

**Management Trial to reduce Hen Harrier  
predation on Red Grouse at Langholm in  
1998 and 1999: the effect of providing hen  
harriers with supplementary food**

Report No. F99AC419

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**MANAGEMENT TRIAL TO REDUCE HEN HARRIER PREDATION ON RED GROUSE AT LANGHOLM IN 1998 AND 1999: THE EFFECTS OF PROVIDING HEN HARRIERS WITH SUPPLEMENTARY FOOD**

**Report No: F99AC419**

**Contractor: Centre for Ecology and Hydrology**

## **BACKGROUND**

An experiment was conducted in 1998 and 1999 on Langholm moor in south west Scotland, to see whether predation by hen harriers on red grouse could be reduced by placing carrion (dead rats and poultry chicks) in harrier territories in spring and close to harrier nests in summer

Langholm moor was divided into two areas: area A and area B. In spring, food was placed in harrier territories on area A only in 1998 and on area B only in 1999. Harrier breeding numbers, laying date, clutch size and adult grouse survival on the areas over the two years were compared. In summer, food was placed close to some nests on both areas from hatch to dispersal. In this period harrier breeding success, dispersal dates and the rate at which prey (and in particular grouse chicks) were delivered to nests with and without supplementary food, were compared.

## **MAIN FINDINGS**

- Evidence that providing harriers with food in spring increased the breeding density was equivocal. More harriers nested on area A in both years. On area A, harrier numbers were high in 1998 (when food was provided) despite a crash on small mammal numbers. There was no similar increase in harrier numbers when food was provided on area B in 1999. Differences in harrier numbers in relation to feeding may therefore have been due to some effect associated with area or year. There was no evidence that feeding in 1998 lead to more young females returning to breed in 1999.
- Harriers on the areas where food was provided had larger clutches, though the number of chicks hatching did not differ significantly between the fed and unfed areas. Laying date was earlier in both years on area A and harriers took food earlier on area A in 1998 than on area B in 1999. Harriers only started to take food as they approached egg laying. There was no evidence that laying date was determined by the availability of supplementary food.
- Between 78% and 96% of grouse dying in the spring were killed by raptors. However, providing harriers with food in spring did not significantly improve adult grouse survival. This suggested that much grouse mortality at this time of year was probably due to other raptor species.
- The extent to which harriers took supplementary food in the summer was influenced by the breeding system of the harriers and whether or not the birds were fed in spring. Females took supplementary food at a much higher rate than males. Only bigamous males used the supplementary food to any great extent. Females that had been fed in spring took over twice as much supplementary food in the summer compared with unfed females in spring.

- Fed broods were on average 1 chick larger than unfed broods, though this difference was not statistically significant.
- Fed harriers caught grouse chicks at a lower rate than unfed harriers. For both years combined, harriers that were provided with supplementary food delivered 0.5 grouse chicks per 100 hours to their nests, compared to 3.7 grouse chicks for harriers at nests where no food was provided.
- Numbers of grouse on Langholm moor in autumn have been declining steadily since 1993. In both 1998 and 1999, numbers of grouse chicks lost between early June and mid July were three times higher than expected from harrier predation rates. Some other, unknown, factor had a strong influence on grouse chick survival in these years. The feeding of harriers in 1998 did not lead to an increase in grouse density in 1999.
- Feeding hen harriers during summer reduced predation on grouse chicks by 86%. If the same pattern holds for other areas, the benefits of feeding harriers are likely to be most apparent when grouse chick density is about 60-70 birds per km<sup>2</sup> (where the impact of harriers is considered to be greatest). However, to maximise the benefit of feeding it is important that foxes and other factors limiting grouse breeding success are controlled. Overall, we estimated that feeding harriers at Langholm cost between £840 and £920 per harrier nest.

**TO BE COMPLETED BY SNH NOMINATED OFFICER**

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## 2. INTRODUCTION

Heather moorland is an internationally important habitat and its maintenance is viewed as a conservation priority (Anon 1995, Thompson *et al.* 1995). Within this habitat the management of moorland for red grouse (*Lagopus lagopus scoticus*) represents an important form of land use (Hudson 1992). The aim of grouse management is to maximise the number of birds available for shooting, through heather burning, parasite and predator control (see Hudson & Newborn 1995). Raptors have traditionally been killed along with foxes and corvids, and their persecution on grouse moors is still widespread despite the fact that they have received full legal protection since 1954 (Etheridge *et al.* 1997, Scottish Raptor Study Groups 1997).

Recent research has strongly suggested that hen harriers (*Circus cyaneus*) and peregrines (*Falco peregrinus*) breeding at high density were able to limit grouse populations at low density (Redpath & Thirgood 1997, Redpath & Thirgood 1999, Thirgood *et al.* 2000 a & b). This has highlighted the conflict between those who wish to manage grouse and those who wish to conserve raptors (Thirgood *et al.* 2000 c). One possible short-term solution to this conflict is to provide harriers with food throughout the breeding season, thus reducing predation rates on grouse. The effects of feeding on hen harriers have not been investigated, although other harrier species have successfully been fed during the pre-lay period (Simmons 1994). In this report we examine the effectiveness of feeding harriers as a management tool in reducing predation on grouse.

In a wide range of raptor species, there are good correlations between breeding density and food abundance (Newton 1998). It is possible therefore that providing food for harriers may lead to increases in their nesting density. In addition, studies that have provided supplementary food to other raptor species have found an effect of feeding on laying date and clutch size (eg. Dijkstra *et al.* 1980, Newton & Marquiss 1981, Korpimaki 1987), and fledging success (eg. Korpimaki 1987). We therefore also examine the effect of feeding on harrier density and breeding success.

The findings in this report are based on an experiment undertaken on Langholm moor in south-west Scotland in 1998 and 1999, where the main aim was to find whether supplementary feeding reduced predation on adult grouse and on grouse chicks. In this report we:

1. Examine to what extent harriers take supplementary food and whether the food is a supplement or a substitute for wild prey.
2. Examine the effect of feeding on harrier breeding density. Feeding may lead to an increase in harrier density either by attracting more adults into an area with food in the spring, or by improved survival of chicks fed at the nest and returning in subsequent years. We therefore compare breeding density on areas where food was provided and areas where no food was provided and examine the return rates of chicks hatched in 1998.
3. Examine the effect of feeding on harrier breeding success.
4. Examine the effect of feeding on survival rates of adult grouse in spring and on grouse chicks in the summer.
5. Examine whether food provision to 60 days (the normal age of dispersal) caused chicks to stay longer than 60 days on territory.
6. Consider the costs and benefits of feeding as a management tool and assess the overall effectiveness of the technique in reducing predation on grouse.

### **3. METHODS**

This study was based on Langholm moor in south-west Scotland. Within this study area, heather moorland was estimated to cover a total of 41km<sup>2</sup>, with grass (mainly *Molinia caerulea*) covering much of the remaining moorland (see Redpath & Thirgood 1997).

#### **3.1 Spring feeding**

On the basis of the distribution of heather-dominant vegetation (Redpath & Thirgood 1997) and harrier nests in 1997 (see later), Langholm moor was divided into two areas, A and B (Fig.1). During spring, harriers were provided with food (treatment) on area A in 1998 and area B in 1999. Harriers on the other half were not fed (control). Harriers were located as they returned to their breeding sites in March and feeding perches were erected in their territories. At this time of year, harrier territories are relatively small and the perch was sited in the area where males were most active. Two posts were erected in territories where two females were seen associating with individual males in late March. Posts consisted of standard 5' high, 4" diameter fence posts with a 12" section of post nailed across the top, to create a T perch.

Food, primarily dead white rats and poultry chicks, was placed daily on the perches from late March until the start of incubation. These items were used so that they

could easily be identified in pellets and at nests. Items were thawed out the night before, so that they were fully defrosted before being put on the perches. We monitored food disappearance through systematic observations in male territories and also on an *ad hoc* basis during general fieldwork. Any food that was left over on the next day was removed and disposed of. Because feeding attracted potential harrier egg predators (see later), we did not put out food during the incubation period.

Harriers started laying from mid-April and in each area the number of females laying eggs, their mating system (monogamous and polygynous) and breeding success were recorded. Nests were located during egg laying or early incubation, and both laying date (first egg) and clutch size were recorded. Female harriers were aged as first year birds or older, based on their tags or eye colour (1<sup>st</sup> year birds have brown eyes). Some birds failed during incubation and re-laid (one nest in each year). Clutch size and lay date of the first clutch were used in analyses.

Small mammal and adult grouse abundance levels were estimated in both years. Small mammal abundance was estimated from 10 lines of 50 traps set for 2 nights in spring and grouse were counted with a dog on 10, 0.5 km<sup>2</sup> areas in spring (see Redpath & Thirgood 1997 for details). During March, a total of 100 grouse in 1998 and 91 grouse in 1999 were fitted with 15g necklace radio-transmitters (Biotrack UK). Of these, 51 grouse in 1998 and 48 grouse in 1999 were tagged on area A and the remainder on area B. Birds were caught at night in hand-held nets after dazzling them with a strong light. All birds were located once before 1 April and their survival monitored weekly until the end of June. We calculated weekly survival rates on the basis of the spring season starting on 1 April. We used Kaplan-Meier product limit method and tested for end-point differences in survival using a two-tailed z-test statistic (details in Redpath & Thirgood 1997).

### **3.2 Summer feeding**

Because of variation in harrier breeding density and laying date between treatment and control areas (see results), a number of broods were selected from each area to be fed from hatch to chick dispersal. Nests were allocated randomly within the constraints that both groups showed similar median lay dates and contained similar numbers of monogamous and bigamous females. In total, food was provided to nine nests in 1998 and to five nests in 1999. No food was provided to six nests in 1998 and to five nests in 1999.

Once chicks had hatched, perches were placed on average  $9\text{m} \pm 1\text{m}$  away from the nests. Food was placed on perches each morning and the amount varied according to the maximum food requirements of the chicks. Estimates of food requirements were based on previous observations of harriers at Langholm (Redpath & Thirgood unpub. data). As in the spring, any food remaining the next day was removed. Harriers were provided with food from hatch for 60 days, which was the estimated time to dispersal based on previous data from nests where no food was provided (Redpath & Thirgood 1997).

To examine what the harriers were eating, we set up hides 5-7m from all nests. We aimed to spend a minimum of two, six hour watches per nest per week, from hatching to fledging. All nests were watched, with the exception of one nest in 1999 with no food, which was judged to be too close to a public road. During each watch we recorded: start time, total time watched, number of chicks, amount of food available on perch, and time and identity of food brought to the nests by males and females. After fledging, some territories (10 over two years) were observed every 2-3 days to monitor dispersal date, taken as the day after the last day on which the birds were seen on the moor. Because few items can be identified after fledging, only prey data in the 35 days after hatching are included in analyses.

