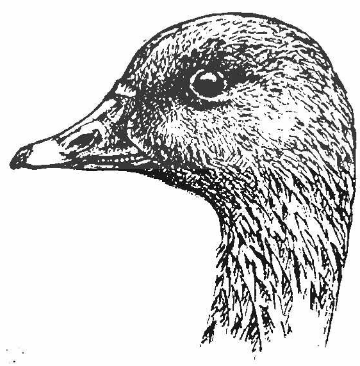
Daily movements and habitat use by radio-tagged Pink-footed Geese *Anser brachyrhynchus* wintering in northeast Scotland



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Daily movements and habitat use by ten radio-marked Pink-footed Geese were studied in northeast Scotland during winter and spring. The time spent by geese away from the roost during a day increased throughout the study, whereas the proportion of time allocated to feeding decreased from 75% in winter to 54% in spring. Pink-footed Geese spent most of their time on grasslands and cereal stubble and made little use of winter cereals. The attractiveness of cereal stubble was indicated by the larger distance travelled by geese to reach this crop, by the larger flock size observed in this habitat and by the tendency of the birds to return to stubble following a disturbance. On a daily basis, each goose concentrated its activities in 1 km² located predominantly within 5 km of a roost. Individual birds had overlapping seasonal ranges of 50 km² totalling more than 100 km² for the ten birds. Repeated use of some sites by the marked birds indicated the presence of activity centres and fidelity to specific areas. Considering the ranging behaviour of Pink-footed Geese, creation of small management units of 1 km² each, scattered within a 100 km² area centred on the roosts, could be a better approach to reduce goose damage than the establishment of a single large reserve. The land within these units could be incorporated into a set-aside scheme by which farmers would be compensated to retain stubble cereal fields and to improve grasslands.

Key words: Scotland, Wintering, Agriculture, Feeding, Home Range, Pink-footed Goose

The number of Pink-footed Geese *Anser brachyrhynchus* breeding in Iceland and Greenland has increased considerably from approximately 70,000 in 1970 to more than 230,000 in 1991 (Fox *et al.* 1989, Cranswick 1993). These birds winter in Britain where they feed almost exclusively on agricultural lands (Newton & Campbell 1973, Bell 1988, Patterson *et al.* 1989). Although the effects of goose grazing on crops are quite variable, significant yield losses have been measured in several studies (Patterson 1991a, Teunissen 1992). Considering that the size of most goose populations is greater now than ever previously recorded (Madsen 1991), concerns have been expressed both by farmers and managers responsible for these populations (Owen & Pienkowski 1991, van Roomen & Madsen 1992). The conflict between agriculture and waterfowl will most likely be exacerbated in the future because numbers of several goose species are still increasing (Madsen 1991) and because farmers currently face increasing economic pressures (Teunissen 1992).

Because goose damage is usually a local rather than a widespread problem (Patterson *et al.* 1989, Owen 1990), solutions to prevent or at least alleviate it should be based on local management measures. Most managers and researchers agree that a promising approach is to select and designate a number of areas where geese are tolerated and/or attracted (Owen 1990, Patterson & Fuchs 1992, van der Sar 1992, van Paassen 1992). In order to structure detailed management plans based on these recommendations, it is imperative to establish whether some feeding areas are preferred and used consistently by geese throughout the winter (Patterson & Fuchs 1992). It is also important to quantify the daily and seasonal ranges of the birds and to determine factors that influence movements of geese on the feeding grounds.

The general objective of our study was, therefore, to characterise daily movements and seasonal activity ranges of individually-marked Pink-footed Geese. More specifically, we assessed whether some crop types were used to a greater extent than their availability and determined the effects of various causes of disturbance, including scaring, on the ranging behaviour of the geese.

Study area

The study area was located in northeast Scotland around Newburgh, Grampian, and covered 340 km^2 (**Figure 1**). Agricultural lands dominate this coastal landscape and include grasslands characterised by Ryegrass *Lolium perenne* used for grazing, silage and hay production, as well as Barley *Hordeum* sp. and Wheat *Triticum aestivum* crops sown in autumn and spring (Patterson *et al.* 1989).

