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Ranging behaviour of Hen Harriers breeding in Special Protection Areas in Scotland

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Running head: Hen Harrier ranging distances

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Capsule Breeding female Hen Harriers hunted mostly within 1 km from the nest and males mostly within 2 km.

Aims To quantify temporal and spatial variation in home range sizes and hunting distances of breeding male and female Hen Harriers.

Methods We radio-tracked ten breeding harriers (five males and five females) in three Special Protection Areas (SPAs) in Scotland between 2002-2004.

Results Male Hen Harriers travelled up to 9 km from nests but had a home range size that averaged only 8 km^2 (90% kernel); average home range size for females was 4.5 km^2 . Hunting distances did not vary throughout the season. No significant differences were found among study areas, but there was large individual variability.

Conclusions Our results provide information on foraging harriers to support management: actions within 1 km of nesting sites will favour both sexes, and within 2km will mostly favour males. Our data also suggest overlap between foraging areas of neighbouring birds. Thus, there is the potential for good foraging areas to be utilised by multiple breeding pairs.

Habitat loss and land use change are recognised as major threats to many bird populations, including raptors (Newton 1979). Populations of raptors have been shown to decline due to loss of their preferred habitats (Donazar et al. 1993, Amar & Redpath 2005, Thiollay 2006). Legislative protection of habitats is thus a major conservation tool used all over the world. In Europe the two most influential pieces of protective legislation relating to nature conservation are the Habitats (92/42/EEC) and Birds Directives (2009/147/EC). These Directives give EU member states the power and responsibility to create Special Protection Areas (SPAs) to protect birds which are rare or vulnerable in Europe, forming the European network of protected areas known as Natura 2000. SPAs are intended to safeguard the habitats of the species for which they are designated and to protect the birds from significant disturbance. There may be financial incentives for sustainable management of the land, in ways that have been recognised as beneficial to the species either directly, for example by providing nesting habitat, or indirectly, for example by providing habitats for their prey species.

A number of studies have highlighted that effective management of areas for vulnerable species must consider their foraging needs in addition to their nesting needs (Donazar et al. 1993, Martin & Possingham 2005, García et al. 2006). Studies have shown that availability of good foraging areas around nest sites can influence breeding success (e.g. Tella et al. 1998, Rodriguez et al. 2006, Amar et al. 2008, Hinan & Clair 2008). Furthermore, some birds may regularly forage far away from their nests, so protected areas based only on distribution of nests may be insufficient to contain all resources needed for a given species (Martinez et al. 2007, Guixé & Arroyo 2011). Information on ranging behaviour may thus provide critical information for management of protected species in protected areas.

The Hen Harrier *Circus cyaneus* is a medium-size raptor which is listed on Annex 1 of the EU Birds Directive. In the UK, it breeds predominantly in heather moorland (including grouse moors, Redpath et al. 1998, Sim et al. 2007, Hayhow et al. 2014), where it preys mainly on small passerines and small mammals, although they also sometimes take larger prey like grouse, waders and young rabbits (Redpath et al. 2002, Amar et al. 2003). When breeding in moorland, the best foraging habitats for the species include areas of heather *Calluna vulgaris* mixed with rough grass habitats (Amar & Redpath 2005, Arroyo et al. 2009), where prey abundance is highest (e.g. Smith et al. 2001, Vanhinsbergh & Chamberlain 2001, Amar & Redpath 2005).

National surveys for this species over recent decades have shown that there have been marked declines in some regions and the population is currently well below its potential population size and range (Sim et al. 2007, Anderson et al. 2009, Fielding et al.2011, Hayhow et al. 2014). The conservation status of the species in the UK is threatened because Hen Harriers can, in certain circumstances, reduce the numbers of red grouse available for recreational shooting (Thirgood et al. 2000), and as a result they are illegally killed on certain grouse moors (Etheridge et al. 1997). There is, therefore, a strong conservation concern for this species, with UK government listing the species as a conservation priority, and a series of SPAs have been identified in the UK for this species (http://jncc.defra.gov.uk/pdf/UKSPA/UKSPA-A6-47A.pdf).

