habitat requirements of hen harriers, in order to inform the implementation of Natural Care and other support mechanisms for moorland management.

Specifically, the project included the following objectives:

1. To investigate the ranging behaviour and habitat use of breeding hen harriers on representative SPAs where Natural Care Schemes have or will be implemented.

In particular, the objectives for 2003 were to answer, through radio-tracking, the following specific questions: the average size of the home ranges for both sexes, the maximum distances at which harriers hunt from the nest, and whether hunting ranges overlap or not between neighbouring birds. These issues are important in terms of evaluating the optimal distances at which to implement habitat management, and for whether management implemented in a given area is likely to benefit more than one pair simultaneously.

2. To develop a model that predicts range use in breeding hen harriers.

Such a model would allow predicting the relative frequency of hunting throughout the space according to landscape variables and distance to the nearest harrier nest. Management can then be aimed at increasing the availability of preferred landscape variables to harriers, and the model would also give indication about where to implement management in relation to nest distribution. Methods to achieve this objective include observations of hunting harriers at the population level, analysed in conjunction with habitat variables in the observation areas. In 2003, we aimed to initiate the habitat/hunting analyses for two areas with long-term data sets (Orkney and Langholm).

3. To produce a set of criteria on which to assess and monitor the success of Natural Care management prescriptions on moorland SPAs for hen harriers.

This will require the development of population models that are specific to individual SPAs and to wider (e.g. regional) areas since it is unlikely that any SPA's interest will be isolated from the wider countryside. No work was carried out in 2003 in relation to this objective.

4. To produce a set of management recommendations for every Scottish SPA for breeding hen harriers to inform effective and cost-efficient management prescriptions.

Effective habitat management for hen harriers on moorland SPAs under the Natural Care Scheme requires knowledge of those habitats that are best for hen harriers. Information about how habitat influences harrier distribution and breeding success allows to identify which habitats to favour within protected areas. It is also important to determine whether management rules can be applied to any given area, or must be designed on a site-by-site basis. Analysing whether the relationships between habitat variables and harrier breeding is site-specific or general across areas would allow answering the latter question. In 2003, we aimed to analyse the relationship between habitat and harrier distribution in four SPA-pSPA with long-term data sets on harrier breeding.

We present below the detailed up-to-date results in relation to objectives one, two and four. Additionally, we present an assessment of progress towards project objectives.

A- RANGING BEHAVIOUR

A1- EVALUATION OF THE RADIO-TRACKING ACCURACY

Estimates of home ranges inevitably involve an amount of error. It is critical that this error be quantified, so that the precision of home range estimates can be determined. Such an evaluation was made at Langholm in 2002 (Arroyo et al. 2003). Here we evaluate: the accuracy of locations, whether accuracy changed between sites with different topography, and whether error could be associated with other variables potentially modifiable by the observers.

METHODS

We used 10 “dummy” tags (i.e., tags glued to the top of a 2 m bamboo canes which were placed in positions unknown to the observers) for the evaluation of error. Telonics TR-4 receivers were used with 3-element Yagi antennae. Two or three observers were located at vantage points, from where they tried to locate all the operational dummy tags. GPS were used to identify the locations of observers and tags. Bearings of a given tag were not taken simultaneously (which was not a problem, given that the dummy tags did not change position during the whole test period): observers at a vantage point would locate all possible tags, then move to another vantage point, and locate the same tags from there. Bearings (the estimated direction between the observer and a transmitter) were plotted onto 1:25 000 maps, and the point where two bearings crossed was considered as the estimated location of the dummy tag.

Three variables were examined:

1. Bearing accuracy, or angle error (defined as the difference between the actual and the estimated direction between the observer and a transmitter).
2. The accuracy of estimated location derived from pairs of bearings. – We calculated the distance between the estimated location (the crossing of two bearings) and the actual position of the tag.
3. The accuracy of estimated location derived from triangulation of three bearings. – We calculated the distance between the actual position of the tag, and the midpoint of the triangle formed by the intersection of the three bearings.

RESULTS AND DISCUSSION

Figure 1 shows the frequency distribution of error (difference between the real and estimated location of the tags) for both twin fixes and triangulations. Estimated locations ranged from 0 to more than 3.5 km away from the real locations. Average error for twin fixes was 0.728 ± 0.546 km (n = 86); average error for triangulations was almost significantly smaller (0.567 ± 0.364, n = 36; t-test, t = 1.92, P = 0.058). All estimated locations with error higher than 1.5 km corresponded to twin fixes. These results are similar to those found in Langholm in 2002 (Arroyo et al. 2003).

The six fixes with lowest accuracy (> 1.5 km error) corresponded to situations that would have rendered the bearings unacceptable had they been simultaneous: in all six cases, both bearings were almost parallel (and see below); additionally, in two of the cases, there was a hill directly in between one of the observers and the tag. Eliminating fixes arising from bearings with high or low angles (see below), there was no significant difference between the accuracy

of twin fixes and triangulations (t-test, $t = 0.7$, $P = 0.49$). Subsequently, those six fixes were eliminated from all analyses.

We conclude that in most field conditions, the use of triangulation is no more accurate than the use of twin fixes, and therefore, in terms of accuracy, there is no major advantage in using three people simultaneously to locate birds with radios. However, there are advantages in the use of three people, as more ground is covered simultaneously (see below in “home ranges”).

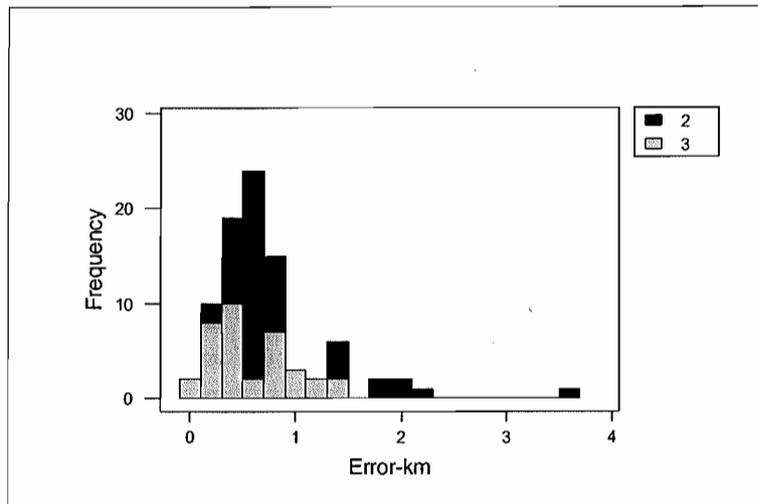


Figure 1. Frequency distribution of the accuracy (distance between the estimated location and the real location of dummy tags) of twin fixes (2) and triangulations (3).

Factors that influenced accuracy

When triangulating a tagged animal's position, errors can arise from topographical features deflecting signals or causing interference, from problems in the receiving systems (such as antenna errors), and from the angle between bearings because the error polygon formed between two bearings (plus or minus the bearing error) increases as the angle between bearings decreases (Kenward 2001). In Orkney, there was a quadratic relationship between the angle between bearings (in degrees), and the accuracy of the estimated locations (Fig. 2; $F_{2,83} = 13.00$, $P < 0.001$, $R^2 = 22\%$). This means that error was greater when bearings were almost parallel: i.e., when the observers were either facing each other, or pointing in the same direction. When using bearings with angles higher than 45 or lower than 135 degrees, there was no longer a relationship between angle and accuracy ($F_{2,45} = 0.22$, $P = 0.8$, $R^2 = 0\%$).

Accuracy decreased with increasing distance to the tag (evaluated as the maximum of both distances between each observer and the tag) ($F_{1,78} = 7.62$, $P = 0.007$), although the relationship was not strong ($r^2 = 7\%$). Accuracy of the estimated locations also decreased significantly with the bearing error (evaluated as the maximum error of both bearings) ($F_{1,78} = 22.9$, $P < 0.0001$, $r^2 = 22\%$, Fig. 3).

Bearing error did not vary significantly among observers ($F_{2,99} = 0.47$, $P = 0.66$), despite the fact that there were observers with vastly different radio-tracking experience. Bearing error was also normally distributed around zero (Fig. 4).

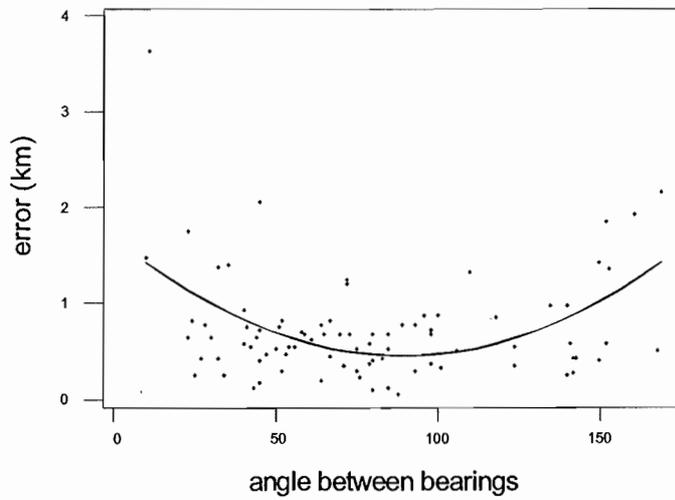


Figure 2. Accuracy of the estimated locations based in twin fix crossings, in relation to the angle between bearings