The overwintering population of Pink-footed Geese averaged 6,000–8,000 during the study, with peaks of 12,000–14,000 during the autumn and spring migrations. In addition, approximately 2,000 Greylag Geese *Anser anser* wintered in the area. Geese roosted on Meikle Loch (26 ha), on a semi-permanent floodwater pool near Knapsleask (4 ha) and on a portion of the 185 ha Ythan estuary (**Figure 1**). The inland

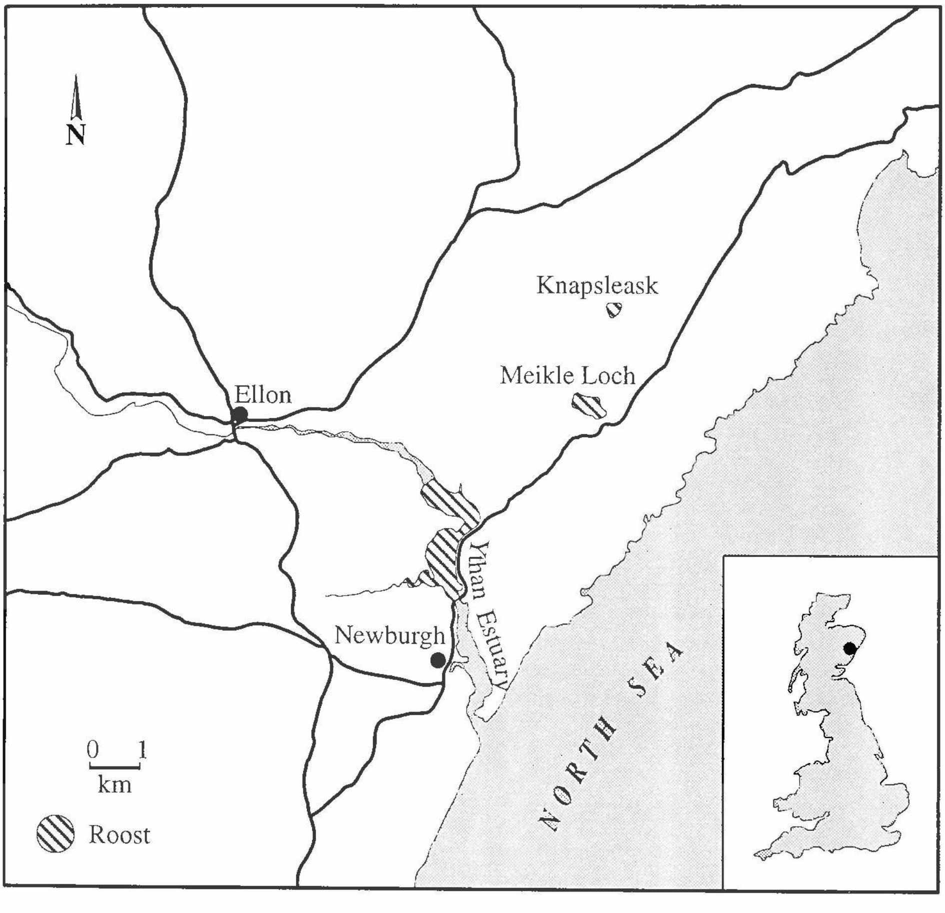

Figure 1. Location of the roosts used by wintering Pink-footed Geese in the Grampian area, northeast Scotland.

roosts were used throughout the winter, whereas the estuary began to be used only after the hunting season closed (Giroux 1991). The open season extends from 1 September to 31 January around the lochs and in the fields and from 1 September to 20 February along the estuary.

Methods

Capture and marking of geese

Three geese were captured and marked during the winter 1986-87 and eight during the following winter as a result of nine catching attempts. Captures were made after the peak of the autumn migration in order to mark birds that would remain in the area throughout the winter. Except for one bird captured in a field near the Ythan estuary, all geese were caught along the shore of the two inland roosts just before their morning departure. Geese were caught with a clap net and fitted with a 10 g radio transmitter mounted on the tail (Giroux *et al.* 1990), two coloured plastic rings and one British Trust for Ornithology metal ring. Picric acid was applied on the white feathers under the tail and abdomen to aid visual detection in flocks. The geese were released at night at their respective roosts, together with any other birds caught at the same time. Signals could be detected at up to 1–3 km.