In May radio-transmitters were used to locate grouse nests, so that clutch size and the number of chicks hatching could be recorded. In late July, grouse broods were located with trained pointing dogs and the number of chicks in each brood was counted. This gave estimates of the number of grouse chicks available to harriers and the number present after the main period of harrier predation (see Redpath & Thirgood 1997).



Statistical analyses were done in Minitab (v11) and SAS (v6.12). When analysing breeding data and grouse provisioning data, PROC GENMOD was used on count data, assuming a poisson distribution, with a log link function and, for provisioning rates, log hours were set as an offset variable. For bigamous males the average time spent watching the two nests he provisioned was used as the offset time. The outputs from two models are presented. One output includes all terms (year, area, spring feeding and summer feeding) and the other output is the final model after backward elimination, dropping the least significant term in the model, until only terms significant at the 10% level remained. Variation in breeding parameters were tested using the GLM procedure. Statistics for Type III analyses are given, which in effect examine how much variation is explained by a given variable, whilst holding the effects of other variables constant.

## **4. RESULTS**

### **The spring feeding experiment**

#### ***4.1 Food put out and removed in spring.***

During spring (end March to egg laying), 193 kg of food was put out in area A on 8 territories (8 males, 13 females) in 1998 and 63kg of food was put out on area B on 5 territories (5 males, 3 females) in 1999. In 1999, two male territories on area B were occasionally visited by females that did not settle. Less food was put out in 1999 partly because there were fewer females, but also because less food was removed in total (Table 1).

In 1998, 91% of the food had disappeared by the next day, whereas in 1999, only 44% of the food had disappeared. A similar proportion of food was seen taken in both years (4% in 1998, 3% in 1999), and of this harriers took a similar proportion. There was a clear difference in when harriers took food. In 1998, the first item seen taken by harriers was on 4th April, whereas in 1999 the first item seen taken was on 4th May. This difference was also reflected in the timing of harrier breeding (see later).

#### ***4.2 Harrier breeding density***

Within the Langholm area, field voles appear to cycle with a period of 3-4 years between peaks (Taylor 1994, Redpath et al. In review). Since 1992 there have been two peaks in vole abundance, in 1994 and 1997 (Fig. 2) and the numbers of harriers

attempting to breed (ie. lay eggs) has reflected these changes. As harriers have shown a general increase since the start of the study in 1992, we fitted a linear regression line through the harrier breeding data and compared the residuals around this line with the field vole data (Figure 3. Redpath et al. In review). More harriers bred in years when more field voles were trapped in spring.

In 1997 twenty harrier nests were found on Langholm moor. Since then numbers of nests have declined as have the number of small mammals caught. Seventeen breeding females were located in 1998 and thirteen in 1999. In 1997 similar numbers of females bred in areas A (11) and B (9), but this pattern was not repeated in either of the following two years (Figs. 2 & 4).

In addition to the males with females that laid eggs, there were also some adult (grey) males present in both years which established territories, but failed to attract females. In 1998 three such males were present (2 on area A, 1 on area B) and in 1999 five unmated males were present (3 on A and 2 on B). No such cases were reported in previous years.

In 1997, seven (41%) of seventeen females were first year birds, of which three bred on area A and four on area B. In 1998, four (25%) of sixteen aged females were first year birds, which all bred on area A. In 1999, three (25%) of twelve aged females were first year birds, two of which bred on area A. There was thus no apparent increase in the proportion of young females breeding in the population during years when birds were fed. Of birds tagged as chicks in 1998, three returned to breed in 1999, two on area A and one on area B. Two of these were from a nest provided with food and one was from a control nest. This pattern was not unusual. In other years an average of 19% of breeding females were born on Langholm moor in the previous year (range 0% in 95 to 36% in 94), compared to 23% in 1999. Thus feeding in 1998 did not lead to a large increase in young females entering the breeding population in 1999.

Most males first bred as grey birds (ie. over 1 year old). At Langholm, only 1 of 67 breeding attempts by males have been by first year birds and no brown males attempted to breed in 1998 or 1999. So if feeding does lead to an increase in numbers of males in subsequent years, the effect may not be noticeable until 2000/01.

If feeding influenced harrier breeding numbers then in 1998 we would have expected an increase in numbers on area A relative to previous trends and relative to area B in 1998. Similarly, in 1999 we would have expected an increase in area B relative to previous trends and relative to area A in 1999. The results indicated that more harriers bred on area A than on area B in both years and that the proportion of harriers that nested on area B varied little between 1998 (24%) and 1999 (23%). More harriers bred on area A in both 1998 and 1999 than expected given the decline in field voles (Fig. 4). This provided some support for the idea that feeding may have attracted more breeding adults into area A in 1998. However, if this were the case we would have expected an increase in harriers on area B in 1999, when in fact female numbers declined (Fig. 4). The results are therefore inconclusive as to the effects of feeding on harrier breeding numbers.

#### **4.3 Harrier clutch size and laying date**

A comparison of clutch size and laying date with previous years indicated that clutches were large and laid earlier in 1997, when voles were abundant (Fig. 5). Feeding influenced clutch size, as clutches were larger on area A than on area B in 1998 and on area B than on area A in 1999 (Controlling for year and area effects:  $F_{1,26} = 7.8$ ,  $P = 0.01$  Fig. 5). Laying date was earlier on area A in both years and for both areas was later in 1999, indicating that feeding did not influence laying date (Controlling for year and area effects:  $F_{1,26} = 0.47$ ,  $P = 0.50$  Figure 5). There was a significant effect of area on laying date, with birds on area A laying earlier ( $F_{1,26} = 14.9$ ,  $P = 0.001$ ). On the fed areas, mean laying date varied from day 112 to day 131, a difference of 19 days. This was similar to the dates when harriers were first seen to take food from the perches (Area A 1998: first food seen taken 4<sup>th</sup> April, laying date 18<sup>th</sup> April. Area B first food 4<sup>th</sup> May, laydate 11<sup>th</sup> May). This suggests that the use of supplementary food in the spring may be a consequence of female condition, rather than of food availability.

One further difference between years was in the level of polygyny (Fig. 3). In 1997, 43% of males (N=6) were polygynous, in 1998, 45% (N=5) males were polygynous, whereas in 1999 all males were monogamous.

#### **4.4 Adult grouse survival**

Raptors were the main source of mortality for adult grouse over the radio-tracking period in 1998 and 1999, killing a minimum of 18% of the grouse overall and a minimum of 78% of birds that were killed (Table 2). Survival rates of radio-tagged

grouse on area A did not differ significantly from survival rates on area B in either 1998 or 1999 (Table 3, Fig. 6, 1998:  $Z=0.48$ ,  $P>0.5$ ; 1999:  $Z=0.36$ ,  $P>0.5$ ). Similarly, survival in each area did not differ between years (Area A,  $Z = 0.92$ ,  $P > 0.1$ , Area B,  $Z = 0$ ,  $P = 1.0$ ).

We also compared survival rates of all radio-tagged grouse at Langholm in 1998 and 1999 to survival data collected during the springs of 1995 and 1996 when no supplementary feeding was conducted (details of data collection in these years in Redpath & Thirgood 1997). Spring survival rates in 1998 and 1999 tended to be higher, but these differences were not significant (Table 2, Fig. 7; 1995 vs 1998:  $Z=1.04$ ,  $P>0.1$ ; 1995 vs 1999:  $Z=0.57$ ,  $P>0.1$ ; 1996 vs 1998:  $Z= 1.72$ ,  $p>0.1$ ; 1996 vs 1999:  $Z=1.18$ ,  $P>0.1$ ).

#### **The summer feeding experiment.**

##### ***4.5 Location of harrier nests***

Of the seventeen females that laid clutches in 1998, three failed at incubation or during hatch. A predator (probably a stoat) ate one clutch, another clutch disappeared and one young brood apparently starved, despite both adults being present. Two of these nests were on area A and the remainder (which re-laid) was on area B. Of the 13 females that laid in 1999, four failed due to fox predation (determined from tooth marks) on area A during incubation. Two of these females were killed on the nest by foxes and one of the other two re-laid. Because of the large differences in harrier density, laying date and mating system (in 1998) between the two areas, some harriers in each area were fed during the summer period (Fig. 8).

##### ***4.6 Harrier breeding success***

Harrier breeding success varied between years, with 50 chicks fledging from 17 nests in 1998 and 28 chicks fledging from 13 nests in 1999 (Table 4). Although fed broods tended to have improved breeding success, none of the differences was significant. The number of young hatched at nests with and without food during the spring varied from 4.0 chicks (fed nests) to 3.3 chicks (unfed nests). Controlling for year and area  $F_{1,29} = 0.06$ ,  $P = 0.8$ ). Fledged broods were on average one chick larger than unfed broods (3.4 young .v. 2.4 young. Controlling for year, area and spring feeding  $F_{1,22} = 2.2$ ,  $P = 0.15$ ). Similarly, the difference between the number of chicks dying at nests in relation to food provision was not statistically significant (1.5

young for unfed broods, 0.9 young for fed broods  $F_{1,22} = 1.8$ ,  $P = 0.20$ ). We found no evidence for interactions between treatment and area.

#### **4.7 Provisioning of supplementary food**

In summer 1998, 6499 food items were put on posts next to nine harrier nests, of which 85% had disappeared by the next day. Harriers took 92% of the food seen taken, while crows (*Corvus corone*) and lesser black-backed gulls (*Larus fuscus*) took the remaining 8%. In summer 1999, 4069 items were put out at five harrier nests, of which 69% had disappeared by the next day. Harriers took 83% of the food seen taken with the remaining 17% taken by lesser black-backed gulls.

In 1998, 1074 hours were spent in the fifteen hides, with 616 hours of observation at nine nests with supplementary food and 457 hours at six nests without food. In 1999, 919 hours were spent in nine hides, with 547 hours of observation at five nests with food and 371 hours at four nests without food. In 1999, one nest was too close to a public road to allow a hide to be erected, so no diet data were obtained.

We first compared the rates at which male and female harriers delivered supplementary food to their young (Table 5, Figure 9). Supplementary prey items were only seen delivered to nests where food was provided. Over the two years females provisioned supplementary items at a far higher rate than males ( $T = -6.1$ , 19df.,  $P < 0.0001$ ). Neither male nor female provisioning of supplementary food varied significantly between years (Male:  $T = 1.40$ ,  $P = 0.21$ . Female:  $T = 0.60$ , 5 df.,  $P = 0.57$ ). There appeared to be an effect of mating system on provisioning of supplementary food by males, though sample sizes were too small to test statistically. The two bigamous males in 1998 brought in 34 and 11 supplementary items per 100 hours respectively. In contrast, the remaining five monogamous males in 1998 delivered on average 0.6 items in 100 hours (range 0-2), and the five monogamous males in 1999 delivered on average 0.2 items in 100 hours (range 0-1).

For females, the use of supplementary food appeared to vary according to whether or not they were fed during the spring. For both years combined, females fed in spring delivered  $50.3 \pm 5$  supplementary items in 100 hours, whereas females not fed in spring delivered  $23.3 \pm 7$  such items in 100 hours (Fig. 10). This difference was significant ( $T = -3.1$ , 7df.  $P = 0.016$ ).