Accurate information on home range size of Hen Harriers is important to understand whether all the needs for the species are likely to be covered within these SPAs. Evaluation of hunting distances will also provide information on the ideal locations to deploy conservation measures in support of the SPA, such as agro-environmental support schemes (Amar et al. 2011). This information will also be useful for development issues such as placement of windfarms (Madders & Whitfield 2006, Whitfield & Madders 2006), or in the context of the conflict with grouse shooting (Redpath & Thirgood 2009, Thompson et al. 2009, Sotherton et al. 2009). For example, management of SPAs may include measures to reduce the impact of predation on grouse (e.g. Langholm Moor Demonstration Project, http://www.langholmproject.com/index.html), if part of the area is used for commercial shooting.

Published information on the home range sizes for this species is limited. Picozzi (1978) estimated foraging range of male harriers in NE Scotland as 14 km^2 based on observations of hunting birds. Radio-tracking studies of the closely related Northern Harrier *Circus hudsonius* in Idaho, USA, produced an estimated average breeding male range size of 16 km^2 (Martin 1987). Both of these estimates were however based on Minimum Convex Polygons, which may overestimate ranging areas if there are outlying locations (Kenward 2001). Beyond these studies, there exists only a limited amount of indirect information about maximum hunting distances based on observations of hunting birds in continental Europe (Schipper 1977, García & Arroyo 2005).

This paper aims to investigate the ranging behaviour of breeding Hen Harriers. Specifically, we aim to evaluate the average home range size and maximum hunting distances of breeding Hen Harriers, and test whether home ranges varied between sexes or study areas and whether there was any temporal variation in ranging distances over the course of the nestling period.

METHODS

Study areas and radio-tracking data

The study was carried out on three Scottish SPAs over three years. Harrier nests were located in each area early in the breeding season. Breeding adults were trapped, under the appropriate licences, during the nestling period (using dho-ghaza collapsible nets set close to the nest with a nest predator decoy, or mono-filament noose bonnets on a plastic eagle owl) and fitted with 8g tail mounted radio telemetry tags (Biotrack Ltd, Dorset). In total twelve adults were tagged: three birds (one male and two females) in Langholm in 2002, three birds (two males and one female) in Orkney in 2003 and six birds (two males and four females) in Galloway in 2004.

Locations of birds were evaluated through bi or tri-angulations from multiple vantage points distributed throughout the study areas: observers stationed at elevated fixed points conducted scans for each tagged individual using a 3 bar Yagi antennae and radio-receiver. When a signal was located, observers communicated using two-way radios, and simultaneously took a compass bearing for that signal. Positions were then calculated by plotting compass bearings on 1:25 000 maps.

We calculated the error in the estimation of the locations derived with this method using tags attached to poles located in certain (immobile) positions unknown to observers, which were asked to provide a fix for them (n = 133 crossings on 20 dummy tags in Langholm; n = 142 crossings on 25 dummy tags in Orkney; n = 31 crossings on 4 dummy tags in Galloway). Locations of these fixed tags based on bi- or triangulations were associated with an error of x meters (range 501-728 m). Accuracy depended mainly on the angle between the bearings: error was greater when bearings crossed at angles higher than 135º or lower than 45º. When eliminating these fixes, the error made with bi- or triangulations was not significantly different (P > 0.3), and averaged 308 ± 172 m (mean ± sd, n = 6) in Langholm, 65 ± 220 m (n = 28) in Orkney, and 206 ± 125 m (n = 19) in Galloway. This figure may not necessarily be comparable to the error in fixing moving birds, because there is probably less time for observers to obtain a locational fix, however the signal from transmitters in the air is better than that of transmitters closer to the ground (which was the case for those used to estimate errors).

In Galloway and Orkney, fix locations were taken every ten to fifteen minutes from the same vantage point for a period of several hours, and repeated every few days. In Langholm, the monitoring was less intensive, with one or two bearings being taken per day per bird, repeated every few days. Locations were obtained throughout the nestling period, until the chicks had left the nest. A total of 1146 fixes were obtained (all birds combined). We carried out an initial selection of these fixes, eliminating those (n = 523) based on bearings crossing at angles lower than 45 or higher than 135 degrees. After that selection, the average time between successive fixes on the same bird in 2003-2004 was 33 ± 33 min (2-198). As some bearings were taken at short intervals, some fixes may not have been independent (Kenward 2001), therefore we ran autocorrelation analyses with Ranges VI, and calculated Shoenener's (1981) test of Time to Independence between fixes (Kenward 2001) for each bird. This analysis indicated that locations were independent for all birds but one (a female, tag 658, in 2004), for which time to independence was 1100 minutes, a figure much larger than our recording sessions. That particular female moved little around the nest (see results). We therefore included all fixes for this female in further analyses, while noting its spatially restricted behaviour. In contrast, we eliminated data from two females (one in Langholm and one in Galloway), for which only 3 and 6 fixes (respectively) were available after selection, because this sample size was insufficient to calculate home range size. The average number of fixes for the other tracked birds was 61 ± 33 (n = 10, range 11-116).