Tracking of geese

Habitat use and movements of geese were established by daily tracking. A marked bird was randomly selected among the two to four birds present on any given day and continuously followed by car from its departure from the roost in the morning to its return at dusk. Each site where the radio-tagged geese landed was noted using the coordinate system of the 1:25,000 Ordnance Survey maps and categorised into one habitat type. When possible, the marked birds were located visually, otherwise the birds were considered to be in the portion of the flock where the strongest signal came from. Each time the tracked goose took off, as determined visually or by changes in signal strength, the cause of the flush was noted. If the bird took off while the majority of its neighbours remained in the field, it was considered to have left on its own, whereas the cause was attributed to a disturbance when the entire flock took off suddenly. A move was recorded if a bird flew more than 100 m from its previous location.

Every 30 minutes, the size of the flock in which the marked bird was found as well as the proportion of time spent feeding by the geese were recorded. This was based on the proportion of birds feeding when scanning up to a maximum of 200 geese throughout the flock (Altmann 1974). Finally, regular observations of the marked birds were conducted to obtain additional data on daily locations and causes of flushes.

Habitat survey

A random sample of 18 blocks, each of 1 km^2, was inspected in January and late March 1988 to determine the relative importance of each habitat type. The area covered by each type was plotted on 1:10,000 Ordnance Survey maps and then measured with a planimeter. Fields covered by winter cereals, including additional ones used by the marked geese, were verified again in June when precise identification of the crops was easier. Spring cereals undersown with grass were classified as stubble up to January and grass thereafter.

Statistical analyses

For most analyses, data were separated into two periods corresponding to the hunting season along the estuary (before 20 February) and thereafter. When sample size was sufficient, a third period (9–27 April) was considered, to take into account the spring period.

The area covered by each crop type and their use by the radio-tagged geese were compared between the two periods of the winter 1987–88 with Mann-Whitney tests. The Friedman method was employed to test whether the geese consistently used some habitats more or less than their availability (Alldredge & Ratti 1991). The Fisher's least significance difference procedure was subsequently used to determine which habitats differed in terms of use versus availability (Conover 1980).

The following characteristics were determined for each day of continuous tracking: the total distance travelled by the marked goose calculated by summing each move including those from and to the roost, the maximum straight-line distance between the morning roost and the most distant location, the total number of moves on the feeding grounds, the average distance per move and finally the major diurnal activity range (MDAR, *sensu* Bray *et al.* 1975), calculated by connecting the outermost locations (n≥3) recorded on the feeding grounds.

Fidelity to seasonal ranges during and after the hunting period was assessed for each goose by comparing their mean location with MANOVA and the Wilks' Lambda criterion (White & Garrott 1990). Seasonal activity ranges were estimated for birds with ≥30 days of loca-