#### **4.8 Provisioning of natural food.**

Do rats and day-old chicks act as a substitute for or a supplement to natural prey? If this food acts merely as a substitute then we would expect the delivery rate of all prey combined to be the same between treatments and the delivery rates of natural prey to be lower at nests where food was provided. If this food acts as a supplement then we would expect total provisioning rates to be higher at nests with food and rates of natural prey deliveries to be the same with and without additional food.

The provision of supplementary food in summer had a significant effect on the overall provisioning rates of females (fed – 48 items 100 hrs<sup>-1</sup>, unfed - 30 items 100 hrs<sup>-1</sup>. Controlling for year and area  $F_{1,20} = 6.0$ ,  $P = 0.024$ ). Supplementary food also had a large effect on the provisioning rates of natural prey by females (fed – 8 items 100 hrs<sup>-1</sup>, unfed - 30 items 100 hrs<sup>-1</sup>. Controlling for year and area  $F_{1,20} = 17.1$ ,  $P < 0.001$ ). So, for females the additional food acted as both a substitute and supplement – they took 72% fewer natural prey, but took more food overall.

For males, the provision of supplementary food in summer had no effect on the overall provisioning rates ( $F_{1,16} = 0.172$ ,  $P = 0.21$ ). Similarly, the provision of supplementary food in summer had no effect on male provisioning rates of natural prey ( $F_{1,16} = 0.84$ ,  $P = 0.37$ ). So the rate at which males delivered wild prey did not appear to be affected by the provision of supplementary food.

#### **4.9 Provisioning of grouse chicks.**

In 1998, 23 grouse chicks were seen delivered to the 16 harrier nests in 1074 hours (Table 5). Of these, only 2 (9%) were delivered to the nine nests where food was provided. In 1999, 16 grouse chicks were seen delivered to nine harrier nests in 919 hours, of which 5 (31%) were delivered to the five nests where food was provided.

We first compared the rate at which harriers delivered grouse chicks to nests over the two years in relation to feeding (Fig.11, Table 5). There was a significant effect of providing supplementary food during the summer on the rate at which both male and female harriers delivered grouse chicks to their nests. Over both years combined, harriers at nests where food was provided delivered 0.5 grouse chicks every 100 hours. In contrast, harriers at nests where no food was provided delivered 3.7 grouse chicks every 100 hours, an 86% reduction.

In 1998 & 99 harriers delivered grouse chicks to their nest at a lower rate than during 1993-96. In years prior to the experiment males delivered grouse chicks at 7.6 per 100 hours, compared to 2.3 since 1998 (unfed nests only). For females the rate dropped from 6.7 to 1.8 grouse. These differences were significant (Male:  $T = 3.17$ , 21df.,  $P = 0.009$ . Female:  $T = 4.11$ , 26df.,  $P = 0.0004$ ) and reflect reductions in grouse chick abundance over the years (Table 7).

The effects of feeding on the losses of grouse chicks to harriers are shown in table 7. We estimated the number of grouse chicks taken by harriers from hatch to dispersal as follows:

**Number of grouse = Rate (grouse hr<sup>-1</sup>) x no. nests x 15 hours (per day) x 60 days.**

The results indicate that feeding the harrier population during the nestling and post-fledging period can potentially save large numbers of grouse chicks from being taken by harriers (Table 7). The difference in numbers of grouse chicks taken by the harrier population had they all been fed compared to none having been fed was 562 grouse chicks in 1998 and 144 grouse chicks in 1999.

#### **4.10 Change in grouse density and breeding.**

From 1993 to 1999 there was a consistent decline in the number of grouse counted in autumn from 37 per 0.5km<sup>2</sup> to 16 per 0.5km<sup>2</sup> on the areas within the bounds of the feeding experiment (Fig.12). Over the same period the numbers of grouse counted in spring have also shown a significant decline (Thirgood *et al.* 2000a) and since 1997, numbers have declined from 15.1 per 0.5km<sup>2</sup> to 7.4 per 0.5km<sup>2</sup>. Feeding harriers in 1998 did not lead to an increase in grouse density in 1999.

We monitored the number of grouse chicks hatching per clutch and conducted counts of grouse broods in July, to find how brood size changed over that period, which was when harriers were feeding their young. We used provisioning rates to estimate the number of grouse chicks taken by harriers from hatch to fledging and compared this to the number lost before the July count (Table 8).

The figures in table 8 show two clear patterns. First, the average losses of grouse chicks from hatch to mid July increased from 45% in 1995/96 to an average loss of 63% in 1998/99. However, this increased loss was not due to increased predation by harriers. Indeed harriers took only 6.5% of the available grouse chicks in the years of the feeding trial, compared to 28% in 1995/96. The reduction in grouse chick losses

to harriers in the last two years was partly as a result of feeding and partly as a result of fewer grouse chicks being available.

As there was approximately 41.45 km<sup>2</sup> of suitable grouse habitat on the estate (Redpath & Thirgood 1997), we were able to estimate the number of grouse taken by harriers 0.5 km<sup>2</sup>. In 1998, we estimated that harriers took 187 ± 80 grouse chicks, or 2.2 ± 1.0 per 0.5 km<sup>2</sup>. If this is expressed in terms of confidence intervals, we were 95% confident that the true level of grouse chick loss to harriers per 0.5 km<sup>2</sup> lay between 0.2 and 4.2 chicks. Yet observed overall chick losses were 21.7 chicks, or ten times higher than the numbers lost to harriers. Similarly in 1999, we estimated that harriers took 107 ± 53 grouse chicks, or 1.3 ± 0.6 per 0.5 km<sup>2</sup>. We were 95% confident that the true level of grouse chick loss to harriers per 0.5 km<sup>2</sup> lay between 0.1 and 2.5 chicks. Yet observed overall losses were 12.7 chicks, or ten times higher than expected if harriers had been the sole mortality agent.

Much grouse chick mortality occurs in the first two weeks of life, before the chicks can thermoregulate properly. We therefore estimated brood size in early June (at about two weeks old) and compared to the offtake of grouse chicks by harriers (Table 8). Even if all grouse chicks taken by harriers occurred in this six-week period, harriers could only account for a third of all grouse chick losses in 1998&99. Clearly, some other mortality agent had a strong influence in 1998&99, but whether this was related to weather, food, other predators or parasites was unknown.

Had all the harriers been fed, the data suggested that from hatch to dispersal, harriers would have taken 43.1 grouse chicks in 1998 and 81 grouse chicks in 1999 (Table 7). Given the density of grouse chicks available in May in these years (Table 8), this suggests that harriers would have taken 1.6% of grouse chicks in 1998 and 4.5% in 1999, had they all been fed. Had none of them been fed data suggested that harriers would have removed 23% in 1998 and 12.5% in 1999.

#### **4.11 Harrier chick dispersal.**

Once harrier chicks fledged, at around 35 days, we watched the area around some of the nests until flying young were no longer seen. We obtained data on estimated dispersal dates for four broods in 1998 and six broods in 1999. These data were compared to data from previous years (Table 9). There was no evidence that chicks from fed broods stayed longer on the moor after fledging (median 62 days), than chicks from broods that were not fed (median 61 days).



#### **4.12 Costs of food provisioning.**

##### *Food costs*

In 1998, 660kg of food was put out for harriers. If all harriers had been fed the total weight of food needed would have been 1020kg. In 1999, 276kg of food was put out; had all harriers been fed, this would have amounted to 639kg. The cost of this food depended on the type of food put out (rats £0.30 each and chicks £0.025 each). If rats (weighing 160g) only were used, we would have required 6375 rats in 1998 (at a cost of £1912, or £127 per nest) and 3994 rats in 1999 (at a cost of £1198, or £120 per nest). Had chicks (weighing 40g) only been used, the cost in 1998 would have been £637 (£42 per nest ) and in 1999 would have been £399 (£40 per nest). These costs could have been reduced through the provision of other prey such as rabbits.

##### *Transport costs*

Transport costs varied between years, as most nests were reasonably close to public roads in 1998, but not in 1999. In 1998, we estimated that we covered 3500 miles feeding the harriers at Langholm. At £0.25 per mile, this was equivalent to £875. In 1999, we hired a quad-bike for £2k and covered an estimated 6000 miles, equivalent to £1500. In total therefore travel costs were £3500 in 1999.

##### *Other costs*

A freezer and associated electricity were necessary for storing the food. In the first year, this cost us an estimated £540, and in 1999 £40 for electricity alone.

##### *Overall costs*

The main cost of feeding will lie in wages. Feeding all the harriers on Langholm from March to August would take over seven hours a day, every day and will therefore be equivalent to one full-time job, plus additional casual help. An approximate cost of such man-time for 5 months would be £7.5k.

Had all the harriers been fed at Langholm, we estimate that the cost per annum would have been between £10k and £11.5k (Table 8). These costings would clearly have varied depending on the number of harriers requiring feeding and the transport costs of getting to the harriers each day and are provided here only as a rough guide to the costs associated with the technique.

## **5. DISCUSSION**

Since the start of the initial study at Langholm, there has been a 6-fold increase in the ratio of harriers to grouse in spring (Fig. 13). This reflects the decline in the grouse population (Fig. 12) and the fact that harrier numbers have increased following protection from human interference (Fig. 2). The increasing ratio of harriers per grouse highlights the importance of finding ways to reduce the numbers of grouse taken by harriers in the short-term. In this report we have tested one of the most tractable of the possible solutions outlined by Thirgood et al. (2000c); feeding harriers with supplementary food to reduce the rate at which they eat grouse.

Providing harriers with supplementary food on Langholm moor had a number of effects. The clearest effect was on the rate of provisioning of grouse chicks. Over both years combined, harriers at nests where food was provided, delivered a grouse chick to their nest every 200 hours, whereas harriers without supplementary food delivered a grouse chick every 27 hours. This alone suggests that supplementary feeding provides a useful tool in reducing the number of grouse chicks taken by hen harriers.

### ***Spring feeding experiment***

The two areas of Langholm in which the experiment was conducted differed in their elevation. Harriers appeared to show a preference for the lower of these areas (A), as they consistently bred at higher density there and laid clutches earlier in this area. In 1997, a similar number of harriers bred on the two areas, but since then numbers of harriers have been considerably higher on area A. For Langholm as a whole, there was clear evidence that the number of harrier nests was related to field vole abundance. Yet on area A, the numbers of harriers increased in 1998, despite a crash in small mammals. This was consistent with the possibility that feeding may have attracted more breeding harriers onto the area. However, in 1999, feeding was switched to area B, but failed to increase harrier density there. So the change in harrier numbers appeared to be due to some effect associated with area or year. This may or may not have been related to feeding. For example, it may be that area A was a preferred area for breeding harriers (see Redpath and Thirgood 1997) and feeding in such an area lead to an increase in harrier numbers, whilst feeding on less preferred areas did not lead to increases in harrier numbers. At this stage the results are inconclusive, and to test whether feeding would lead to higher harrier breeding densities in other years or different areas further manipulations would be necessary.