Analyses

Home range size was estimated with ArcView 3.2, using Kernel Contours least squares cross validation (LSCV) method to provide 50, 70 and 90% kernels. Kernel-based LSCV home-range estimators are generally favoured with respect to space use patterns (Worton 1989, Boitani & Fuller 2000). Kernel estimators provide an indication of the relative frequency of use of different areas within the home range, thus providing biologically meaningful information, and can give stable area estimates with only 15-20 fixes (Kenward 2001). Minimum Convex Polygons (MCP) from fixes were also calculated to allow comparisons with other studies.

We examined the relationship between hunting distance (distance from the nest to tracking fix, calculated with ArcView) and the phase of the nestling cycle using General Linear Mixed Models, with a normal distribution and an identity link function, using "individual" and "area" as random variables to account for the lack of independence of observations of the same bird and fixes within the same study area. We defined a "relative date" with day 1 being the hatching date of a tracked bird's brood. In two cases in Orkney, monitored males were bigamous. In those cases, we considered the hatching date of the earliest female, and distance to the nest from each fix was evaluated as the distance to the nearest nest.

Differences in home range size among areas or among sexes were tested with General Linear Models, fitting the response variables (home range size in km^2) with a normal distribution and an identity link function.

Statistical analyses were carried out using SAS 9.2 (SAS Institute Inc. 2004)

RESULTS

Most female fixes (67%, $n = 272$) were within 1 km of the nest (Fig. 1). In contrast, only 44% ($n = 343$) of male fixes were within that distance. The maximum distance from the nest at which a male was recorded was 8.5 km (Fig. 1). The average proportion of male fixes beyond 2 km was 24 ± 16% ($n = 5$, range 9-45).

Distance from the nest did not vary in relation to relative date (days from hatching), but varied in relation to sex (relative date: $F_{1,603} = 0.001$, $P = 0.95$; sex: $F_{1,603} = 5.18$, $P = 0.02$, LS Means for males: 1.52 ± 0.23; for females 0.85 ± 0.22; Fig. 1).

There was large variability in home range size between individuals, for both sexes (Table 1, Figs. 2-4). However, average male home range size was almost twice the size of females, irrespective of which method of estimation was used (Tables 1 & 2). Differences between sexes were statistically significant, whereas differences in home range sizes between study areas were not, although sample size was small (Table 3).

DISCUSSION

Our results showed that male Hen Harriers in Scotland mostly hunted within 2 km of their nest and the estimated 90% kernel of their home ranges averaged 8 km^2. Female harriers mostly hunted within 1 km of their nest and average home range estimates were half the size of that of males. These figures did not vary significantly among the three study areas, although there was large individual variability.

Geographical variations in home range are expected as a result of differences in habitat and food (Tella et al. 1998, Jedrzejewski et al. 2007, Schmidt 2008). The fact that we did not find statistical differences among study areas may be a consequence of the large individual variation and our small sample size: our data may thus lack power for between-region comparisons. However, our results suggest that, at least within the study areas, these differences are not extremely marked. The two previous studies calculating estimates of home range size for this species or the closely related Northern Harrier in the US were larger, at 14 km^2 (Picozzi 1978) and 16 km^2 (Martin 1987). Both studies used minimum convex polygons to estimate ranges, and those values are similar to the 17 km^2 we estimated in our study using that method. The lack of important differences in average home range sizes among areas (both in this study and in relation to the two other previous ones) may reflect similar prey abundances in all studies, or that there is a maximum distance from the nest beyond which it is unprofitable for this species to regularly forage.

Sexual differences in ranging behaviour such as those found in this study were not unexpected. Martin's (1987) study of radio-tracked breeding northern harriers 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, which is, again, very similar to our findings from this current study. Other previous studies have also suggested that males hunt further away from their nests than females, both in the UK (Picozzi 1978, Thirgood et al. 2003) and in Spain (García & Arroyo 2005). This may also explain why habitat around the nest affected prey delivery to the nest by females, but not males, at Langholm (Amar et al. 2004). Hunting closer to the nest may enable females to quickly return to brood the young if weather conditions change (Redpath et al. 2002) or to observe their nesting area and protect the nestlings from predation (Amar & Burthe 2001).