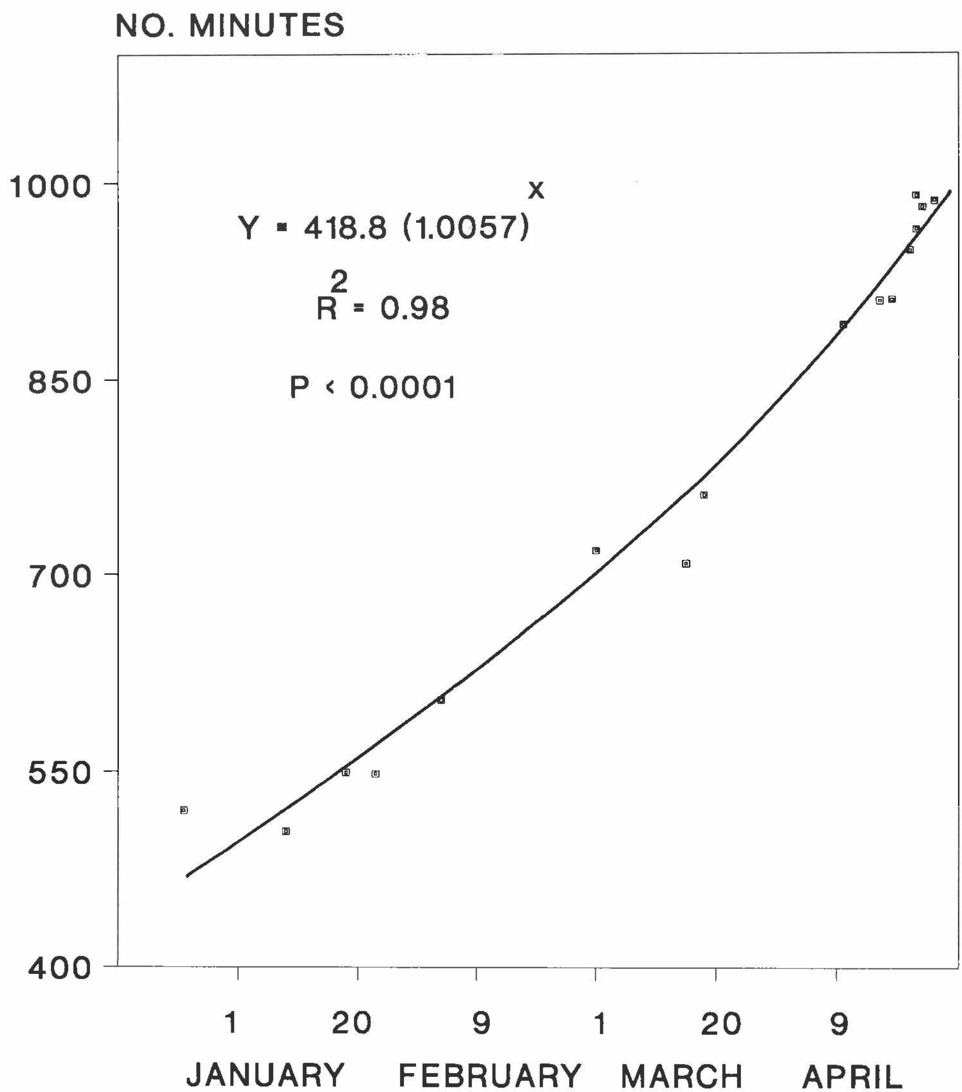

Figure 2. Amount of time per day spent by radio-marked Pink-footed Geese away from the roost (Y) in relation to date (X) in northeast Scotland, 1987–88. The date is calculated from December 1 as day 1.

Table 1. Time in the fields, percentage of time spent feeding and time spent feeding each day by wintering Pink-footed Geese on grasslands in northeast Scotland, 1988.

Period (n)[1]	Time in the fields (min)[2]	% of time feeding[3]	Time feeding (min)
6 Jan – 29 Feb (9)	616±21A[4]	75±3A	462±24A
1 March – 8 April (13)	811±13B	72±2A	586±17B
9 – 27 April (8)	931±10C	54±3B	499±19A

1 Number of days with daily tracking.
2 Estimated from equation in **Figure 2**.
3 Established for the flocks in which the marked geese were found.
4 Means followed by different letters within a column are significantly different (Student-Newman-Keuls tests, $P<0.05$).

tions using Dixon & Chapman's (1980) harmonic mean. A 90% isopleth was computed with the McPAAL software package (Stüwe & Blohowiak 1985) based on a 25 cells grid. For birds with several locations per day, one was randomly chosen to ensure independence of the data. Tests for a bivariate uniform distribution of locations were performed for each goose using the Cramér-von-Mises W^2 statistic (Samuel & Garton 1985).

The significance level for all tests was established at 0.05, except for the goodness-of-fit test of the uniform distribution for which 0.1 was used, as recommended by Samuel & Garton (1985) for small sample sizes. Throughout the text, means are presented ±1 SE.