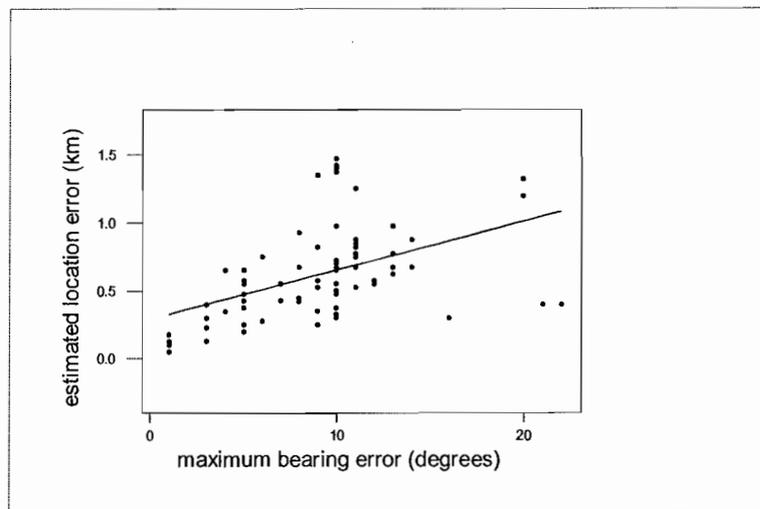


Figure 3. Accuracy of the estimated locations based in twin fix crossings, in relation to the maximum error for each bearing

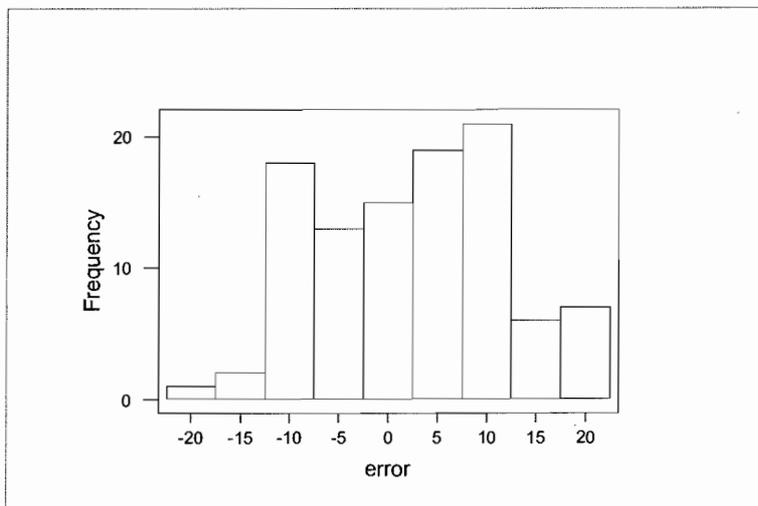


Figure 4. Frequency distribution of bearing error (in degrees).

Overall, maximum bearing error, maximum distance to the tag, angle between observers and its square value were all significant predictors of fix accuracy (GLM, $F_{1,75} = 44.1$, $P < 0.0001$ for bearing error; $F_{1,75} = 18.7$, $P < 0.0001$ for distance; $F_{1,75} = 5.9$, $P = 0.017$ for angle; $F_{1,75} = 7.4$, $P = 0.008$ for angle²). When eliminating bearings crossing at high or low angles (below 45° or above 135°), maximum bearing error alone explained 35% of the variance in accuracy. The combination of maximum bearing error and maximum distance explained 44% of the variance.

Bearing error cannot be evaluated (or modified) by observers in the field when following radio-tagged birds (and thus when the location is unknown). However, the angle between bearings may be evaluated for all estimated locations. Bearings crossing at high or low angles should then be eliminated to minimise error. Even doing this, we conclude that all estimated locations have an associated error of around 500m. This implies that we probably cannot associate each estimated location to a habitat type (using GIS), as an error circle with 500 m radius around each estimated location often contains more than one habitat type (see Fig. 5). However, estimated locations from radio-tagged birds may still be useful in evaluating home range sizes, provided that sample size (number of locations per bird) is relatively high, and assuming that the error of each location is similar and, importantly, relative differences in range size among individuals should not be affected (Marzluff et al. 1997), so it will still be a good tool to compare between individuals or sites. Another assumption is that home range size and variability between birds is large relative to fix error, which seemed to be validated with the data this year (see section below).

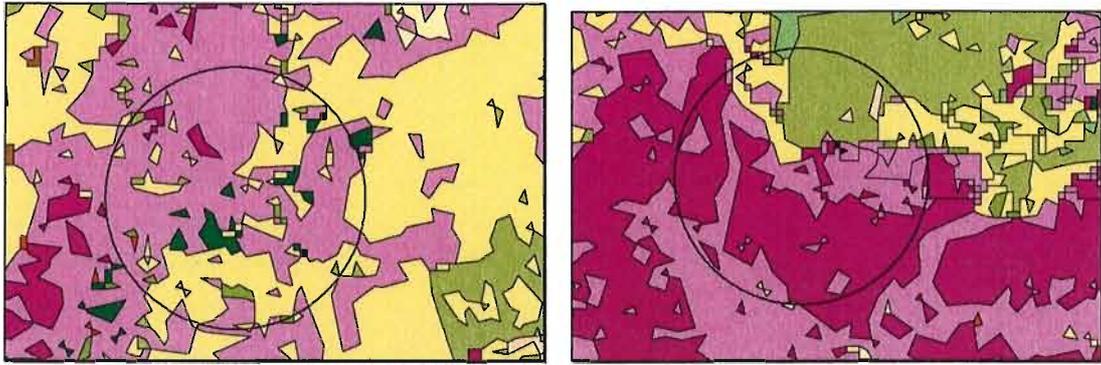


Figure 5. Circles of 500 m radius around notional estimated hunting locations in Langholm (left) and Orkney (right), and the habitats variation therein (each colour represents a different habitat – heather in purple, rough grass in yellow, forest in green)

A2-EVALUATION OF HOME RANGES

We aimed to evaluate the average size of home ranges of breeding harriers, and the maximum hunting distances. This has relevance for management, as it gives an indication of the maximum and optimum distances from the nest at which management should be applied for it to benefit breeding harriers. In addition, we aimed to test whether home ranges varied between sexes, and whether home ranges overlapped between neighbouring individuals. The latter has implications for whether management in a given area is likely to benefit more than one breeding pair.

METHODS

Radio-tags were fitted to three adults in Orkney in 2003, two males and a female (see Annex 1 for details of trapping success). Both males were bigamous. Field data from these three birds was used to assess their home ranges. Tracking sessions involved two or three observers in communication through CB radios. When a tag signal was detected, a bearing was taken by as many observers as could do so. Observers maintained radio contact to ensure that the bearings were taken simultaneously. Bearings were taken every ten to fifteen minutes from the same vantage point for a period of several hours, and repeated every few days.

Home range size was evaluated with the Home Range extension of ArcView 3.2 using all or a selection of points. We calculated Minimum Convex Polygons (MCP) with 100% and 90% of the points, as well as kernel analyses (using 90% and 70% of the points). The fact that bearings were taken every 10-15 min means that some of the fixes may not have been independent (Kenward 2001). ArcView does not calculate Shoenener's (1981) test of Time to Independence between fixes (Kenward 2001). Harriers can travel fast however, and moved far between fixes at least in cases (see Annex 2). Because of that, we consider that the potential influence of non-independence of fixes is probably small. Additionally, no consideration has been given to the potential effect of the inaccuracy of fixes on the estimation of home range sizes. As stated above, we assumed that if the error of each location is similar, that relative differences in range size among individuals should not be affected.

In addition to data from Orkney obtained in 2003, we also included data from the three birds monitored in Langholm in 2002 (see Arroyo et al. 2003). Bearings in 2002 were not taken continuously, but only once or twice a day. Thus, no problems of non-independence existed with Langholm radio-tracking data. Results are presented separately for both years/sites, except when otherwise indicated.

RESULTS AND DISCUSSION

Home range sizes

Table 1 shows the size of the home ranges of the monitored birds, using different calculating methods. MCP range estimates using 100% of fixes were rather large in Orkney, and much smaller in Langholm. Minimum convex polygon calculations of home range are strongly dependent on sample size (number of fixes, Kenward 2001). For the three birds in Orkney, we performed bootstrap calculations of the home range area in relation to the number of fixes (Fig. 6). These showed that home ranges calculated with less than 60 fixes are likely to be grossly underestimated if using MCP. Differences in sample size may partly explain the differences between Orkney and Langholm for MCP calculations (Table 1).

Table 1. Home range size (in km²) of radio tracked birds in two study sites. N = number of fixes. Means \pm SD

	N	MCP 100%	MCP 90%	Kernel 90%	Kernel 70%
Orkney					
Male 296	96	27.33	7.92	8.67	2.89
Male 286	110	25.95	14.00	10.48	2.72
Female 115	111	14.21	5.59	5.55	1.43
Langholm					
Male 279	14	6.83	5.32	9.09	2.13
Female 225	6	1.17	0.79	7.04	3.72
Female 257	16	4.08	2.76	5.93	2.27
Mean males		20.0 \pm 11.5	9.1 \pm 4.5	9.4 \pm 0.9	2.6 \pm 0.4
Mean females		6.5 \pm 6.8	3.0 \pm 2.4	6.2 \pm 0.8	2.5 \pm 1.2

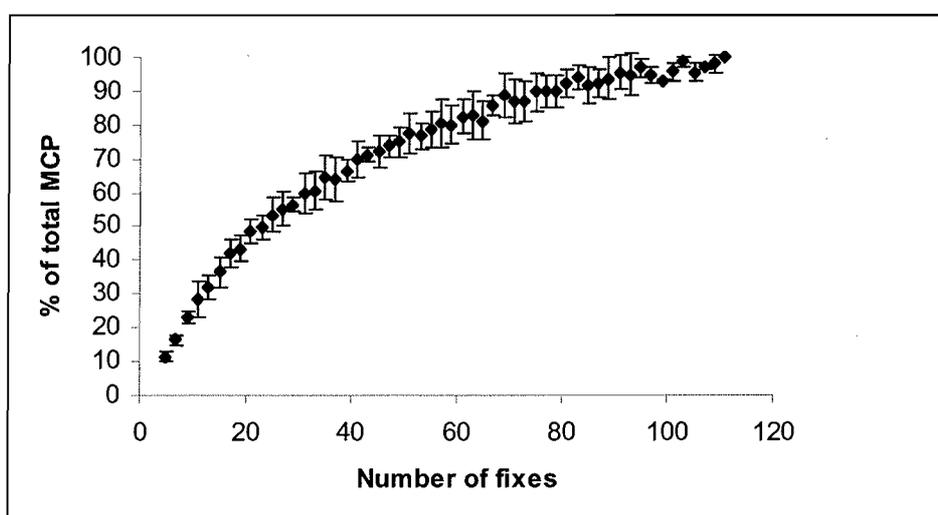


Figure 6. Size of the range (as mean \pm SD) percentage of total MCP) according to sample size (number of fixes) based on bootstrap calculations for the three birds monitored in Orkney.