We also considered whether feeding led to more harrier chicks returning in subsequent years from nests where food was provided. There was no evidence that feeding in 1998 led to more female harrier chicks returning to breed in 1999. Males, however, start breeding in their second year so an effect on males returning would not yet be apparent.

Feeding led to increased clutch size, but it did not lead to an increase in the number of chicks hatching. As in previous years (1994-97), laying date was consistently earlier on area A and was not apparently altered by feeding. There was a clear difference between years in when harriers took the food and this was reflected in the laying date. In 1998, the first food was seen taken on 4<sup>th</sup> April and the mean laying date on area A was 18<sup>th</sup> April. In 1999, the first food was seen taken on 4<sup>th</sup> May, although food was available from the end of March, and the mean laying date was on 11<sup>th</sup> May. We conclude that harriers only started to take food as they approached egg laying, and that egg-laying was determined by female condition and not by the availability of supplementary food.

Adult grouse survival was slightly higher in 1998 and 1999 than it was in 1995 and 1996, though the differences were not statistically significant. This pattern may have reflected the decrease in grouse density and an associated decline in density dependent mortality (Redpath & Thirgood 1997). There was also no significant difference in grouse survival between the two areas in either year, or between the two years in either area A or area B. Clearly, these results indicated that providing harriers with food in spring did not greatly improve adult grouse survival. This could either be because feeding did not stop harriers killing grouse and they were killing grouse over the whole moor, or because harriers were killing few adult grouse anyway at this time of year. We know little about the ranging behaviour of harriers in spring, but two to three weeks prior to laying females appeared to spend most of their time on territory being fed by their males. In addition, analysis of harrier pellets collected in spring 1997-1999 indicated that grouse formed a relatively small proportion of the harriers' diet at that time of year, forming 9% of prey identified from pellets (unpublished data). Given the fact that most grouse mortality in spring was due to raptors, the likeliest explanation for the apparent lack of an effect of feeding on grouse mortality rates is that most mortality at this time of year may have been due to other raptors, such as Peregrines and Goshawks.

In summary, the results of a two-year supplementary feeding experiment at Langholm were inconclusive regarding the effects of feeding on harrier breeding density, although there may have been different responses to feeding between the areas. There was an effect of feeding on clutch size, though not on brood size at hatching. The data suggested that harriers only took food once they were approaching egg-laying, rather than supplementary feeding influencing laying-date. We were unable to detect a significant difference in adult grouse survival between fed and unfed areas.

### ***The summer feeding experiment***

Providing harriers with food during the nestling period had a marked effect on harrier provisioning patterns. Comparing rates of prey deliveries at nests with and without supplementary food we found a significant difference in the rate at which all prey were delivered by females. Natural prey items were delivered by females at a lower rate to nests with extra food. Males did not alter their overall delivery rates when supplementary food was provided and it was only the bigamous males (in 1998) that delivered any of the supplementary food. Females delivered much more supplementary food than males and fed females decreased their delivery rate of natural prey. In addition, females fed in spring used considerably more of the supplementary food during summer than females fed in summer alone.

There was a tendency for harrier breeding success to be improved by summer feeding, with fed broods rearing on average 1 more young, and having fewer deaths during the nestling stage than unfed broods. The fact that supplementary feeding did not have a clearer impact on harrier breeding success was probably because of small sample size and the variation in the use of the additional food by the harriers, especially in the first two weeks after hatch when most of the chick mortality occurs. Other studies have found that food supplementation at raptor nests increased the number of fledgings and decreased nestling mortality (Wiebe & Bortolotti 1994, Gehlbach & Roberts 1997, Wiehn & Korpimaki 1997).

Unlike some other studies involving supplementary food, we found no evidence that feeding increased the time that young spent on territory before dispersing (Kenward *et al.* 1993, Frumkin 1994). However, in contrast to these studies, we only put food out up to a previously determined dispersal date (Redpath & Thirgood 1997). The other studies fed the young until they dispersed. Summer feeding may improve overwinter survival and subsequent returns of juveniles to Langholm to breed. But, as

stated earlier there was no evidence of this for females in 1999, though the effects on males may not be witnessed until at least two years after feeding.

Grouse chicks were seen delivered to only 4 of 14 nests where food was provided, compared to 7 of 10 nests where no food was provided. Overall, male and female harriers delivered 86% fewer grouse chicks to nests where supplementary food was available. So, providing harriers at Langholm with food clearly reduced the number of grouse chicks they caught. If all harriers had been fed at Langholm in 1998 and 1999, data suggested that only 1.6% and 4.5% of grouse chicks available at hatch would have been taken by harriers in 1998 and 1999 respectively. This compares to figures of 23% and 12.5% had none of the harriers been fed.

In both years, delivery rates of grouse chicks were low, even at unfed nests, and this reflected the scarcity of grouse on the moor. In July 1999 there were only 18 grouse chicks  $\text{km}^{-2}$ , compared to 50 grouse chicks  $\text{km}^{-2}$  in 1994. From hatching in May, harriers were estimated to have taken 7% of available grouse chicks in 1998 and 6% in 1999. This compared to up to 29% in previous years. Yet despite the reduced predation by harriers, losses of grouse chicks were higher than in previous years (63% in 1998/99 compared to 45% in 1995/96). We infer that some other factor was having a strong influence on grouse chick survival in these two years, but whether this was related to weather, food quality, parasites or other predators was unknown. The summer of 1998 was wet and cold and in 1999 there was a severe outbreak of heather beetle over Langholm moor. Also, the loss of two adult harriers and two further clutches to foxes suggested that there may have been more foxes on the moor in 1999 which may in turn have reduced grouse brood size. However, as we did not focus our studies on grouse chick survival and we have no data on changes in fox abundance we are unable to pinpoint the mechanism responsible.

In conclusion, providing harriers with food during the nestling period had a clear impact on harrier provisioning rates. Both male and female harriers reduced the rate with which they caught grouse chicks when they were provided with supplementary food. However, there was no clear improvement in grouse breeding success compared to previous years and grouse density declined over the course of the experiment.

Given the results presented here and elsewhere (Redpath & Thirgood 1997, 1999) we can predict under what conditions predation of grouse chicks by harriers will be

greatest. Predation rates are related to grouse chick density, breeding system and harrier brood size (Redpath & Thirgood 1999). Greatest predation levels are therefore likely to occur at grouse chick densities of about 60-70 chicks per km<sup>2</sup> and be highest for bigamous birds with large broods. At Langholm, supplementary feeding reduced predation levels of grouse by 86%. If this pattern holds across a range of grouse densities supplementary feeding is likely to save the greatest numbers of grouse chicks when it is carried out on areas where there are 60-70 grouse chicks per km<sup>2</sup> and when feeding is focused on bigamous birds, especially those with large broods. In addition, it may be advisable to feed during the spring, so that birds concentrate on the supplementary food during the summer period when grouse chicks are available. Finally, the results presented in this report suggest that the benefits of feeding are most likely to be apparent where considerable effort is put into controlling other predators and maximising grouse breeding success.