Results

Goose tracking

Ten geese were tracked for periods of 6-128 days ($\bar{x}$=58±13) and one provided no radio signal. The tracked birds included one adult male and one adult female with their respective families, one paired adult female, four unpaired adult-plumage males, two single juvenile females and one adult-plumage male for which the social status could not be established. Continuous daily tracking was conducted on 47 days resulting in 461 locations and 498 hours of observation. Additional tracking yielded 412 locations and 275 hours of observation. The radio-marked geese were located visually on 32.6% of the 873 observations.

Time spent in feeding areas

The time spent by Pink-footed Geese away from the roost during a day increased logarithmically throughout the winter and spring (**Figure 2**). Geese spent twice as much time in the fields in mid-April (16.5 h) than in early January (8.5 h). On the other hand, the proportion of time spent feeding decreased significantly from 75% in winter to 54% in spring (**Table 1**). Only birds using grasslands for at least 60% of the day were considered in this analysis to overcome the confounding effect of crop types. Combining these data, we calculated that the actual amount of time spent feeding per day was 15–20% lower in January/February and in April than in March (**Table 1**).

Habitat use

A total of 93.6±1.2% of the area was covered by agricultural land, rough pastures and wet meadows while the rest included woods, waterbodies, roads and farm buildings. Grass was the main crop type in the area, followed by winter cereals, stubble and ploughed fields (**Table 2**). Winter wheat covered twice as much area as winter barley. The only significant change during the winter was a decrease of cereal stubble (Z=3.494, n=36, P=0.001) and a concomitant increase of ploughed fields (Z=-3.402, n=36, P=0.001). The second survey was conducted just before sowing of cereals in mid-April.

During the first part of the winter, Pink-footed Geese spent most of their time on grasslands, cereal stubble and potatoes (**Table 2**). Thereafter, they increased their use of grasslands (Z=-1.965, n=46, P=0.05), winter barley (Z=-2.350, n=46, P=0.052) and wet meadows (Z=-2.030, n=46, P=0.04) and spent less time on winter wheat (Z=2.393, n=46, P=0.02), cereal stubble (Z=3.727, n=46, P=0.01) and potatoes (Z=1.99, n=46, P=0.05). Ploughed

Table 2. Habitat availability and use by wintering Pink-footed Geese at two periods in northeast Scotland, 1988.

	Period 1		Period 2	
Crop	Use[1]	Availability[2]	Use	Availability
Grasslands	62.3±8.2[3]	41.3±4.0	83.9±4.9	41.6±3.6
Winter wheat	4.7±2.2	12.8±4.5	0.7±0.6	12.8±4.5
Winter barley	1.9±1.6	5.9±1.6	11.7±4.8	5.9±1.6
Ploughed fields	2.3±2.2	10.5±3.1	0.2±0.1	27.1±3.5
Cereal stubbles	20.5±6.9	16.9±3.9	0	1.4±0.7
Oilseed rape	0	6.9±2.9	0	6.9±2.9
Rough grass/wet meadows	0	3.1±0.9	2.0±0.9	3.1±0.9
Potatoes/Turnips	8.3±4.7	2.6±0.9	0	1.3±0.6
Sown cereals	0	0	1.5±1.2	–[4]

1 Use was established by tracking geese for 20 days during Period 1 (5 January – 20 February) and 26 days during Period 2 (21 February – 27 April).
2 The same 18 1-km² blocks were surveyed at each period.
3 Data are mean percentages. ±1 SE.
4 Not measured.

Table 3. Flock size of wintering Pink-footed Geese on different crops in northeast Scotland, 1987–88.

Period	Grasslands	Stubbles and potatoes	Winter and sown cerals
21 Dec – 29 Feb	3322±185 (244)Aa[1]	4363±254 (120)b	2031±200 (29)Ac
1 March – 8 April	1238±69 (333)Ba	–	822±159 (43)Bb
9 – 27 April	1106±62 (234)Ba	–	1046±60 (69)Ba

1 Data are means ±1 SE (*n*). Means followed by different capital letters within each column are significantly different among the three periods whereas means followed by different lower case letters within each row are significantly different among crop types (Student-Newman-Keuls tests, $P<0.05$).

fields were used occasionally, whereas Oil-seed Rape *Brassica napus oleifera* was not used during the daily tracking. In the only instance when a marked goose landed in an Oil-seed Rape field with 500 geese it stayed there for only a few minutes.