Additionally, because MCP gives the same weight to each location, it may overestimate home range if there are occasional excursions to relatively distant points, but that are visited only infrequently (see e.g. Fig. 7d). With larger sample sizes, there is a higher likelihood to incorporate extreme locations for places that are rarely used, but that give a strong weight to the shape and size of the whole polygon. To avoid biases due to extreme positions, some studies have used MCP 90% as a comparable reference between individuals or species (Harris et al. 1990, White & Garrot 1990). Differences between Orkney and Langholm were less accentuated when using MCP90%, although ranges were still bigger in the former area. MCP range estimates for one female in Langholm were particularly small (Table 1). This was due to the fact that most locations were somewhat aligned, producing a very thin polygon (Fig. 7a).

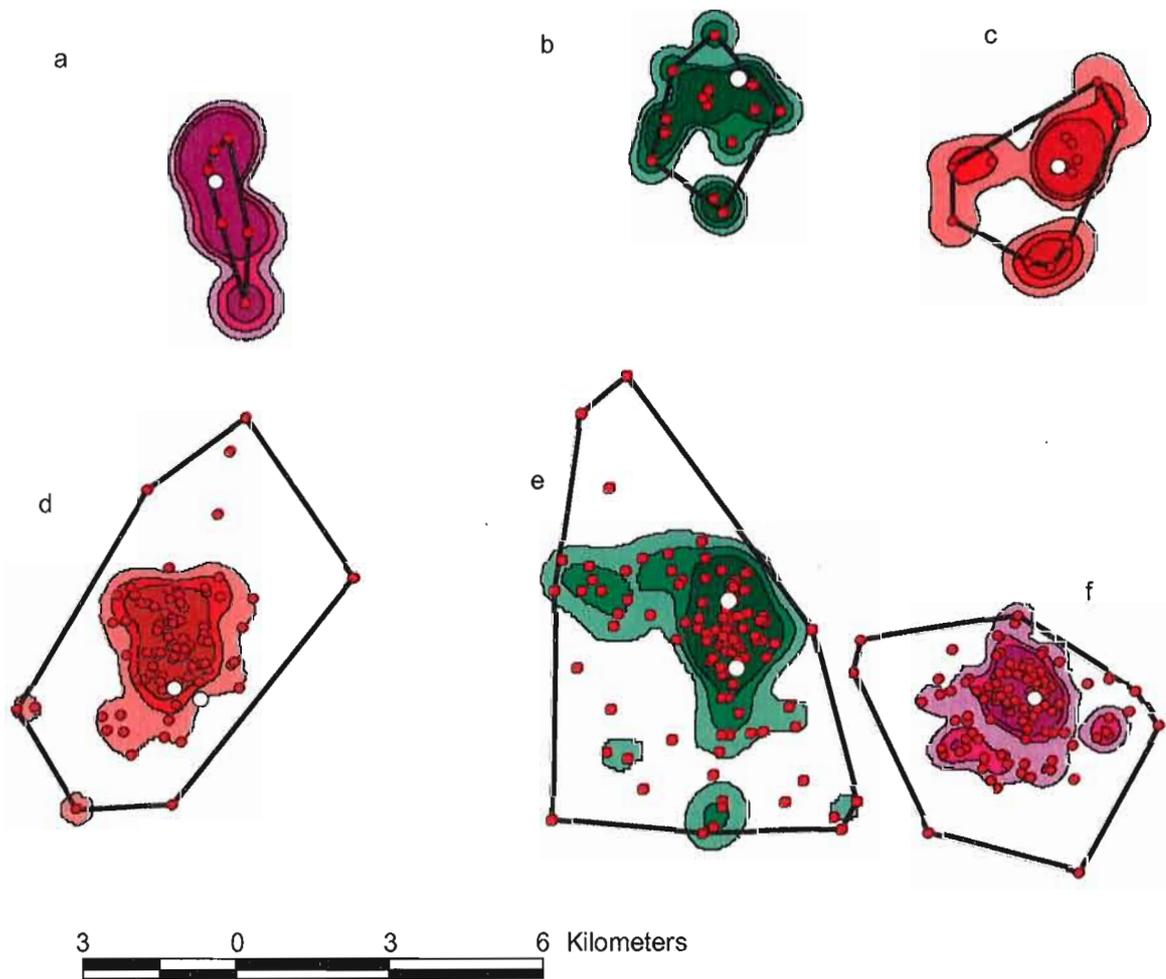


Figure 7: Home ranges of three different birds, as calculated with MCP (thick line) or Kernel (coloured shades). Red points represent each radio-tracking location. White points represent nest locations. a: Langholm female; b: Langholm female; c: Langholm male; d: Orkney male; e: Orkney male; f: Orkney female.

Kernel contour ranges are location density estimators (or probability distributions of finding the animal, Kenward 2001). These can have some drawbacks, for example different results can be obtained with different software, because variation in some of the parameters of the estimation, such as the smoothing parameter, may produce different contours (Worton 1995, Kenward 2001). On the other hand the information they provide may be more biologically meaningful when evaluating frequency of occurrence of a bird in space. Additionally, they may render more reliable estimations of maximum range in certain cases, for example when using small data sets (Kernel contours typically require less than half as many locations to reach a maximum size, Kenward 2001). In all three cases in Orkney, where sample size (number of fixes per bird) was large, MCP estimates were always larger than kernel calculations (Fig. 7), whereas the opposite occurred in Langholm, where sample sizes were small (Table 1, Fig. 7). Overall, kernel-based home-range estimators have been favoured by many authors for analysing home range data with respect to space use patterns (Worton 1989, 1995; Boulanger & White 1990, Boitani & Fuller 2000, Marzluff et al. in press). Home range estimates for Orkney birds were similar when using kernel 90% and MCP 90% (Table 1). Based on kernel calculations, the estimated sizes of home ranges for birds in Orkney and Langholm were similar (Table 1). Kernel contours are used in all subsequent analyses.

Sexual differences

With any method (except for 70% kernel in Langholm), female home ranges were estimated to be about half as large as those of males (Table 1). Females thus hunted closer to the nests than males. This was also confirmed looking at the position of each location: birds were located at distances ranging from 35 to 5600 m away from their nests. Maximum distances for both males in Orkney were above 5 km (5596 and 5195 m respectively). Both Orkney males were located regularly at distances around and above 2 km from their nests, whereas that only happened twice for the female (Fig. 8). This sexual difference in ranging behaviour is not unexpected. Martin's (1987) study of radio-tracked breeding northern harriers *Circus hudsonius* in southwestern Idaho found that female harriers never ranged further than 2 km from their nest sites, whereas males spent 26% of their time ranging over 2 km from the nest. Further hunting distances for male than female hen harriers had also been suggested in the UK (Picozzi 1978, Thirgood et al. 2003, Amar 2001) and in Spain (García & Arroyo in press), but this is the first time that it has been quantified for this species.

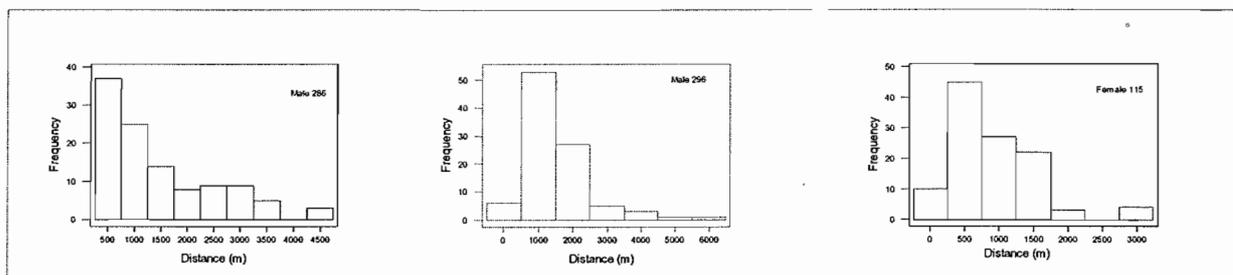


Figure 8. Frequency distribution of the distances from the nest at which the Orkney birds were located.

Relationship between neighbouring birds

Home ranges seemed to overlap largely between individuals. This was particularly clear for the birds in Langholm, which were trapped from neighbouring nests (Fig. 9). Home ranges of these three birds overlapped strongly, with more than 60% of the ranges overlapping. However, this was also probably true for Orkney. In this study site, birds trapped come from nests which were far apart from each other. However, the home ranges of both males included the nest sites of other birds, suggesting that they must have overlapped at least partly with the ranges of some of the neighbouring birds (Fig. 10). The nest where the female was trapped was relatively isolated, but given the average size of the home ranges studied, her range may also have overlapped with those of neighbouring birds.