Knowledge about the degree of overlap in home ranges of neighbouring individuals provides important information on whether good quality foraging patches can benefit more than one breeding pair. In our study, it was not possible to quantify the degree of overlap between neighbouring ranges because not all birds nested adjacent to each other. However, home ranges of the two neighbouring males in Galloway did overlap extensively, as did those of two females, to a certain extent (Fig. 2), although the smaller size of female home ranges and the tendency for the range to be centred around the nest implied that the overlap for females in general might be less extensive. In Langholm and Orkney, it was not possible to evaluate overlap, because trapped birds were from non-neighbouring nests (Orkney), or data came from different sexes (Langholm). However, the home ranges of all three males included the nest sites of other birds (Arroyo et al. 2006, and Fig. 2), suggesting that they must have overlapped with the ranges of at least some of the neighbouring birds. These results also support Redpath (1992), who noted that the hunting ranges of birds in Highland Scotland overlapped considerably. These results have implications for conservation management, because they suggest that when creating good foraging areas there is the potential for them to be utilised by multiple breeding pairs, and therefore their benefit as a conservation measure can be maximised if they are located within close enough proximity to multiple nesting territories.

SPA management should consider as a priority the creation or maintenance of favoured foraging habitats for harriers (Arroyo et al. 2009). Our results provide information about where to implement management to favour foraging harriers: any action within 2 km of existing nesting sites will favour males, but management within 1 km will be needed to favour foraging females.

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Table 1. Home range size of the ten radio tracked hen harriers according to different methods of calculation, areas shown in km^2. *n* = sample size (number of fixes). MCP = Minimum Convex Polygon

			Kernel home range estimations		
ID	*n*	MCP	50%	70%	90%
Langholm					
Female 257	13	3.38	0.58	1.50	5.33
Male 279	11	5.90	0.95	2.41	8.26
Orkney					
Female 115	89	11.22	1.00	1.58	4.92
Male 286	80	11.92	0.92	1.59	3.96
Male 296	59	12.70	1.71	3.24	7.59
Galloway					
Female 35	61	6.25	0.46	0.97	3.37
Female 155	34	9.50	1.09	2.46	8.23
Female 658	69	4.02	0.19	0.34	0.80
Male 233	77	36.57	2.44	4.92	13.39
Male 543	116	22.04	1.70	4.48	8.38
Average Males	Mean	17.53	1.54	3.33	8.31
	sd	12.14	0.63	1.39	3.36
Average Females	Mean	6.87	0.66	1.37	4.53
	sd	3.41	0.38	0.78	2.73

Table 2. Results from a General Liner Model testing for both site and sex differences in three different home range size estimators from the 10 hen harriers radio tracked in the three Scottish SPAs. Results are for the Type III (partial) tests with both sex and site fitted in each model.

	df	Chi-square	*P*	Parameter estimate (mean ± se)
50% Kernel				Intercept: 1.73 ± 0.25
Sex	1	7.5	0.006	Female -0.92 ± 0.27
Site	2	1.9	0.34	Langholm 0.5 ± 0.35; Orkney -0.21 ± 0.31
70% Kernel				Intercept: 3.93 ± 0.52
Sex	1	8.9	0.003	Female -2.17 ± 0.57
Site	2	2.7	0.25	Langholm -0.89 ± 0.73; Orkney -1.08 ± 0.66
90% Kernel				Intercept: 9.40 ± 1.49
Sex	1	5.2	0.023	Female -4.28 ± 1.64
Site	2	1.6	0.44	Langholm -0.47 ± 2.11; Orkney -2.48 ± 1.89

Figure 1. Frequency distribution of the distances to the nest for each fix of the radio-tracked hen harrier females (n = 272) and males (n = 340) within three study areas in Scotland.