No habitat selection was detected during the first period (T_2=1.755, *df*=7&21, $P<0.05$), each crop being used according to its availability. During the second period, however, geese selected grassland and winter barley to a greater extent than the other crops (T_2=12.143, *df*=7&35, P<0.001).

On a daily basis, the radio-tagged geese visited a maximum of four different crop types (x=1.9±0.1, n=47). When they visited more than one crop, they spent 73.5±3.2% of the time on the most used crop (n=27).

The marked geese occurred in much larger flocks on stubble and potato fields than on any other crop types (**Table 3**). They were also in larger flocks on grasslands than on winter and sown cereals except in spring. Flock sizes on grasslands and winter cereals were significantly larger before 29 February (**Table 3**).

Geese spent less time feeding when they were on winter and sown cereals (40±2%, n=122) than on stubble and potato fields (59±2%, n=87) and more when they were on grasslands (67±1%, n=704), the differences being significant ($F_{2,910}$=87.24, $P<0.001$).

Daily movements

The marked geese took off 402 times during 445 h of daily tracking, an overall rate of 0.9 take-offs/h. The amount of time spent on a field in a continuous bout before flushing did not vary among crops and averaged 66±4 min (**Table 4**). Overall, the birds took off 42% of the time on their own and 58% following a disturbance (n=402). A greater proportion of take-offs resulted from distur-

Table 4. Time of residence (min) of wintering Pink-footed Geese on different crops before flushing and moving, proportion of flushes attributed to disturbances, proportion resulting in a move and mean distance moved (km) in northeast Scotland, 1987–88.

Crop	Time before flushing	% due to disturbances	% resulting in a move	Time before moving	Distance moved
Grasslands (300,254)[1]	70±4A[2]	55A	85A	75±5A	1.0±0.1A
Stubbles and potatoes (44,30)	55±6A	82B	68B	72±12A	1.0±0.3A
Winter and sown cereals (58,51)	55±13A	57A	88A	62±15A	1.3±0.3A
Overall (402,335)	66±4	58	83	73±4	1.0±0.1

[1] Number of flushes and moves, respectively.
[2] Means and percentages followed by different letters within each column are significantly different (Student-Newman-Keuls and chi-square tests, $P<0.05$).

Table 5. Types of disturbance (%) causing wintering Pink-footed Geese to take off from different crops in northeast Scotland, 1987–88.

Disturbance	Grasslands (n=255)	Stubbles and potatoes (n=46)	Winter and sown cereals (n=53)	Total (n=354)
Unidentified	36	28	32	34
Farming activities	13	28	11	15
Scaring	11	7	19	12
Motorised vehicles	8	24	8	10
Observer	11	4	13	10
Hunters and hikers	10	7	9	9
Helicopters	9	2	0	7
Animals	2	0	8	3

bances on stubble and potato fields than on grasslands or winter cereals (**Table 4** X^2=11.641, df=2, P=0.003).

The relative importance of various types of disturbances causing Pink-footed Geese to take off varied among crops (**Table 5**, X^2=20.439, df=10, P=0.025). Motorised vehicles and helicopters were pooled for statistical analyses as well as hunters, hikers and animals. The major differences were the greater importance of farming activities (heavy machinery) and motorised vehicles on stubble and potato fields and scaring on winter and sown cereals. Geese were chased on foot or aboard vehicles with or without shooting a firearm. In 10% of the cases, geese flushed as a result of the observer's approach by car. Animals that put the geese to flight included Grey Herons *Ardea cinerea*, Foxes *Vulpes vulpes* and Brown Hares *Lepus europaeus*. Finally, the marked birds took off with the rest of the flock without any apparent cause of disturbance in one third of the cases (**Table 5**).