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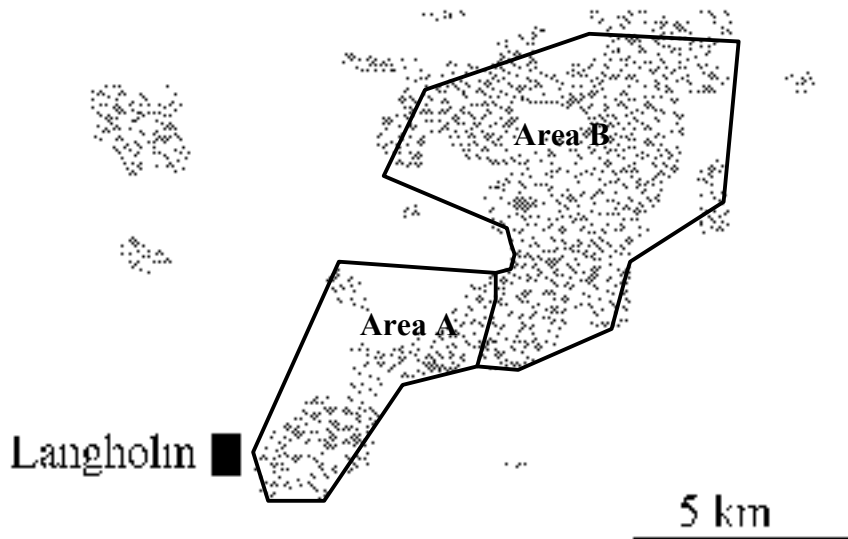
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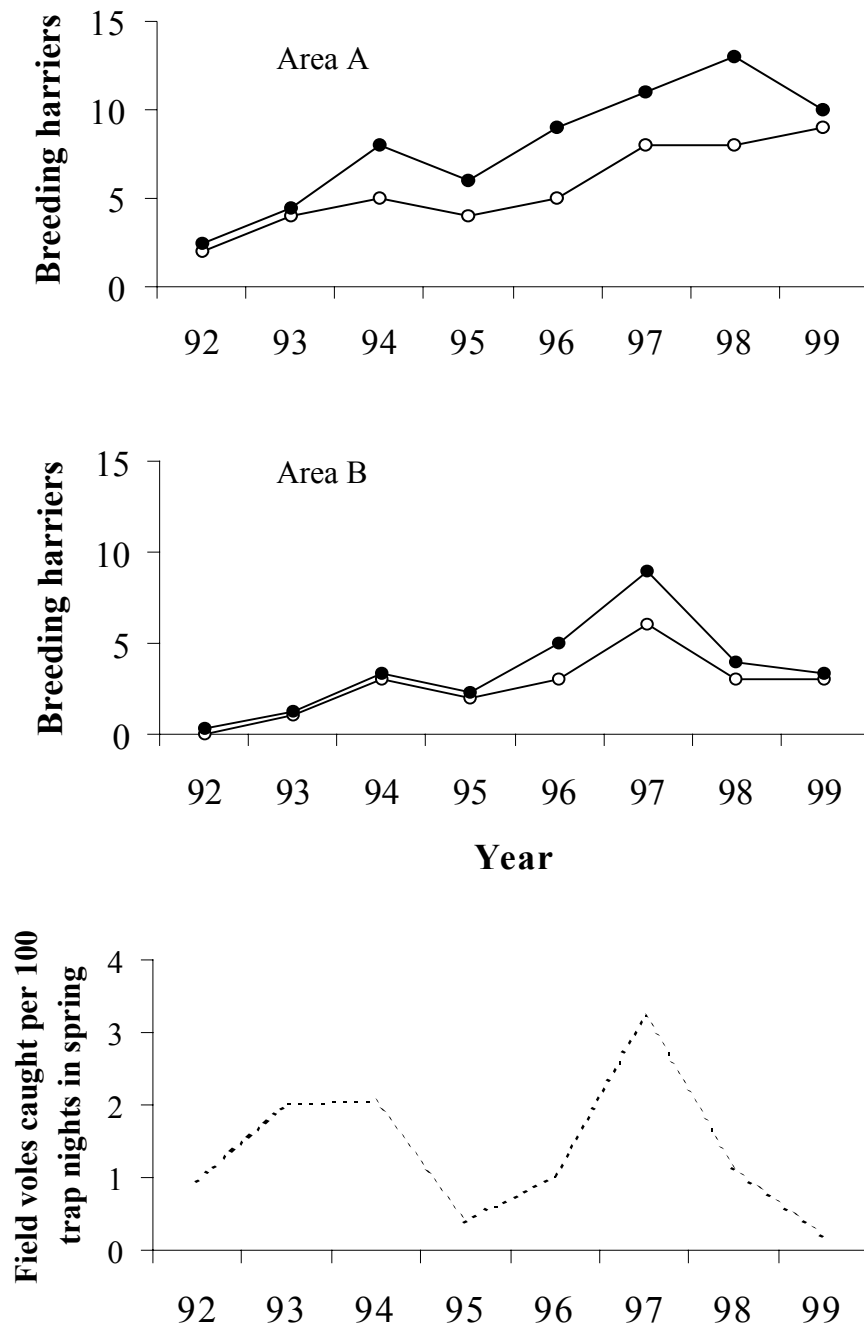
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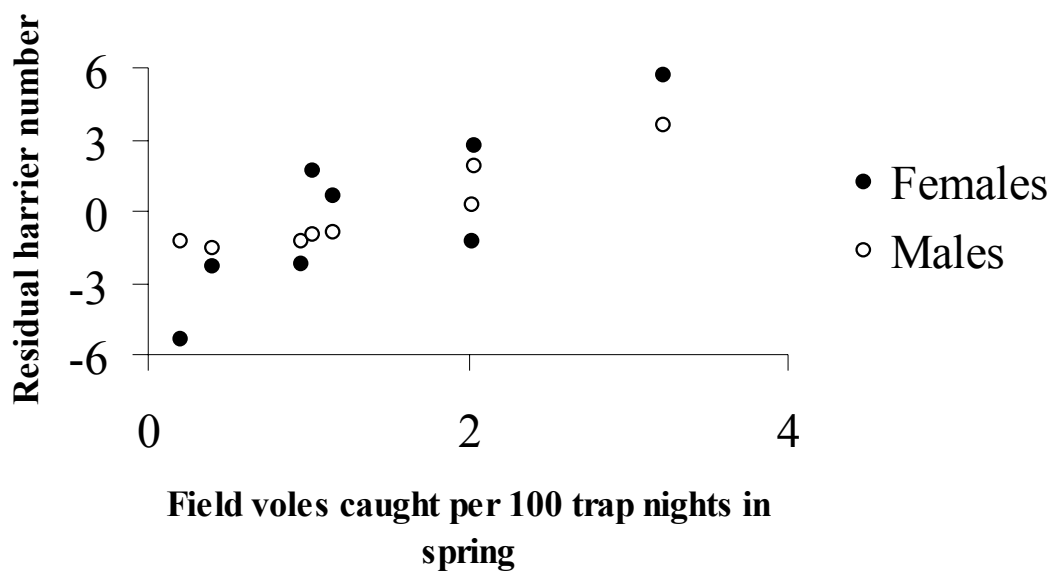
*Figure 1.* Map of Langholm moor, showing location of study areas in relation to heather cover (>30%). Harriers in Area A were fed during spring 1998, and harriers in area B fed in spring 1999. Elevation varied between the two areas, from 150m-370m on area A to 250m-570m on area B. The 2 areas encompassed all the harrier nests recorded at Langholm from 1992 to 2000.



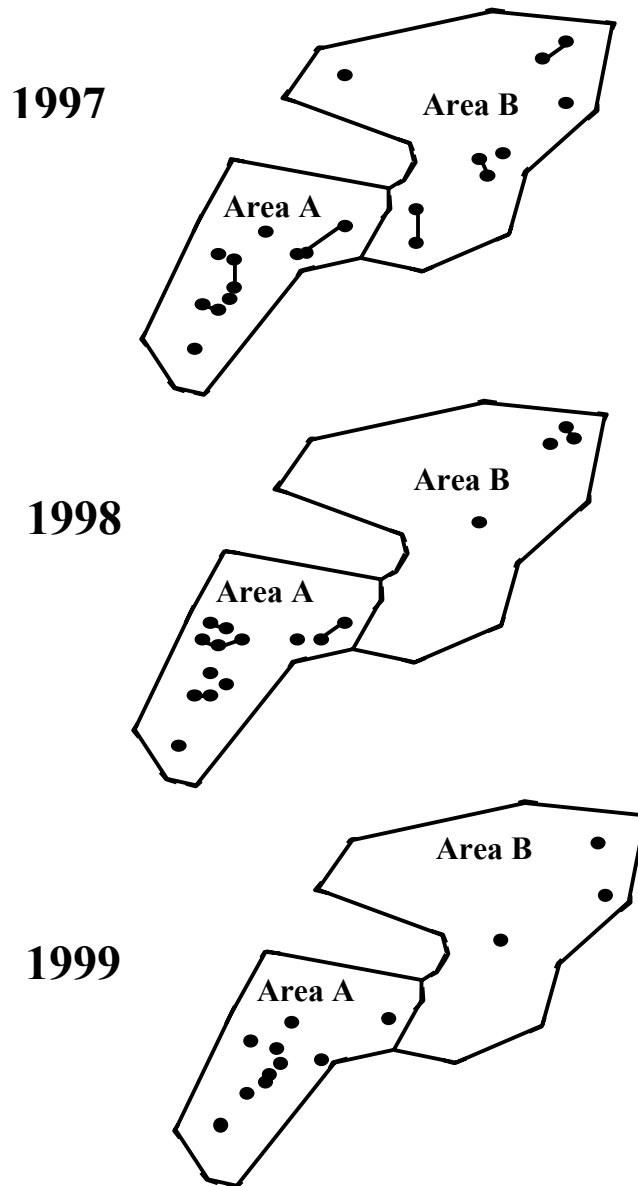
**Figure 2.** Changes in the number of female (filled circles) and male (open circles) harriers attempting to breed on areas A & B of Langholm moor from 1992 – 1999, in relation to the number of field voles caught in spring.



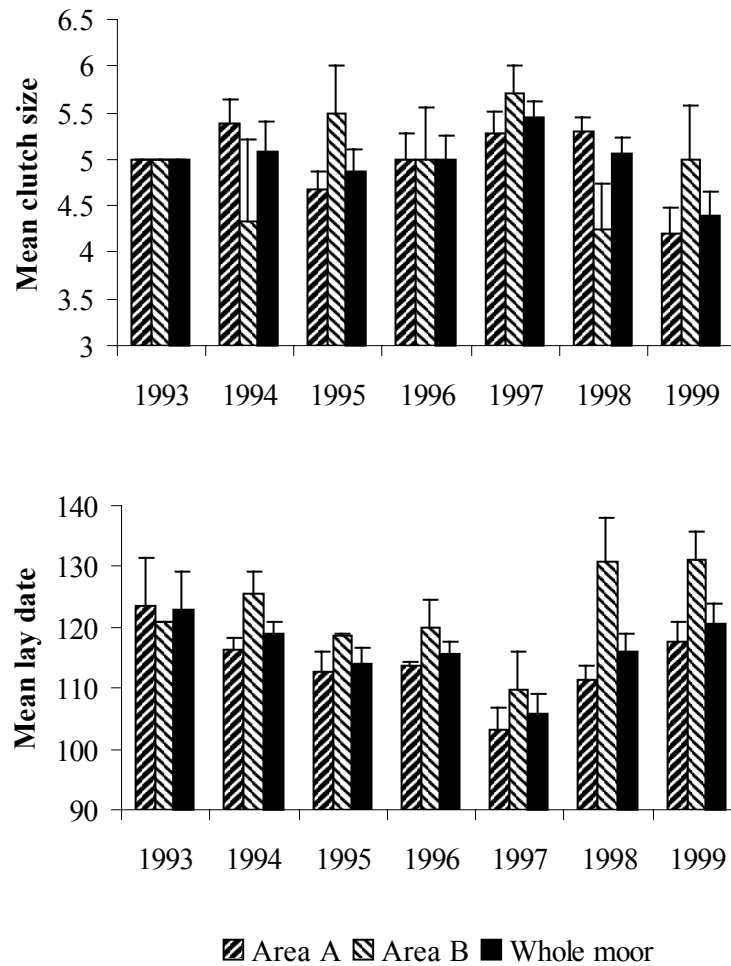
*Figure 3.* Relationship between residual harrier numbers (taken from the relationship between harrier numbers and year) and the number of field voles caught in spring. The relationships were significant for both males ( $r_s = 0.96$ ,  $P < 0.01$ ) and females ( $r_s = 0.90$ ,  $P < 0.001$ )



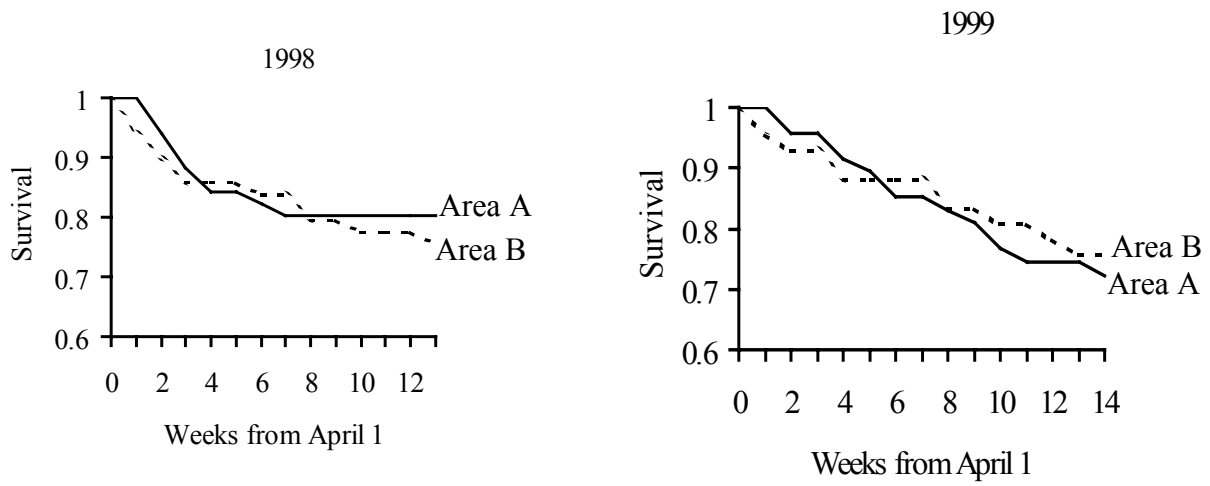
*Figure 4.* Distribution of hen harrier nests on area A and B from 1997-99. Points indicate nests and lines indicate polygynous males. No males were polygynous in 1999.