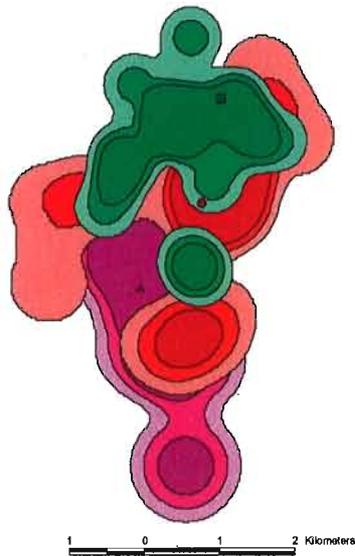


Figure 9. Kernel estimations of home ranges for the three birds trapped in Langholm in 2002. Darker colours within each range represent areas of more frequent use. Red range belongs to a male, the other two to females. Nest locations indicated with symbols: triangle for the purple range, square for the green, circle for the red.

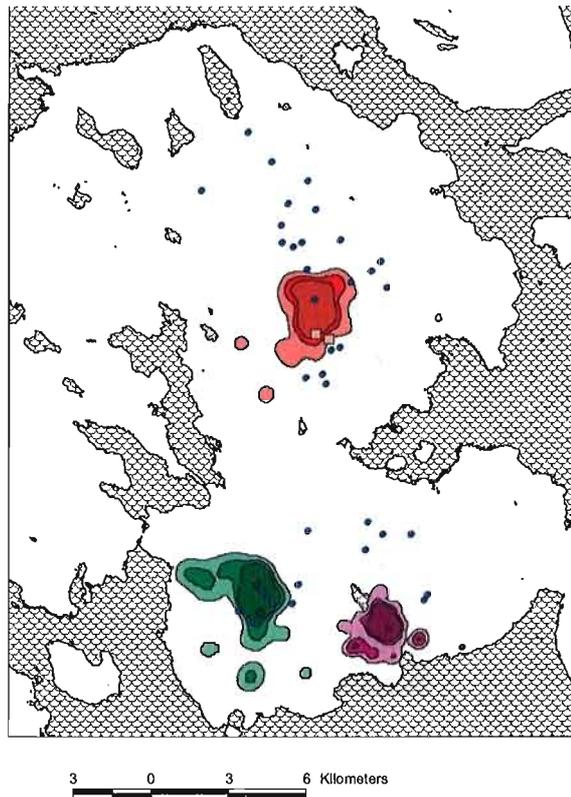


Figure 10. Kernel estimations of home ranges for the three birds trapped in Orkney in 2003. Darker colours within each range represent areas of more frequent use. Red and green ranges belong to male birds, purple one to a female. Nest locations indicated with symbols: triangle for the purple range, circles for the green, squares for the red, small blue circles for neighbouring nests.

A3- HABITAT WITHIN THE RANGES

We tried to evaluate habitat within the range, to see whether areas used contain more of certain habitats than available around the nest, which would give an indication of habitat selection.

METHODS

Using ArcView3.2 and Arcview Spatial Analyst 2.0a, and LCM1990, we calculated the habitat within the kernel estimations of each home range. We calculated the habitat for kernel 90% and for kernel 70%. LCM1990 was used instead of LCM2000, because it provided a better fit to field data for Orkney (Amar et al. 2002) and Langholm (see Annex 3). We calculated for each range the proportion of open heather (codes 10 and 25 in LCM1990), dense heather (codes 11 and 13), rough grass (codes 5, 8 and 9) and smooth grass (codes 6 and 7) (see Annex 4 for the description of the codes).

Additionally, we calculated the proportions of the same habitats around the nests. The average home range using Kernel 90% was equivalent to the area of a circle with 1 km radius for females, and 1.5 km for males. The average home range for kernel 70% was similar to the area of a circle with 0.5 km radius for both sexes. We calculated the difference in the proportion of the main habitat types (heather, rough grass, smooth grass) in the ranges and in circles of similar areas around the nest. This gives an approximate idea of whether harriers' ranges include areas that favour certain habitats as compared to what is available around the nest. No consideration has been given, however, to the potential effect of the inaccuracy of fixes on the location of the home ranges and therefore the habitats identified within them.

RESULTS AND DISCUSSION

The home ranges of all three birds at Langholm contained less heather and more rough grass than available around their nests (Table 2). This was particularly marked in the "core" area of their range (i.e. the polygon estimated with kernel 70%). When considering areas with 90% probability of occurrence, the male's range included habitats in similar proportions (within 10% difference) to those available around the nest.

For the Orkney birds, results were contrasting (Table 2). In the "core" area, one male's range (296) included more heather than expected around the nest, whereas no differences were found for the other two birds. Overall, the other male (286) ranged over an area with less heather and more smooth grass than available around the nest, but no differences were found for the other two birds. No differences were found for rough grass for any bird at either scale. This was somehow contrary to expectations, given that in Orkney rough grass is known to be the most important hunting habitat (Amar 2001, although see next section). This result may appear because the home ranges include locations related to many breeding activities (such as nest attendance, bringing food to nests, territory defence, etc) in addition to hunting, but other factors may also be important (such as low sample size).

Additionally, consideration needs to be given to the fact that there may be differences between sexes in foraging motivation. During the nestling period (when birds were monitored), males may reduce their delivery (and thus foraging) effort, and even start to

disperse (see Fig. 11 below), whereas early in the season males may search for additional females as well as food.

Another option for evaluating habitat use using radio-tracking data would be to subjectively assume that behaviour in the “core” areas is likely to be primarily different from hunting, and evaluate habitat only in the areas that encompass the lowest position frequency (for example, the habitat in the “paler” areas of each range, in Fig. 9-10, excluding the areas with 70% location density). This approach, however, would be based on an assumption (that birds hunt more further away from the nests) that is non-testable, since no observations of radio-tracked birds exist to examine this.

A final alternative would be to model habitat use within each range, creating a utilization distribution function, taking into account nest location and habitat (Marzluff et al. in press). A problem associated with the latter is that it assumes that each location is a foraging point, which may not be the case for the harrier data set.

Table 2. Difference in the percentage of each habitat type in the ranges of different harriers, and those available around the nest.

		Dense Open heather	Dense heather	Total heather	Rough grass	Smooth grass
Kernel 70%						
Langholm	f257	-31.06	-1.91	-32.98	27.18	2.63
	m279	-11.78	-0.41	-12.19	8.00	4.28
	f225	-29.20	-0.49	-29.68	14.57	2.52
Orkney	f115	6.19	-1.87	4.33	-3.24	9.44
	m286	-4.52	4.43	-0.08	0.16	0.00
	m296	12.88	2.62	15.50	-1.25	-8.96
Kernel 90%						
Langholm	f257	-18.36	-1.25	-19.61	16.59	2.59
	m279	-5.25	-1.87	-7.11	-1.37	5.39
	f225	-8.14	-2.20	-10.34	4.57	1.89
Orkney	f115	4.26	1.95	6.20	-1.79	8.14
	m286	-3.81	-13.79	-17.60	-0.65	16.85
	m296	6.49	1.16	7.65	-5.86	1.90

CONCLUSIONS – RADIOTRACKING AND HOME RANGE ANALYSES

Trapping success in 2003 was very low (see Annex 1), and much lower than the previous year in the same study area (Arroyo et al. 2003). Reasons for that are unknown, given that the protocol was similar to the one used previously (Arroyo et al. 2003), but these results confirm that trapping adult harriers before late incubation is probably not worthwhile, and suggest that trapping adult harriers during the nestling period is potentially difficult also in other study areas. This raises the question of whether the returns in terms of data from tagged birds are worth the investment in trapping birds, given the difficulty of getting large sample sizes.

Overall, radio-tracking data provided important information related to size of home range, to the relative overlap in the home range between neighbouring birds, and the maximum distances visited from the nest for each bird. This information would have not been obtained without the use of radios. Getting data from a sample of birds from a different study area will help confirm that results from this year are valid for other areas; at the same time, increasing overall sample size (by, for example, radio-tracking five or six birds of both sexes in 2004) will increase the value of the already collected data (which, otherwise, will not be more than “anecdotal evidence”). Because of that, we believe that it is worthwhile continuing radio tracking.

On the other hand, given the error associated to fixes, and the difficulty to separate hunting fixes from fixes associated to other behaviours, using radio-tracking data to explore habitat selection for hunting may be invalid. An alternative way of evaluating the importance of habitat for hunting using radio-tracking data may be to look at the habitat covered in each “foraging trip” rather than looking at total habitat within the home ranges (see Annex 2). The main problem associated with this approach is also the error associated with each estimated location. If harriers use “edge” areas between habitats, this would be particularly susceptible to be missed given the observed fix errors.

B. PREDICTING RANGE USE IN BREEDING HEN HARRIERS

The most basic way to evaluate habitat selection for foraging is to look at areas with different habitat and quantify whether the frequency at which birds hunt in those areas is dependent on habitat type. A relationship between habitat type and hunting frequency is expected, given that habitat is a surrogate of prey abundance or availability. For example, a relationship between grouse abundance and heather cover has been found within Langholm (Thirgood et al. 2002), whereas a relationship between rough-grass and pipit and vole abundance has been found across moorland areas (Redpath & Thirgood 1999; Smith et al. 2001). Similarly, a significant relationship between the abundance of rough-grass and vole and pipit abundance has been found in Orkney (Amar 2001). We used this approach in two different study sites, Langholm and Orkney.