When geese took off, they moved more than 100 m in 83% of the cases and landed at the same place the rest of the time (n=402). There was a significant difference in the proportion of take-offs resulting in a movement, depending on crop types (**Table 4** X^2=8.539, df=2, P=0.014). When geese flushed from stubble and potato fields, they moved approximately 20% less often than on other crops. Residence time before moving averaged 73±4 min and did not vary among crop types, nor did the distance moved after taking off, which averaged 1.0±0.1 km (**Table 4**).

Residence time before flushing was more than 50% shorter when geese were scared (**Table 6**). They also moved away significantly more often when they took off on their own than when flushes were attributed to an identified cause of disturbance (X^2=47.538, df=3, P<0.001). Interestingly, the birds returned to the same place more often (40%) when the cause of disturbance was not apparent, whereas scaring resulted in a movement in more than 90% of the cases. Time of residence before moving was also the shortest when geese were scared (**Table 6**). Finally, the distance moved following a disturbance was approximately 50%

Table 6. Time of residence (min) of wintering Pink-footed Geese before flushing and moving as a result of different causes of flushes, proportion of flushes resulting in a move and mean distance moved (km) in northeast Scotland, 1987–88.

Cause	Time before flushing	% resulting in a move	Time before moving	Distance moved
Own (169,161)[1]	67±6A[2]	95A	69±6A	1.3±0.2A
Identified disturbance (138,108)	68±6A	78B	78±8A	0.6±0.1B
Unidentified disturbance (68,41)	77±8A	60C	102±12A	0.7±0.1B
Scaring (27,25)	28±5B	93AB	30±6B	1.4±0.2A

[1] Number of flushes and moves, respectively.
[2] Means and percentages followed by different letters within each column are significantly different (Student-Newman-Keuls and chi-square tests, $P<0.05$).

Table 7. Daily movements of wintering Pink-footed Geese in northeast Scotland, 1987–88.

Characteristic[1]	Median	Mean	SE	Min	Max	P^2	P^3
Total distance moved per day (km)	10.6	11.7	0.9	1.6	27.0	0.930	0.053
Maximum distance from roost (km)	4.8	4.8	0.4	0.5	11.4	0.137	0.004
Moves/day on feeding grounds	7.0	7.3	0.5	1	17	0.307	0.362
Distance travelled per move (km)	0.8	0.8	0.1	0.2	3.1	0.440	0.466
Distance moved on feeding grounds (km)	5.3	5.6	0.5	0.7	17.3	0.659	0.068
Area covered on feeding grounds (km^2)	0.6	1.1	0.2	0	5.1	0.717	0.545

[1] n=47 for all characteristics except total distance moved per day (n=38).
[2] One-way ANOVA comparing means among three periods: 20 Dec – 20 Feb, 21 Feb – 8 April and 9 – 27 April.
[3] One-way ANOVA comparing means among eight geese.

shorter than when geese took off on their own or when scared.

The total distance travelled by geese during a day varied between two and 27 km, with a mean of 12 km (**Table 7**). There was no significant difference in the total distance during the three periods of the winter, nor among the marked birds. Although the maximum distance from the roost reached during a day slightly departed from a normal distribution (Shapiro-Wilk W=0.946, P=0.049), the median and mean distances were similar and just under 5 km (**Table 7**). The maximum distance did not vary during the winter but did vary significantly among geese. The difference was attributed to two birds, one travelling to an average distance of 7.6±2.6 km (n=3) and another to 1.9±0.1 km (n=9). There was no difference in the maximum distance reached by geese between those roosting on inland lochs and those roosting on the estuary (t=–1.624, df=45, P=0.111).

Excluding flights from and to the roost, Pink-footed Geese moved an average of seven times per day on the feeding grounds with a mean distance of 0.8 km per move and this remained constant throughout the winter and among geese (**Table 7**). The number of moves per day, however, increased with the number of disturbances (r=0.44, n=47, P=0.002). The total distance travelled on the feeding grounds averaged 5.6 km and was correlated with the area covered by geese (MDAR) which averaged 1.1 km^2 (r=0.70, n=47, P=0.001). Both variables did not vary throughout the winter nor among the marked geese (**Table 7**). The area covered by geese increased with the number of times that they had been scared during a day (r=0.35, n=47, P=0.015).