*Figure 5.* Changes in clutch size and lay date on areas A & B and whole of Langholm moor from 1993 to 1999. Data for females that failed and re-laid was taken from first clutch.

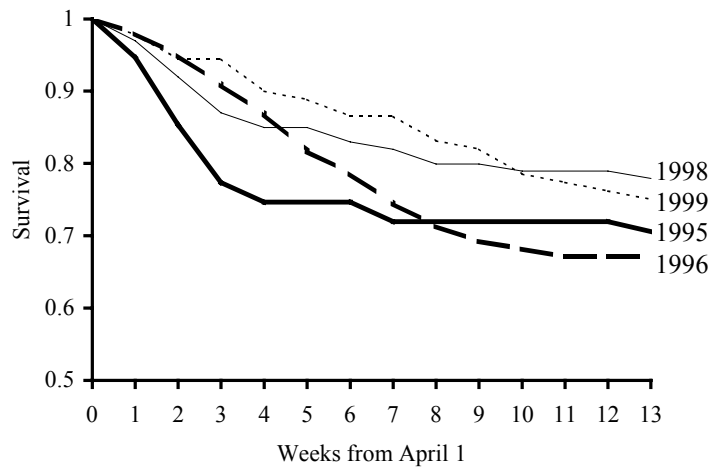


*Figure 6.* Survival rates of radio-tagged grouse on areas A (fed 1998) and B (fed 1999) over the two years of the experiment.

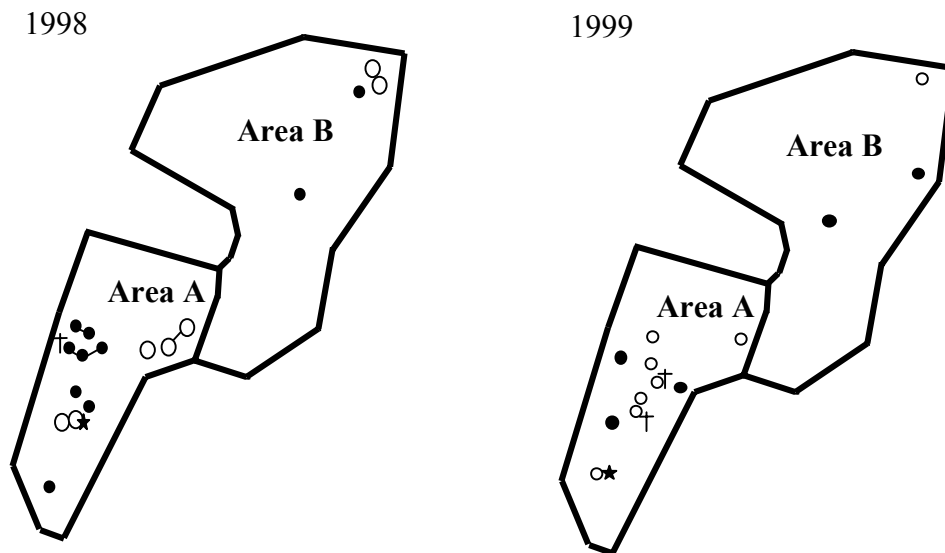




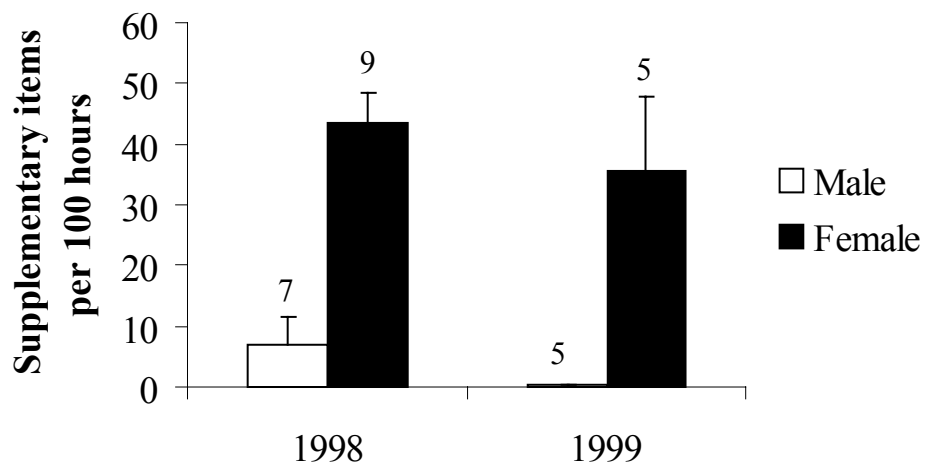
*Figure 7.* Survival rates of radio-tagged adult grouse over the two years of the experiment in comparison with two earlier years.



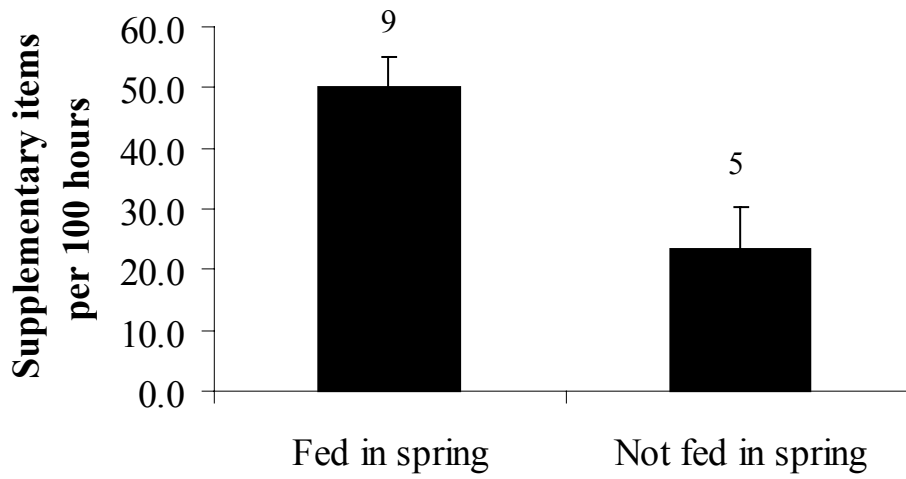
**Figure 8.** Distribution of harrier nests where food was provided (closed circles) or not provided (open circles) during the nestling stage. Crosses indicate failures during incubation that did not re-lay and stars indicate failure during early nestling stage.



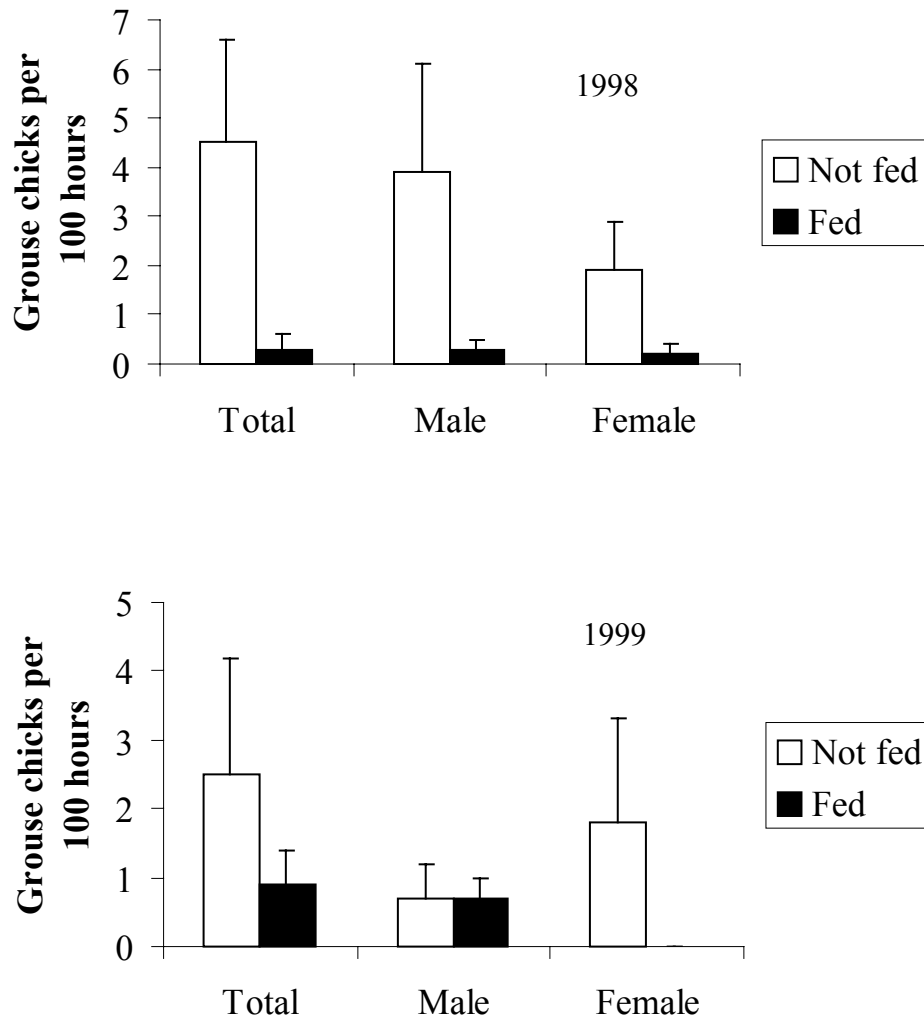
*Figure 9.* Mean provisioning rates ( $\pm$  1 s.e.) of supplementary food by male and female harriers in 1998 & 1999. Numbers indicate sample sizes. Two males took food in 1998 and these were both bigamous. There were no bigamous males in 1999.



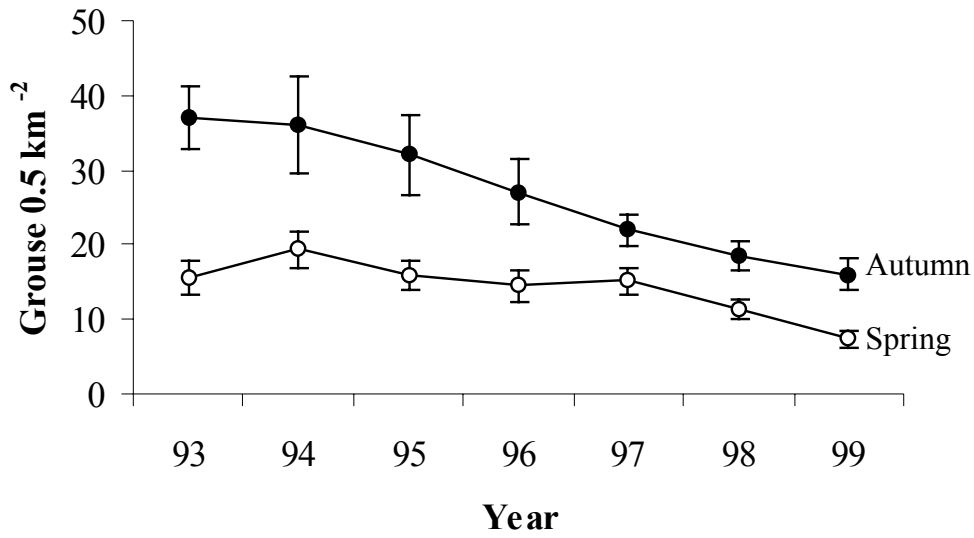
*Figure 10.* Mean rates ( $\pm$  1se.) at which females delivered supplementary food items to their nests during the nestling stage in relation to whether or not they were fed in spring. Data from both years are combined and numbers indicate sample size.