METHODS

Observations of hunting behaviour were carried out at Langholm and on Orkney. Pre-determined areas (chosen partly to maximise habitat differences between areas, but primarily in relation to visibility and distribution around nest sites) were watched regularly throughout the summer. Observers were positioned at vantage points so the whole area was visible. Each area was observed for periods of ca. 2.5 hours on average (range 1-4 hours). During each watch, all hunting behaviour by harriers was quantified. We defined hunting as cruising flight occurring at no more than 5 m from the ground. We measured the time (in seconds) that each harrier was hunting, the number of strikes towards prey, whether those strikes were successful or not, and (in recent years only) in which habitat those strikes were made. Since squares did not include active nests, hunting was the most common behaviour described (>90% time) when harriers were observed inside the squares. We also identified the sex of the bird, as grey male, or brown female (ringtail). When a bird was identified as a first year male (which is also brown), it was excluded from the calculation of female hunting rates, because first year males rarely breed in our study sites (authors, pers. obs.). However, it is possible that some of the observations of ringtails may also include non-identified male juveniles, or non-breeding females.

At Langholm, observations took place in 1994, 1995, 1996 (as part of the Joint Raptor Study, see Redpath & Thirgood 1997) and 2002 (this study). In the first three years, 10 to 14 areas of ca. 1 km² were watched. In 2002, observations were carried out in 23 squares of ca. 0.25 km². Some of these squares were adjacent to each other.

On Orkney, observations took place in the summers of 1998-1999 (as part of A. Amar PhD work, Amar 2001), and 2002-2003 (this study). Additionally, there were observations in March of 1999 and 2000, before breeding started (Amar 2001). These are not included in these analyses. Summer observations in 1998-1999 were carried out in 9 (1998) or 15 (1999) 1 km² quadrats. In 2002, 8 pairs of adjacent quadrats of 0.25 km² surface were observed. In 2003, observations were carried out in all previously observed areas. The 1km² areas of 1998-1999, were however divided in four 0.25 km² subquadrats.

Observations at Langholm took place from early May to early July (1994 and 2002), or late May to late July (1995 and 1996). In Orkney, summer observations took place in July-August (1998 to 2000), July (2002) and May-June (2003). Table 3 includes data of total observation times per site and year. Because lay date changed between years and study sites, we

calculated a relative date for each watch (as the difference between the julian date for the watch, and the average lay date for each year and site).

Table 3. Total observation time (in hours) in each study area each year of the study. If two squares were observed simultaneously, time only one observation bout included below.

Orkney		Langholm	
1998	90	1994	280
1999	248	1995	206
2000	180	1996	231
2002	35	2002	220
2003	158		

The habitat within each of the squares was calculated with ArcView3.2 and analysed with Arcview Spatial Analyst 2.0a using LCM1990. For each of the squares, we calculated the proportion of heather, rough grass and smooth grass (see above for the description of these variables). Additionally, we calculated two variables indicative of the spatial structure of each habitat type within the squares: the number of patches of each habitat type and the total perimeter for each habitat type.

Finally, and also using ArcView3.2, we calculated a nest proximity index (NPI) for each of the squares or subsquares, as sum of the inverse of the squares of all distances from the observation area to each nest (Thirgood et al. 2003). Because the analyses were made for early summer and late summer separately (see results), we calculated different NPIs for each period: in the case of late summer, we excluded those nests that had failed for the calculation of NPI, because birds do not usually stay in the breeding territory after failure. In early summer, we also included locations of occupied territories, even if no clutch was subsequently produced.

Statistical analyses

Analyses were carried out with Generalised Linear Mixed Models, using the procedure GLIMMIX in SAS V8. We used time spent hunting (in seconds) as our response variable, with the log of the sum of the length of the watch (in minutes) and the area of the square (in km²) as an offset. This variable was not normally distributed, and given that “time” is a continuous variable, it does not fit a Poisson distribution either. These data are best described by a gamma distribution (Amar 2001). The properties of the gamma distribution mean that zero figures cannot be accommodated. We therefore performed analyses in a two-step process. First, we evaluated the probability of observing (any) hunting behaviour, fitting a binomial variable and a logit-link function to the response variable. Secondly, using those watches where hunting had been observed, we evaluated whether the amount of time spent hunting depended on the explanatory variables. We fitted a gamma distribution and a log-link function to this variable. In both cases, we used “year(quadrat(subquadrat))” as a random variable, and year, the habitat variables and the nest proximity index as fixed explanatory variables. Because of the large number of habitat variables to test (sixteen plus their interactions), we did not build full models. We forced “year” (as a surrogate of breeding density and prey abundance) and NPI in all models, because they are known to affect hunting behaviour (Thirgood et al. 2003, Amar 2001). We kept them in the model even if they were not significant (see below). Subsequently, we used a forward selection procedure to look for

the best explanatory model of hunting behaviour. We added each habitat variable individually, starting by heather, then rough grass and then smooth grass grass. Any variable that was not significant was removed from the model. If a habitat variable was significant, we also tested for the significance of its “structure” (by including the number of patches and the interaction of the proportion of that habitat with the number of patches, then perimeter and the interaction).

RESULTS AND DISCUSSION

Seasonal and sexual variation in hunting frequency

Hunting frequency (i.e. the frequency with which birds were observed hunting) changed seasonally, particularly for females (Fig. 11): in both sites, it was more common to see hunting females after hatching had occurred (relative week 5 onwards), which was expected given that females are fed by males during egg-laying and incubation, and only start bringing food for nestlings when they are around 2 weeks old (Redpath & Thirgood 1997). Ringtails were also observed hunting during the incubation period on Orkney. However, ringtails also may include non-identified first-year males, usually non-breeders, which were more common on Orkney than at Langholm (authors, pers. obs.). In both sites, hunting activity by males in the first part of the breeding cycle seemed to peak around laying time, and once again in the middle of the incubation period. At Langholm, males were seen hunting less frequently once the females started to hunt (after hatching had occurred). This coincides with a decrease in prey delivery rates by males to the nests at that time (Redpath & Thirgood 1997). In contrast, males in Orkney increased their hunting frequency during the nestling period, even when females are starting to hunt. Female hunting activity peaked about fledging time (5-6 weeks after hatching) in both sites.

Because of these seasonal differences, we carried out analyses separately for the pre-laying and incubation period (i.e. from two weeks before the average laying date for each year/site, to five weeks after laying; hereafter called “early summer”, for which we analysed only adult male behaviour), and for the period starting five weeks after laying onwards (hereafter called “late summer”, for which we analysed both male and female behaviour). For Orkney, this implied that there was only data for one year (2003) for the first period, and data for four years (1998-2000, 2002) for the second period.

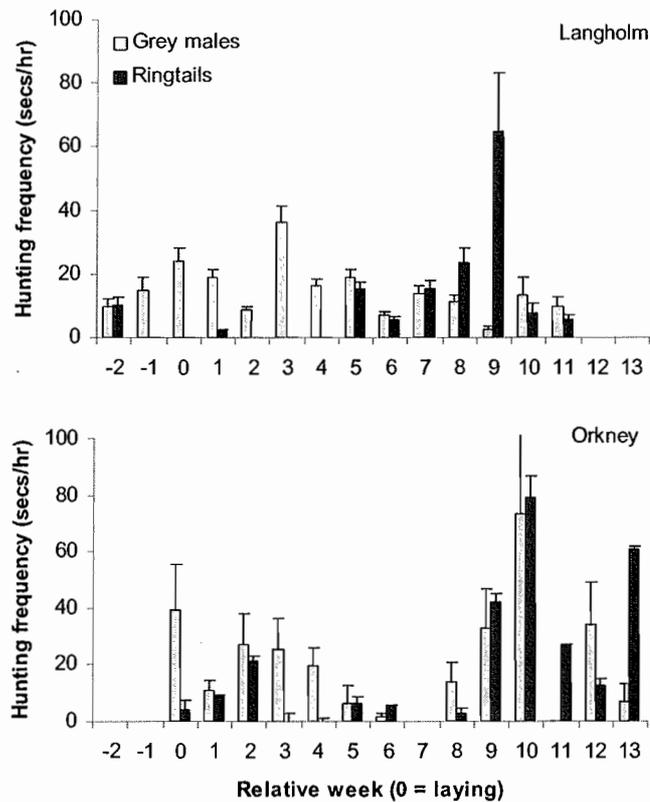


Figure 11. Hunting frequency (in mean \pm SE seconds per hour of observation) of male and female harriers in Langholm (above) and Orkney (below) in relation to relative date (where 0 is the average lay date for each year in each site).

Hunting frequency and habitat

At Langholm, the probability of observing hunting by males in early summer was positively associated with the amount of heather (Table 4). No variables of habitat structure were significant. For those watches where hunting was observed, the amount of time spent hunting in each quadrat was not significantly associated with any considered variable (all $P > 0.10$). In late summer, neither the probability of observing hunting males nor the amount of time spent hunting in each quadrat in late summer were related to habitat or to nest proximity (all $P > 0.10$).

The probability of observing hunting by males in early summer in Orkney was positively associated with the amount of heather and the amount of rough-grass (Table 4). No habitat structure variables were significant. The probability of hunting by males in late summer was positively associated with the amount of heather, but not to the amount of rough grass (Table 4), or any habitat structure variable. For those watches where hunting was observed, the amount of time spent hunting in each quadrat was not significantly associated with any considered variable, in either early or late summer (all $P > 0.10$).

Table 4. Type III results of the GLIMMIX models explaining the probability of observing hunting males in: early summer in Langholm (above; early summer in Orkney (middle); and late summer in Orkney (below). The sign indicates the sign of the parameter estimate for significant continuous variables

	d.f.	F	P	sign
Langholm- early summer				
Year	3,49	2.80	0.05	
Nest proximity index	1,46	0.11	0.73	
Proportion of heather	1,42	5.70	0.02	+
Orkney – early summer				
Nest proximity index	1,57	0.11	0.74	
Proportion of heather	1,117	7.31	0.01	+
Proportion of rough-grass	1,74	3.89	0.05	+
Orkney – late summer				
Year	3,47	3.02	0.04	
Nest proximity index	1,83	0.14	0.7	
Proportion of heather	1,38	4.27	0.05	+

The probability of observing hunting females in Langholm in late summer increased with nest proximity, and also with the proportion of heather (Table 5). No habitat structure variable was significant. For those watches where hunting was observed, the amount of time spent hunting in each quadrat did not depend on any considered variable (all $P > 0.10$). In Orkney, the probability of observing hunting females only depended on nest proximity ($F_{1,45} = 4.38$, $P = 0.04$). For those watches where hunting was observed, the amount of time spent in each quadrat increased with the amount of rough-grass (Table 6). No habitat structure variables were significant.