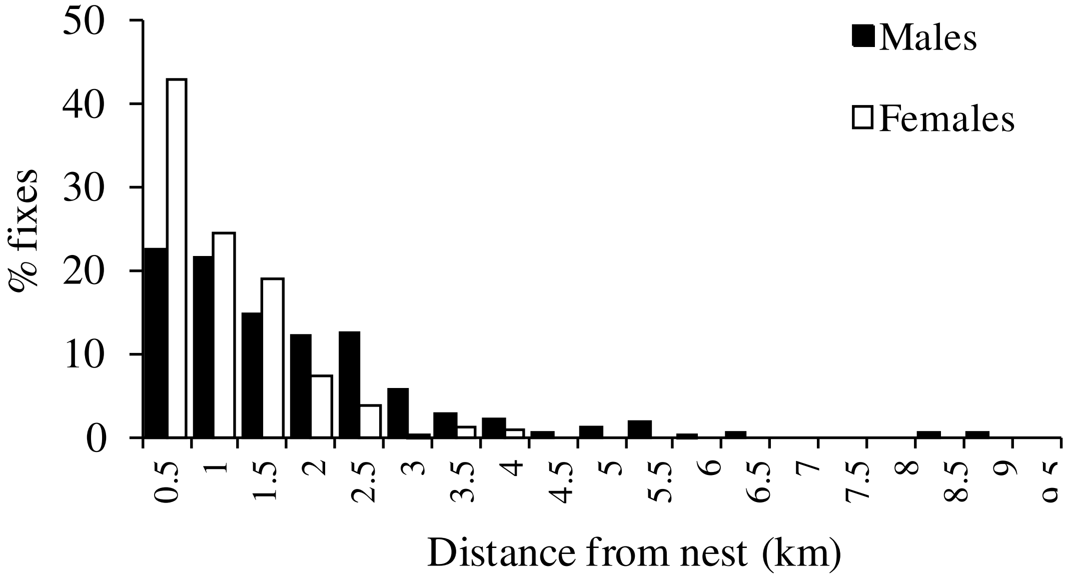

Figure 2. Home ranges ofthe monitored birds female (left) and male (right) in relation to nest site (star) and other nests (white circles) and the limits of the SPAs (in thick lines) in Langholm.

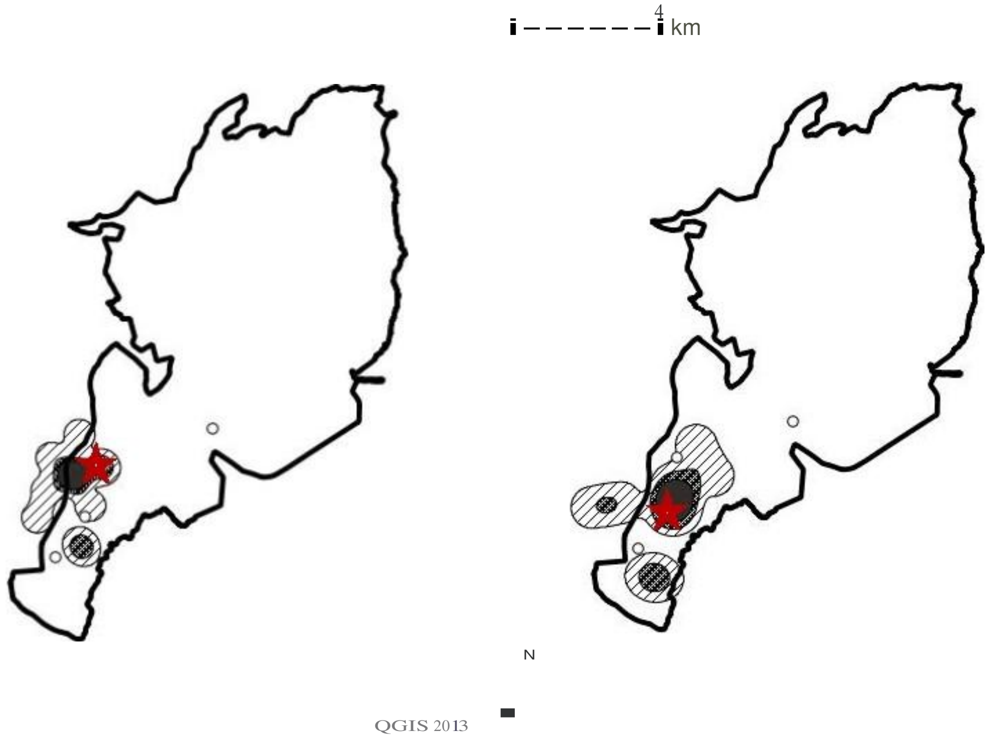

Figure 3. Home ranges of the monitored birds in relation to nest site (star) and other nests (white circles) and the limits ofthe SPAs (in thick lines) in Orkney. The bottom right range corresponds to a female, the two others to males.

Figure 4. Home ranges of the monitored females (top panels) and males (bottom panels) in relation to nest site (star) and other nests (white circles) and the limits of the SPAs (in thick lines) in Galloway.