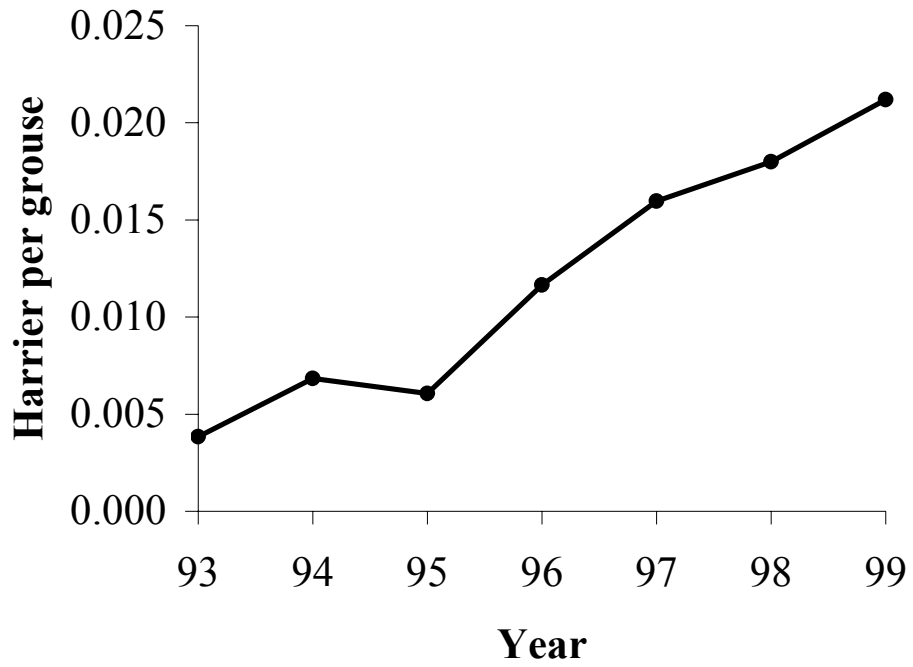
*Figure 11.* Mean rate ( $\pm$  1s.e.) at which harriers delivered grouse chicks to their young in 1998 and 1999. Data shown separately for males and females at nests with and without supplementary food.



*Figure 12.* Change in grouse density on Langholm from 1993-99. Data as means ( $\pm$  1s.e.) from ten 0.5 km<sup>2</sup> count areas within areas A&B.



*Figure 13.* Change in the ratio of breeding female harriers to adult grouse numbers in spring from 1993 to 1999 at Langholm.



**Table 1.** Summary of the number of food items put out on perches, the % removed by the next day and the number seen taken by various species. Feeding started on 25<sup>th</sup> March in 1998 and on 24<sup>th</sup> March 1999.

| <b>Week starting</b> | <b>Items put out</b> | <b>% Items removed</b> | <b>Items seen taken</b> | <b>Items to harriers</b> | <b>Items to ravens</b> | <b>Items to crows</b> | <b>Items to rooks</b> |
|----------------------|----------------------|------------------------|-------------------------|--------------------------|------------------------|-----------------------|-----------------------|
| 25/3                 | 273                  | 96%                    | 12                      | 0                        | 12                     | 0                     | 0                     |
| 1/4                  | 379                  | 81%                    | 23                      | 2                        | 19                     | 2                     | 0                     |
| 8/4                  | 425                  | 93%                    | 20                      | 10                       | 7                      | 3                     | 0                     |
| 15/4                 | 802                  | 87%                    | 6                       | 4                        | 2                      | 0                     | 0                     |
| 22/4                 | 550                  | 94%                    | 11                      | 1                        | 4                      | 0                     | 6                     |
| 29/4                 | 242                  | 100%                   | 38                      | 0                        | 10                     | 8                     | 20                    |
| 6/5                  | 90                   | 100%                   | 0                       | 0                        | 0                      | 0                     | 0                     |
| <b>1998</b>          | <b>2761</b>          | <b>91%</b>             | <b>110</b>              | <b>17 (15%)</b>          | <b>54 (49%)</b>        | <b>13(12%)</b>        | <b>26 (24%)</b>       |
| 24/3                 | 180                  | 8%                     | 0                       | 0                        | 0                      | 0                     | 0                     |
| 31/3                 | 144                  | 50%                    | 0                       | 0                        | 0                      | 0                     | 0                     |
| 7/4                  | 105                  | 40%                    | 6                       | 0                        | 6                      | 0                     | 0                     |
| 14/4                 | 105                  | 29%                    | 0                       | 0                        | 0                      | 0                     | 0                     |
| 21/4                 | 108                  | 28%                    | 0                       | 0                        | 0                      | 0                     | 0                     |
| 28/4                 | 161                  | 76%                    | 12                      | 1                        | 10                     | 1                     | 0                     |
| 5/5                  | 123                  | 50%                    | 10                      | 0                        | 5                      | 5                     | 0                     |
| 12/5                 | 99                   | 73%                    | 2                       | 2                        | 0                      | 0                     | 0                     |
| 19/5                 | 55                   | 51%                    | 2                       | 2                        | 0                      | 0                     | 0                     |
| <b>1999</b>          | <b>1080</b>          | <b>44%</b>             | <b>32</b>               | <b>5 (16%)</b>           | <b>21 (66%)</b>        | <b>6 (19%)</b>        | <b>0 (0%)</b>         |
| <b>Total</b>         | <b>3841</b>          | <b>78%</b>             | <b>142</b>              | <b>23</b>                | <b>75</b>              | <b>19</b>             | <b>26</b>             |



*Table 2.* Numbers of grouse radio-tagged in areas A & B in 1998 and 1999 and numbers killed by raptors, mammals and other causes. Number lost indicate cases where contact was lost with the birds.

|                                    | 1998   |        | 1999   |        | Totals   |
|------------------------------------|--------|--------|--------|--------|----------|
|                                    | Area A | Area B | Area A | Area B |          |
| No. radiotagged.                   | 51     | 49     | 48     | 43     | 191      |
| No. killed by 1 <sup>st</sup> June | 10     | 12     | 13     | 10     | 45 (24%) |
| No. killed by raptors              | 10     | 10     | 8      | 7      | 35 (18%) |
| No. killed by mammals              | 0      | 0      | 2      | 0      | 2 (1%)   |
| No. killed by unknown              | 0      | 2      | 3      | 3      | 8 (4%)   |
| No. lost                           | 1      | 0      | 2      | 3      | 6 (3%)   |

*Table 3.* Survival rates of radio-tagged grouse on treatment and control areas at Langholm during spring 1998 and 1999 in comparison to spring 1995 and 1996. Survival rates (S) and 95% confidence intervals (CI) calculated using the Kaplan-Meier method with staggered entry.

| Year | Area   | N   | S    | 95% CI.   |
|------|--------|-----|------|-----------|
| 1995 | Total  | 75  | 0.71 | 0.60-0.81 |
| 1996 | Total  | 99  | 0.67 | 0.58-0.77 |
| 1998 | Area A | 51  | 0.80 | 0.69-0.91 |
|      | Area B | 49  | 0.76 | 0.64-0.87 |
|      | Total  | 100 | 0.78 | 0.70-0.86 |
| 1999 | Area A | 48  | 0.72 | 0.59-0.85 |
|      | Area B | 43  | 0.76 | 0.62-0.89 |
|      | Total  | 91  | 0.75 | 0.66-0.84 |

**Table 4.** Outcome of breeding attempts by harriers on Langholm moor in 1998 & 99. Spring and summer columns indicate which nests were fed (F) or not fed (U) and mating system indicates monogamy (M) or polygyny ( $\alpha$  - primary female,  $\beta$  - secondary female or  $\gamma$  - tertiary female). Arrows indicate change in status following failure of female sharing same male. Failure indicates reason where known. Clutches in brackets indicate number of eggs in re-laid clutch.

| Nest | Year        | Spring | Summer | Mating system              | Eggs      | Hatch     | Fledge    | Failure                          |
|------|-------------|--------|--------|----------------------------|-----------|-----------|-----------|----------------------------------|
| 1    | 98          | U      | U      | $\alpha$                   | 5         | 5         | 2         |                                  |
| 2    | 98          | U      | U      | $\beta$                    | 3 (5)     | 4         | 2         | 1 <sup>st</sup> clutch to stoat? |
| 3    | 98          | U      | F      | M                          | 5         | 4         | 3         |                                  |
| 4    | 98          | U      | F      | M                          | 4         | 4         | 2         |                                  |
| 5    | 98          | F      | U      | $\alpha \rightarrow M$     | 6         | 5         | 4         |                                  |
| 6    | 98          | F      | U      | $\beta$                    | 5         | 2         |           | Starvation?                      |
| 7    | 98          | F      | U      | M                          | 5         | 5         | 4         |                                  |
| 8    | 98          | F      | U      | $\alpha$                   | 5         | 5         | 2         |                                  |
| 9    | 98          | F      | U      | $\beta$                    | 5         | 4         | 3         |                                  |
| 10   | 98          | F      | F      | M                          | 5         | 4         | 4         |                                  |
| 11   | 98          | F      | F      | M                          | 5         | 5         | 5         |                                  |
| 12   | 98          | F      | F      | M                          | 6         | 6         | 6         |                                  |
| 13   | 98          | F      | F      | $\alpha$                   | 6         |           |           | ?                                |
| 14   | 98          | F      | F      | $\beta \rightarrow \alpha$ | 6         | 5         | 3         |                                  |
| 15   | 98          | F      | F      | $\gamma \rightarrow \beta$ | 5         | 4         | 3         |                                  |
| 16   | 98          | F      | F      | $\alpha$                   | 5         | 5         | 5         |                                  |
| 17   | 98          | F      | F      | $\beta$                    | 5         | 4         | 2         |                                  |
|      | <b>1998</b> |        |        |                            | <b>88</b> | <b>71</b> | <b>50</b> |                                  |
| 18   | 99          | U      | U      | M                          | 4         | 4         |           | Fox                              |
| 19   | 99          | U      | U      | M                          | 2         |           |           | Fox                              |
| 20   | 99          | U      | U      | M                          | 4         |           |           | Fox                              |
| 21   | 99          | U      | U      | M                          | 4         | 3         | 3         |                                  |
| 22   | 99          | U      | U      | M                          | 5         | 5         | 4         |                                  |
| 23   | 99          | U      | U      | M                          | 5         | 2         | 2         |                                  |
| 24   | 99          | U      | U      | M                          | 5         | 4         | 4         |                                  |
| 25   | 99          | U      | F      | M                          | 4         | 3         | 2         |                                  |
| 26   | 99          | U      | F      | M                          | 4 (5)     | 4         | 4         | 1 <sup>st</sup> clutch to fox    |
| 27   | 99          | U      | F      | M                          | 5         | 4         | 2         |                                  |
| 28   | 99          | F      | U      | M                          | 4         | 2         | 1         |                                  |
| 29   | 99          | F      | F      | M                          | 5         | 3         | 2         |                                  |
| 30   | 99          | F      | F      | M                          | 6         | 5         | 4         |                                  |
|      | <b>1999</b> |        |        |                            | <b>58</b> | <b>39</b> | <b>28</b> |                                  |