Table 5. Result of the GLIMMIX models explaining the probability of observing hunting females in Langholm in late summer. The sign indicates the sign of the parameter estimate for significant continuous variables

	d.f.	F	P	sign
Year	3,1	3.02	0.39	
Nest proximity index	1,21	4.56	0.05	+
Proportion of heather	1,22	6.53	0.02	+

Table 6. Result of the GLIMMIX models explaining the time spent hunting in a quadrat if hunting occurred, by females in Orkney in late summer. The sign indicates the sign of the parameter estimate for significant continuous variables

	d.f.	F	P	sign
Year	2,14	1.18	0.33	
Nest proximity index	1,8	0.15	0.70	+
Proportion of rough-grass	1,10	4.84	0.04	+

These analyses are preliminary and more thought should be given at the constraints and limitations of the statistical models used. For example, there exist collinearity between all different habitat variables. However, several issues already arise from the current results in relation to harrier foraging behaviour.

First, more relationships were found when analysing the probability of an area being used, than when analysing the amount of time spent hunting if hunting occurred. This suggests that total use of a given area for hunting depends more on the number of visits to that area than on the amount of time spent in it during each visit. This result implies that foraging harriers tend to return to the same area repeatedly when hunting.

Heather seemed to be the most important foraging habitat in both sites throughout the breeding season. This may be expected in Langholm in late summer (Thirgood et al. 2003, Amar et al. in press), when red grouse can be an important prey species (Redpath & Thirgood 1997). However, it is more surprising for early summer, when the most important prey are voles and pipits, which are particularly abundant in rough grass and not in heather. The importance of heather for hunting was also surprising in Orkney. Results for Orkney are different from those found by Amar (2001) using a subset of the data set (1998-2000) and an overall different analysis (data were pooled for each observation area, so the sample unit was "observation area" rather than "observation bout"). Amar found rough grass to be a more important foraging habitat than heather. More analyses (and statistical advice) need to be developed to evaluate these differences. In any case, current results also confirm the importance of rough-grass as a hunting habitat in Orkney for females, and for males in early summer.

It is also interesting that nest proximity seems to be of such little significance in explaining the probability of observing hunting male harriers in both areas. A similar result was found for Orkney during the breeding period (Amar 2001, although a relationship was found for those observations carried out in March, in the pre-laying period). In contrast, this result is contradictory to previous analyses of hunting behaviour by hen harriers in Langholm (Thirgood et al. 2003) using different analyses (data for each area was pooled, so their sample unit was "observation area" rather than "observation bout"). In the latter study, a relationship was found between harrier foraging and nest proximity index (NPI), whereas no relationship was found between harrier foraging and heather abundance. However, both variables are related to each other (there is more heather in those areas closer to harrier nests). The statistical model carried out by Thirgood et al. (2003) did not include both variables (heather and NPI) simultaneously, so the relationship found for more hunting in areas closer to harrier nests might have disappeared when controlling for the amount of heather in each area. Overall, our results suggest that males do not hunt more often close to their nests. In contrast, the likelihood of observing hunting females increased with nest proximity index at both Orkney and Langholm, which confirms that females spend more time hunting close from their nest sites (see above).

Finally, the overall proportion of heather or rough grass seemed to be more important than the actual structure (in terms of number of patches or perimeter length) for explaining hunting behaviour of harriers. However, this result needs to be confirmed with further analyses, possibly using other variables as indicators of habitat mosaic or edge availability.

C- HABITAT AND HARRIER DISTRIBUTION

Effective habitat management for hen harriers on moorland Special Protection Areas (SPAs) under Natural Care Schemes requires knowledge of those habitats that are best for hen harriers. Identifying habitats selected by breeding harriers and the evaluation of how habitat can explain harrier distribution and success is critical in terms of management. As a contribution to increasing our understanding of habitat requirements of harriers the present project aimed to evaluate any relationships between habitat and harrier distribution using data from harrier SPAs with long-term data sets for nesting hen harriers. There is often considerable variation in harrier density between areas, as well as in the distribution of harrier nests within each area. We aimed to evaluate whether any of this variation can be explained through variations in habitat availability. Given that nest areas are not necessarily used every year (among other things, because breeding density can also vary between years), it is also important to evaluate whether habitat can also explain the likelihood of a given area to be used more regularly. This exercise should increase our understanding of the potential gains in harrier breeding density that may be possible through habitat management and, therefore, the Natural Care programme.

We present here up-to-date results on this aspect of the work, involving data from four different study areas. Further analyses including data from other areas will be included in reports of subsequent years.

METHODS

We obtained long-term data sets of harrier nests locations for Orkney (1989-2000), Langholm (1993-2000), Forest of Clunie (1988-1998) and Arran (1994-2001).

Using ArcView, we superimposed a 1km grid on each of the study areas. We calculated the proportion of each habitat type within each 1km square, as well as the presence and number of hen harrier nests in each of the years of study. We used habitat data obtained from the 1990 Land Cover Map of Great Britain (LCM), which were incorporated into Arcview 3.2 and analysed with Arcview Spatial Analyst 2.0a. As habitat descriptors, we calculated for each of the squares the proportion of heather (codes 10, 25, 11 and 13 in LCM1990), rough grass (codes 5, 8 and 9) and smooth grass (codes 6 and 7) (see Annex 3 for the description of the codes). Additionally, we calculated the ratio of rough grass versus heather, and three variables indicative of the spatial structure of each habitat type within the squares: the number of patches of each habitat type, the average patch size (in hectares), and the total perimeter for each habitat type. We eliminated from the analyses all squares that did not contain at least 10% (i.e. 1 ha) heather, harriers only extremely occasionally bred in areas with such low heather abundance (only one quadrat in Langholm, where the heather patch continued in the adjacent quadrat).

We first evaluated whether habitat had an influence on the likelihood of harrier presence in each square ("presence" was defined as at least one nest in one of the years of study). Models were fitted using the GENMOD procedure assuming a binomial error structure and a logit link function. For those squares that had been used at least once, we performed another analyses to evaluate whether habitat had an influence on the number of years in which that square had been used. The latter variable is an indicator of the regularity of use of an area, and is of importance for management purposes. Given that the length of the study was different in each study area, we evaluated the proportion of years of the study in which a given square

was used. These models were also fitted assuming a binomial error structure and a logit link function. In all models, we included “area” (i.e. study area) and the interaction between that variable and the habitat variables, as explanatory variables. We thus aimed to evaluate whether the patterns between habitat and harrier distribution were consistent between areas, or not. Data were corrected for over-dispersion with the “dscale” parameter.

RESULTS AND DISCUSSION

Presence of harriers depended on the proportion of heather and rough grass, but the relationships changed among areas (Table 7, Fig. 12). These differences arose, partly, because the proportion of heather varied among study areas (Table 8). For example, preference for heather-dominated squares was more marked in Orkney and Clunie, whereas this variable seemed less important in both Langolm and Arran (Fig. 12), where nests were found in squares with very little heather cover. The same area differences were found when looking at the influence of rough grass availability or the number of patches of heather and rough grass on explaining the probability of finding breeding harriers (Table 7). Overall, harriers favoured areas with heather and rough grass, and where these habitats were continuous rather than patchy.

Table 7. Results of the GENMOD analyses explaining the probability of presence of a harrier nest in relation to various habitat variables. NRG = number of rough grass patches; NH = number of heather patches. Sign = sign of parameter estimate for simple variables

Variable	d.f.	Chi-square	P	Sign
Area	3	8.35	0.04	
Heather	1	35.9	0.0001	+
Area*heather	3	9.12	0.03	
Rough grass	1	22.9	0.0001	+
Area*Rough grass	3	13.4	0.004	
NRG	1	0.2	0.6	-
Area*NRG	3	11.9	0.008	
NH	1	0.2	0.7	-
Area*NH	3	8.5	0.04	

Table 8. Average proportion of different habitat types within 1 km squares in the study areas

	Arran	Clunie	Langholm	Orkney
Heather	60.86 ? 25.7	57.16 ? 28.9	42.29 ? 26.2	52.02 ? 31.2
Rough grass	11.45 ? 11.3	15.20 ? 13.7	41.70 ? 22.4	12.36 ? 9.0
Smooth grass	7.15 ? 14.5	11.05 ? 16.2	4.61 ? 5.1	32.21 ? 25.8
Other	20.45 ? 18.13	16.67 ? 15.8	11.42 ? 2.5	3.42 ? 0.03

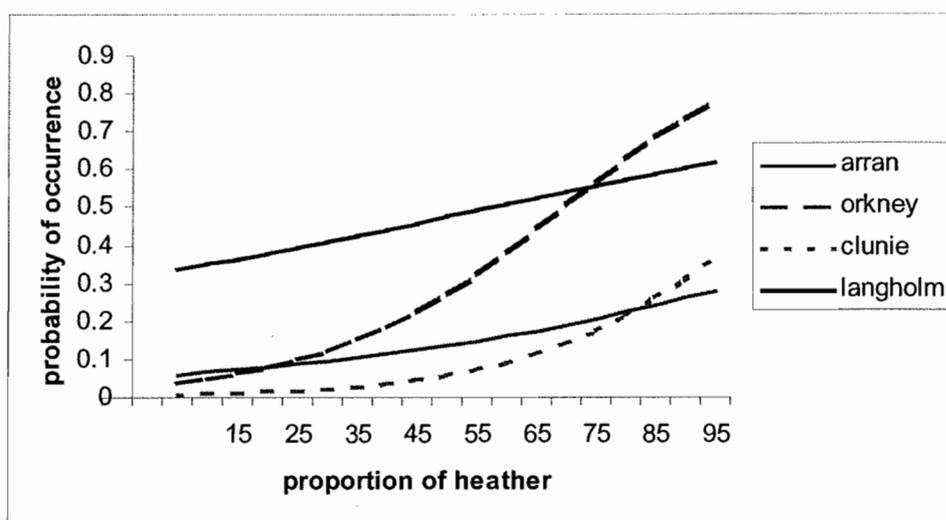


Figure 12. Predicted values of the models explaining probability of occurrence of breeding harriers in 1 km squares in relation to the proportion of heather in four different areas. The x axes indicate the range of values of that habitat variable actually observed.

For those squares where breeding had occurred at least once, the proportion of heather and rough grass, the number of patches of heather and the total perimeter of rough grass also explained the frequency with which those squares were used, but those relationships also changed significantly between areas (Table 9).

Table 9. Results of the GENMOD analyses explaining number of years of occupancy of each 1 km square in relation to habitat. Nh = number of patches of heather; Per RG = total perimeter of rough grass; Sign = sign of the parameter estimate for continuous simple variables

Variable	d.f.	Chi-square	P	Sign
Area	3	24.03	< 0.0001	
Heather	1	15.09	< 0.0001	+
Area*heather	3	21.78	< 0.0001	
Rough grass	1	0.21	0.64	+
Area*Rough grass	3	18.29	0.0004	
Nh	1	0.04	0.83	-
Nh*Area	3	9.68	0.02	
Per H	1	4.79	0.03	+

Overall, it seems that rough grass and heather, unsurprisingly, are critical to explain harrier space use for breeding. Big patches of heather are preferred, and areas where rough grass is highly intricate (giving more habitat edge) are used more regularly. However, more analyses are necessary in order to investigate area differences, and to develop general management recommendations at a site and regional level.

ASSESSMENT OF PROGRESS TOWARDS PROJECT OBJECTIVES

Two years of fieldwork have now been completed – at Langholm in the spring and summer of 2002 (pilot study, Arroyo et al. 2003) and Orkney Mainland Moors in 2003 (this report). This section considers progress to date against the project objectives:

1. To investigate the ranging behaviour and habitat use of breeding hen harriers on three representative SPAs where Natural Care Schemes have or will be implemented.

The original aim was to achieve this through either radio-tracking or observations of individually recognisable wing-tagged hen harriers. A pilot study (Arroyo et al. 2003) showed that the feasibility of observing and identifying wing-tagged harriers while foraging was extremely low. Further observations in Orkney in 2003 showed the same results. In addition, the likelihood of adult birds captured and tagged the previous year returning to Orkney to breed was also low, as well as the proportion of nestlings of 2002 entering the breeding population. Radio-tracking is therefore considered as the primary method to achieve this objective.

Though sample sizes are low (a total of 6 birds tracked up to date, 3 males and 3 females) the combined results from 2002 and 2003 show that males range over larger areas than females, and that ranges of neighbouring birds do overlap. Average range size for males was ca 9 km², and for females 6 km². Maximum distances recorded from nest sites were respectively 5600 and 3000 m. Our results also suggest that home range sizes of hen harriers breeding on Langholm and Orkney may be similar.

On the other hand, difficulties have been encountered in terms of capturing birds to attach radio-tags. It has not been possible to tag birds early in the breeding season (pre-laying and incubation periods) so the estimated home range sizes relate only to the nestling period.

In addition issues related to the accuracy of pinpointing radio-tagged birds (associated error of about 500m) indicate that radio-tracking data cannot be used with confidence to identify preferred foraging habitats and to relate ranging behaviour of tagged birds to habitat use.

Overall, however, it will be worthwhile to try and increase sample size from both sexes, in order to conclude and reinforce the validity of the current results in terms of overall home ranges and maximum hunting distances, provided that this does not interfere with achieving other project objectives. Given that trapping was unsuccessful in the early part of the breeding season, trapping and radio-tagging should be concentrated in the late incubation/early nestling period.

2. To develop a model that predicts range use in breeding hen harriers.

The original aim was to base this aspect of the work on the model developed by Dr Mike Madders (Madders 2003). This still needs to be done with the Langholm and Orkney data, which will allow to test the validity of Madders' model in different areas, and will give indications of further developments needed.

The analyses as carried out in this report confirm the importance of heather and rough grass as foraging habitats, with a suggestion that heather is more important than was previously

demonstrated. They also show that nest proximity is important for females but not males, so a different model is needed for each sex. These analyses suggest some differences in results from previous work in Orkney and Langholm in terms of the relationships between foraging behaviour and habitat. It is unclear at this stage whether this is a product of the different analytical methods and, if that is the case, which analytical methods are the most robust. This will be evaluated in 2004.

A further issue is the consideration of whether LCM1990 is a good habitat descriptor for all sites. Results (Annex 3) suggest that this is not the case for Langholm, which may further explain the differing results at both sites. Ground surveys in Glen App in 2004 (and potentially in other areas in 2005) will be critical to ensure that the habitat data use for predictions is accurate.

A critical aspect of the work will be to test these models in new areas. Work in 2004 will include collecting hunting data in Glen App, which will be incorporated to analyses subsequently. Additionally, possibility of incorporating variables such as strike rate in different habitats in the models may be explored.

3. To produce a set of criteria on which to assess and monitor the success of Natural Care management prescriptions on moorland SPAs for hen harriers.

As specified before, no work was carried out in 2003 (or 2002) in relation to this objective. Data should be prepared for initiating population viability analyses (PVA). This will require compiling all data on population parameters from the SPAs or the RSPB wing-tag data sets.

4. To produce a set of management recommendations for every Scottish SPA for breeding hen harriers to inform effective and cost-efficient management prescriptions.

Results up-to-date are too preliminary to evaluate to which point rules will be applied to all sites, or whether site-specific considerations are needed. There is a priority for concluding the analyses of the relationship between habitat and harrier distribution (including data for Glen App and Ladder Hills), as well as analyses of the relationship between habitat and breeding success for Langholm and Forest of Clunie.

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ANNEX 1. TRAPPING ATTEMPTS IN ORKNEY IN 2003

Trapping success was low (7%), much lower than that observed in 2002 with the same techniques (Arroyo et al. 2003). These differences may have been due to weather (visibility in Orkney was extremely good in 2003), but otherwise remain inexplicable. Response of birds to the decoys was strong (see Table below), but the traps failed to trap them. New less visible nets will be bought for 2004.

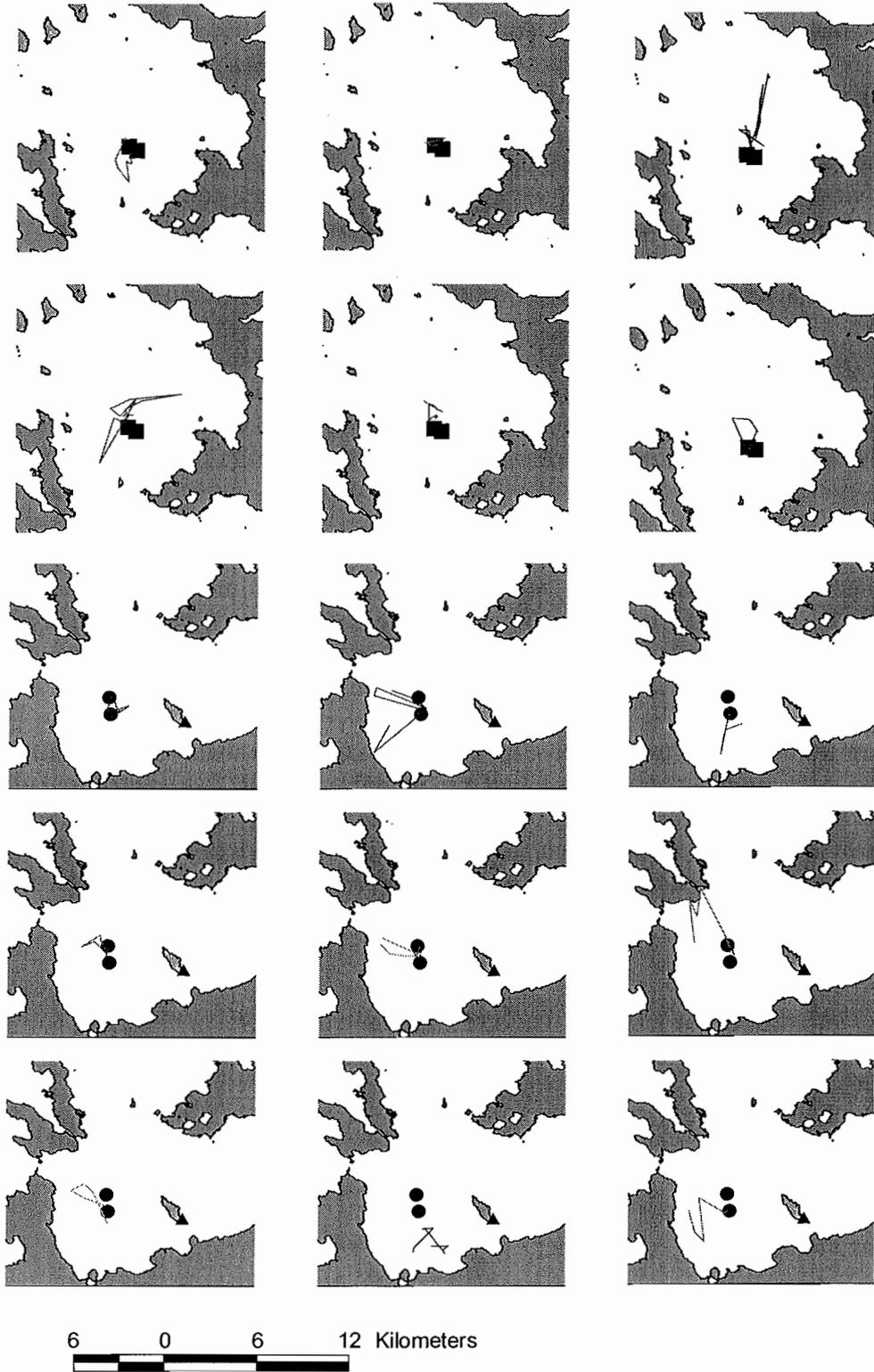
Trapping attempts and their outcome on Orkney in 2003; Sex = sex of harrier present after detection of decoy.