**Table 5.** Number of prey seen delivered to 24 harrier nests at Langholm in 1998-99 in relation to spring and summer feeding (F = fed, U = unfed). Hours indicates the number of hours spent watching each nest in first five weeks after hatching. Total indicates number of all prey brought to the nest, natural is the number of wild prey and supplementary the number of rats and poultry chicks. The number of grouse delivered is shown for male, female and unknown.

| Year | Spring | Summer | Hours       | Total       | Natural    | Supple-<br>mentary | Grouse<br>total | - Grouse<br>male | - Grouse<br>female | - Grouse<br>unknown |
|------|--------|--------|-------------|-------------|------------|--------------------|-----------------|------------------|--------------------|---------------------|
| 98   | U      | U      | 64.58       | 37          | 37         | 0                  | 1               | 1                | 0                  | 0                   |
| 98   | U      | U      | 71.67       | 59          | 59         | 0                  | 3               | 1                | 2                  | 0                   |
| 98   | U      | F      | 58.5        | 42          | 30         | 12                 | 0               | 0                | 0                  | 0                   |
| 98   | U      | F      | 70.48       | 63          | 36         | 27                 | 0               | 0                | 0                  | 0                   |
| 98   | F      | U      | 82.09       | 90          | 90         | 0                  | 0               | 0                | 0                  | 0                   |
| 98   | F      | U      | 77.67       | 40          | 40         | 0                  | 11              | 6                | 5                  | 0                   |
| 98   | F      | U      | 82.95       | 97          | 97         | 0                  | 4               | 2                | 2                  | 0                   |
| 98   | F      | U      | 78.34       | 70          | 70         | 0                  | 2               | 2                | 0                  | 0                   |
| 98   | F      | F      | 70.35       | 78          | 22         | 56                 | 2               | 1                | 1                  | 0                   |
| 98   | F      | F      | 57.43       | 36          | 1          | 35                 | 0               | 0                | 0                  | 0                   |
| 98   | F      | F      | 53.91       | 54          | 26         | 28                 | 0               | 0                | 0                  | 0                   |
| 98   | F      | F      | 59.5        | 44          | 27         | 17                 | 0               | 0                | 0                  | 0                   |
| 98   | F      | F      | 95.33       | 117         | 81         | 36                 | 0               | 0                | 0                  | 0                   |
| 98   | F      | F      | 63.99       | 69          | 32         | 37                 | 0               | 0                | 0                  | 0                   |
| 98   | F      | F      | 86.77       | 129         | 71         | 58                 | 0               | 0                | 0                  | 0                   |
|      |        |        | <b>1074</b> | <b>1025</b> | <b>719</b> | <b>306</b>         | <b>23</b>       | <b>13</b>        | <b>10</b>          | <b>0</b>            |
| 99   | U      | U      | 78.41       | 39          | 39         | 0                  | 0               | 0                | 0                  | 0                   |
| 99   | U      | U      | 113.66      | 97          | 97         | 0                  | 8               | 1                | 7                  | 0                   |
| 99   | U      | U      | 101.58      | 112         | 112        | 0                  | 3               | 2                | 1                  | 0                   |
| 99   | U      | F      | 112.84      | 82          | 68         | 14                 | 0               | 0                | 0                  | 0                   |
| 99   | U      | F      | 125.25      | 106         | 53         | 53                 | 1               | 1                | 0                  | 0                   |
| 99   | U      | F      | 112.09      | 142         | 137        | 5                  | 3               | 2                | 0                  | 1                   |
| 99   | F      | U      | 77.84       | 47          | 47         | 0                  | 0               | 0                | 0                  | 0                   |
| 99   | F      | F      | 95.5        | 96          | 26         | 70                 | 1               | 1                | 0                  | 0                   |
| 99   | F      | F      | 101.58      | 94          | 46         | 48                 | 0               | 0                | 0                  | 0                   |
|      |        |        | <b>919</b>  | <b>815</b>  | <b>625</b> | <b>190</b>         | <b>16</b>       | <b>7</b>         | <b>8</b>           | <b>1</b>            |

**Table 6.** Outputs from generalised linear model, explaining variation in the delivery rate of grouse chicks by male, female and both harrier sexes combined. In the initial model, the effects of year, area and spring feeding are controlled for. In the final model a process of backwards elimination removed the least significant terms until only the significant terms remained.

| INITIAL        | Male harriers |          |              | Female harriers |          |                  | Male & female harriers |          |              |
|----------------|---------------|----------|--------------|-----------------|----------|------------------|------------------------|----------|--------------|
|                | d.f.          | $\chi^2$ | P            | d.f.            | $\chi^2$ | P                | d.f.                   | $\chi^2$ | P            |
| Year           | 15            | 0.58     | 0.45         | 19              | 0.89     | 0.34             | 19                     | 0.24     | 0.62         |
| Area           | 15            | 0.62     | 0.43         | 19              | 3.13     | 0.08             | 19                     | 2.37     | 0.12         |
| Spring feeding | 15            | 0.01     | 0.92         | 19              | 1.27     | 0.26             | 19                     | 0.29     | 0.59         |
| Summer feeding | 15            | 4.85     | <b>0.028</b> | 19              | 13.98    | <b>&lt;0.001</b> | 19                     | 9.94     | <b>0.002</b> |
| FINAL          | d.f.          | $\chi^2$ | P            | d.f.            | $\chi^2$ | P                | d.f.                   | $\chi^2$ | P            |
| Summer feeding | 18            | 5.40     | <b>0.020</b> | 22              | 14.65    | <b>&lt;0.001</b> | 22                     | 10.68    | <b>0.001</b> |

*Table 7.* Numbers of grouse chicks taken by harriers on Langholm moor from hatch to dispersal in 1998 and 1999. Figures are given per fed and unfed nest and based on these estimates are given of the number of grouse chicks that would have been removed had none or all the harriers been fed.

|  | 1998  | 1999  |
|--|-------|-------|
| Harrier nests  | 15    | 10    |
| Number of fed nests                                    | 9     | 5     |
| Grouse chicks delivered per fed harrier nest           | 2.9   | 8.1   |
| Grouse chicks delivered per unfed harrier nest         | 40.3  | 22.5  |
| Grouse chicks delivered had all harrier nests been fed | 43.2  | 81.0  |
| Grouse chicks delivered had no harrier nests been fed  | 604.8 | 225.0 |

**Table 8.** Comparison of grouse chick density  $0.5\text{km}^{-2}$  after hatch (late May) and in mid July in relation to number of harrier nests (successful nests) and numbers of grouse chicks estimated to have been taken by harriers. Two periods are compared where similar data were collected: 1995/96 when no feeding of harriers occurred and 1998/99 when some harriers were provided with food.

| Year | May<br>chicks<br>$0.5\text{km}^{-2}$ | June<br>chicks<br>$0.5\text{km}^{-2}$ | July<br>chicks<br>$0.5\text{km}^{-2}$ | Difference<br>May-July<br>$0.5\text{km}^{-2}$ (%) | Difference<br>June-July<br>$0.5\text{km}^{-2}$ (%) | Successful<br>harrier<br>nests | Taken by<br>harriers<br>$0.5\text{km}^{-2}$ |
|------|--------------------------------------|---------------------------------------|---------------------------------------|---|--|--------------------------------|---|
| 1995 | 39.1                                 | 30.7                                  | $22.4 \pm 3.5$                        | 16.7 (43%)  | 8.3 (27%)  | 8 (8)                          | 11.2 (29%)                                  |
| 1996 | 35.7                                 | 24.8                                  | $18.8 \pm 2.5$                        | 16.9 (47%)  | 6.0 (24%)  | 14 (12)                        | 9.7 (27%)                                   |
| 1998 | 31.7                                 | 16.6                                  | $10.0 \pm 1.3$                        | 21.7 (68%)  | 6.6 (40%)  | 17 (15)                        | 2.2 (7%)                                    |
| 1999 | 21.7                                 | 13.0                                  | $9.0 \pm 1.5$                         | 12.7 (58%)  | 4.0 (31%)  | 13 (10)                        | 1.3 (6%)                                    |

*Table 9.* Estimated dispersal dates for harrier broods at Langholm in 1998 and 1999, relative to treatment (fed or not fed) and compared to data from previous years.

| Brood    | Year    | Treatment | Age at dispersal (days)        |
|----------|---------|-----------|--------------------------------|
| 1        | 1998    | Fed       | 61                             |
| 2        | 1998    | Fed       | 62                             |
| 3        | 1998    | Fed       | 62                             |
| 4        | 1998    | Not fed   | 64                             |
| 5        | 1999    | Fed       | 63                             |
| 6        | 1999    | Fed       | 64                             |
| 7        | 1999    | Fed       | 59                             |
| 8        | 1999    | Not fed   | 58                             |
| 9        | 1999    | Not fed   | 66                             |
| 10       | 1999    | Not fed   | 50                             |
| 8 broods | 1994-96 | Not fed   | Median = 60<br>(range 58 - 64) |



*Table 10.* A rough guide to the financial cost of feeding all breeding harriers at Langholm in 1998 & 1999.

| <b>Cost</b>                   | <b>1998</b>        | <b>1999</b>          | <b>Years combined</b> |
|-------------------------------|--------------------|----------------------|-----------------------|
| <b>Food</b>                   | £637 - £1912       | £399 - £1198         | £1036 - £3110         |
| <b>Transport</b>              | £875               | £3500                | £4375                 |
| <b>Miscellaneous</b>          | £540               | £40                  | £580                  |
| <b>Wages</b>                  | £7500              | £7500                | £15,000               |
| <b>Total</b>                  | £9552 - £10827     | £11439 - £12238      | £20991 - £23065       |
| <b>Total per Harrier nest</b> | <b>£637 - £722</b> | <b>£1143 - £1224</b> | <b>£840 - £923</b>    |