Date	Stage	Location	Decoy	Trap	Sex	Success	Comments
22/04/2003	Pre-lay	Naversdale upper	male and owl	nooses on both and net on harrier	both	0	both ignore decoys , M flies over them, but no other reaction
23/04/2003	Pre-lay	Naversdale lower	male	noose and net	both	0	M only perches nearby decoy. F swoops, and attacks decoy, knocks net down
23/04/2003	Pre-lay	russadale	male	noose and net	both	0	M displays, both fly over
24/04/2003	Pre-lay	burrallie 1	male	noose and net	both	0	No reaction
25/04/2003	Pre-lay	kingsdale	male and owl	nooses on both and net on harrier	f	0	No reaction
25/04/2003	Pre-lay	burrallie 2	male	noose	both	0	No reaction
26/04/2003	Pre-lay	burrallie 1	male and female	net on male, nooses on female	both	0	F a couple of high swoops over both
27/04/2003	Pre-lay	lushan	male and female	net on male, nooses on female	both	0	no reaction
01/05/2003	Pre-lay	blubbersdale	2 male	net on male, male on post with nooses, pole noose trap on big pole too	both	0	No reaction
01/05/2003	Pre-lay	Lyde - Cuppablack	male and female	noose on male	none	0	No birds seen on this area, plenty on south side.
05/05/2003	Pre-lay	Burrallie North	male	noose	m	0	heavy wing-beats, 1 swoop 2 to 3 feet away.
15/05/2003	Eggs	blubbersdale	male and owl	nooses on both, and pole noose trap	m	0	flew over hide and decoys, no other reaction
02/06/2003	Chicks	Lyde - South	2 owl	noose on one and net on other	m	0	17 swoops at owl with noose, very close, ignoring owl with net.
03/06/2003	Chicks	Lyde - South	male	net	m	1	male flies over decoy and yickers, net caught male.
04/06/2003	Eggs	blubbersdale	male	net	m	0	m did not visit this nest area, female got up so stopped.
09/06/2003	Chicks	Upper Burrallie	male	net	m	1	caught m with first swoop.
09/06/2003	Chicks	naversdale upper	male	net	m	0	male flew around area, no other reaction.
11/06/2003	Chicks	cruan	male	net	both	0	female yickered at decoy and hide, male no reaction to decoy. Changed to owl, still no reaction.
14/06/2003	Chicks	blubbersdale	male	net	none	0	decoy taken down when female off nest, twice, male always turned up when traps down.
16/06/2003	Chicks	Braes of Agleth	male	net	m	0	male flew past once.
17/06/2003	Chicks	Northdales	male	net	both	0	male pays no attention to decoy.
17/06/2003	Chicks	Upper Burrallie	male	net	f	0	f flew past, only one yicker.
18/06/2003	Chicks	Upper Burrallie	owl	noose	both	0	after food pass f yickers and circles then returns to nest.
19/06/2003	Chicks	Harabreck	male and female	net	m	1	m flew into net, but not trapped so escaped, vey windy.
22/06/2003	Chicks	Harabreck	male	net	f	1	caught after 10 minutes.
23/06/2003	Chicks	Harabreck	male and owl	net	m	0	m diving repeatedly, but aware of net.

Date	Stage	Location	Decoy	Trap	Sex	Success	Comments
24/06/2003	Chicks	Naversdale lower	male	net	both	0	f no reaction after food pass, m swooped 3 times, none close enough.
25/06/2003	Chicks	Langy Skeo	owl	net and noose	f	0	f flushed from nest, dived at decoy 4 times, poss can see net. Owl moved in closer with noose only, f dived 3 times, hit once, then no further response.
25/06/2003	Chicks	blubbersdale	male	net	both	0	after food pass m swooped at decoy, then perched, another swoop.
07/07/2003	Chicks	Langy Skeo	male and owl	noose	f	0	15 really close dives on owl
08/07/2003	Chicks	Griffyelt	owl	noose	m	0	lots of close swoops, possibly touched it
08/07/2003	Chicks	Naversdale lower	owl	noose	both	0	f 6 close swoops, m 3 close swoops
09/07/2003	Chicks	Naversdale lower	owl	net	both	1	f swooped a few times high over net, yickering, m arrive with prey, yicker and lower swoop. M caught in net, but got free before we could get him.
09/07/2003	Chicks	Braes of Agleth	owl	net	both	0	after food pass m alarms then leaves. F alarms swoops from height.
09/07/2003	Chicks	Burrallie	owl	net	f	0	f attacks close 3 times, touches net, but windy.
09/07/2003	Chicks	Griffyelt	owl	net	f	0	f attacks repeatedly but aware of net, really close.
16/07/2003	Chicks	sleet moss upper	owl	noose	f	0	f aggressive and swooping at us while setting up. Swooped 10 times, hit owl, swooped twice after.
16/07/2003	Chicks	Naversdale lower	owl	net	both	0	both yicker, f swoop high a few times. M yicker a bit.
17/07/2003	Chicks	sleet moss lower	owl	net and noose	f	0	f attack straight away, pulling out at net. Net blown down, f had a few good low swoops, yickering.
17/07/2003	Chicks	sleet moss upper	male and owl	net and noose on owl, male decoy and noose	f	0	f yickering, swooped high over owl only. Tried with FL and chick, not much closer.

ANNEX 2. MOVEMENTS OF RADIO-TRACKED MALES IN ORKNEY

Each figure represents the movements for a given day, for a period of 2 to 6 hours. The top two lines correspond to male A, the lower three lines to male B. The two squares represent the location of both nests for male A, the two circles the locations of both nests for male B.



ANNEX 3. CALIBRATION OF LCM DATA (1990 AND 2000) WITH GROUND TRUTHED DATA IN LANGHOLM AND ORKNEY

In order to estimate the accuracy and relevance of the LCM data in terms of correctly identifying the habitats of interest, we compared the amount of different habitats as identified on the ground with data for the same areas generated from LCM1990 and LCM2000 data.

In Orkney habitat surveys were carried out in 18 1km squares. Ground data from these squares were collected in summer (July-August) 1998 and spring (February-March) 1999. The dominant vegetation type was recorded in each of fifty 25cm² quadrats which were placed every 40 m along two parallel 1km transects, placed 250m and 750m away from one of the sides of the square (for further details on these methods see Amar 2001 – chapter 3). LCM Data came from satellite images, which were taken 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 also averaged the habitat data collected from transects during spring and summer to make the comparisons with the LCM data more realistic.

In Langholm, ground data was taken in summer 2002 from 23 quadrats 0.25 km². Within each of these quadrats, the dominant vegetation type was recorded in each of fifty 25 cm² quadrats which were placed every 20 m along 4 parallel lines within each quadrat. Additionally, percentage of heather cover was evaluated on the ground in 16 areas in 1996 (Thirgood *et al.* 2003).

We compared the proportion of heather, rough (unmanaged) grass or smooth (improved) grass dominated quadrats within each square, with the proportion of those habitats as calculated from the LCM data, or combinations of different habitat measures. We compared the R² of the relationships for LCM1990 and LCM2000, to see which one provides a better fit for the ground data.

Overall, relationships were better (R² were higher) with LCM1990 than with LCM2000 (see Table below), except for data obtained in Langholm in 2002, when R² values were overall low for both LCM data sets. Reasons for this are unexplained, but it is possible that LCM data do not actually provide a good picture of current occurrence of grassy areas at Langholm. We however conclude that we continue to use LCM1990 (instead of LCM2000) as the best estimator of habitat availability in the study areas. Ground-truthing will also be performed in Glen App in 2004.

Table X. R² of the regressions between ground data and estimators of habitat using LCM1990 and LCM2000.

Data set	Habitat type	LCM1990	LCM2000
Langholm 2002	Heather	22.6	46.8
	Rough-grass	25.8	0.8
	Smooth-grass	1.6	4.2
Langholm 1996	Heather	68.5	58.5
Orkney 2000	Rough-grass	55.9	42.1
	Heather	73.7	55.7
	Smooth-grass	78.5	73.4

ANNEX 4: COVER TYPES IDENTIFIED BY LCM1990

TARGET CLASSES (25 class system)	
1 ^a	Sea / Estuary
2	Inland Water
3	Beach and Coastal Bare
4	Saltmarsh
5	Grass Heath
9	Moorland Grass
6	Mown / Grazed Turf
7	Meadow / Verge / Semi-natural
19	Ruderal Weed
23	Felled Forest
8	Rough / Marsh Grass
25	Open Shrub Heath
10	Open Shrub Moor
13	Dense Shrub Heath
11	Dense Shrub Moor
12	Bracken
14	Scrub / Orchard
15	Deciduous Woodland
16	Coniferous Woodland
24	Lowland Bog
17	Upland Bog
18	Tilled Land
20	Suburban / Rural Development
21	Continuous Urban
22	Inland Bare Ground
0	Unclassified

^a label value within the 25 'target' cover-type 25 x 25 metre data.