To examine the effect of crop types on daily movements, we categorised each day according to the crop used predominantly by the marked birds. Grasslands were used on 37 days, stubble and potato fields on eight days and winter cereals on two days. There was no significant variation in the distance travelled on the feeding grounds ($F_{2,44}$=0.17, P=0.846), nor in the area covered by

Table 8. Seasonal activity ranges of wintering Pink-footed Geese in northeast Scotland, 1987–88.

Goose	Age[1]	Sex[2]	*n* locations	90HM[3]	% of total area used	W^2 [4]
G	A	M	58	60	56	0.243*
R	A	M	30	66	62	0.262*
U	J	F	30	32	30	0.208*
V	A	M	31	69	65	0.153
Y	J	F	31	21	20	0.295*

1 A=adult–plumage bird; J=juvenile.
2 M=male; F=female.
3 90% isopleth harmonic mean (km^2)
4 Cramér-von Mises statistic testing for a uniform utilisation distribution (* P<0.1).

geese using different crop types ($F_{2,44}$=0.40, P=0.672). The maximum distance reached during a day, however, increased from 4.2±0.4 km for geese using grasslands, to 6.6±1.0 km for birds on winter cereals and to 7.1±0.6 km for geese feeding on stubble and potato fields ($F_{2,44}$=5.04, P=0.01).

Seasonal activity ranges

Five geese were located ≥30 days and four provided enough observations during and after hunting. None of these birds was paired or in a family unit. Changes in seasonal activity ranges were observed for geese tracked during and after the hunting season (**Figure 3**; Goose G: Wilks' Lambda=0.574, $F_{2,55}$=20.427, P=0.001; Goose R: Wilks' Lambda=0.792, $F_{2,27}$=3.549, P=0.043; Goose U: Wilks' Lambda=0.764, $F_{2,27}$=4.156, P=0.027; Goose V: Wilks' Lambda=0.758, $F_{2,28}$=4.476, P=0.021). The average distance of locations between each period was 4.4±0.4 km in a southwest direction (231±7°).

Adult-plumage birds had activity ranges more than twice as large as those of juveniles (**Table 8**). The average area encompassed by the 90% harmonic mean isopleth for the five geese was 50±10 km^2 which was less than the 106 km^2 computed by pooling data for all marked birds (n=217 locations). The proportion of the overall range used by each goose varied between 20 and 62% and averaged 47±9%. Again, juveniles covered a smaller portion of the total area used than adult-plumage birds. Although the size of individual activity ranges varied, they overlapped considerably and all encompassed at least one of the night roosts (**Figure 3**).

A uniform utilisation distribution was rejected for four of the five geese indicating that these birds had centres of activity (**Table 8**). Only Goose V with the largest activity range had a uniform distribution. We divided the study area into a grid of 1 km^2 cells and found that a total of 108 cells had been visited on at least one day by the radio-marked birds. Sixty-seven cells (62%) had been used more than once, with a maximum of 26 daily visits for the most used cell. Seventy one percent of the visits (n=428) were recorded in only 32% of the cells.

Using the same grid cells, we recorded a total of 190 repeated visits. The mean number of revisits by individual birds to a given cell was 1.8±0.1, with a maximum of six. Sixty-five (34%), 21 (11%) and 11 (6%) of these repeated visits involved intervals of one, two and three days, respectively. These were considered as part of the same utilisation bout because the maximum continuous period that a goose was observed using the same cell was three days (n=8). The interval for the other 93 revisits ranged between four and 106 days with a mean of 24±2 and a median of 16 days. No specific sequence of use of different parts of the area could be detected.

Discussion

We consider that our data adequately describe daily and seasonal movements of Pink-footed Geese of different status and ages even if our sample may not be representative of the population in terms of the proportion of paired and unpaired birds or the percentage of adults and sub-adults. The marked birds flew freely within the entire study area joining flocks of different sizes. Moreover, their behaviour was not

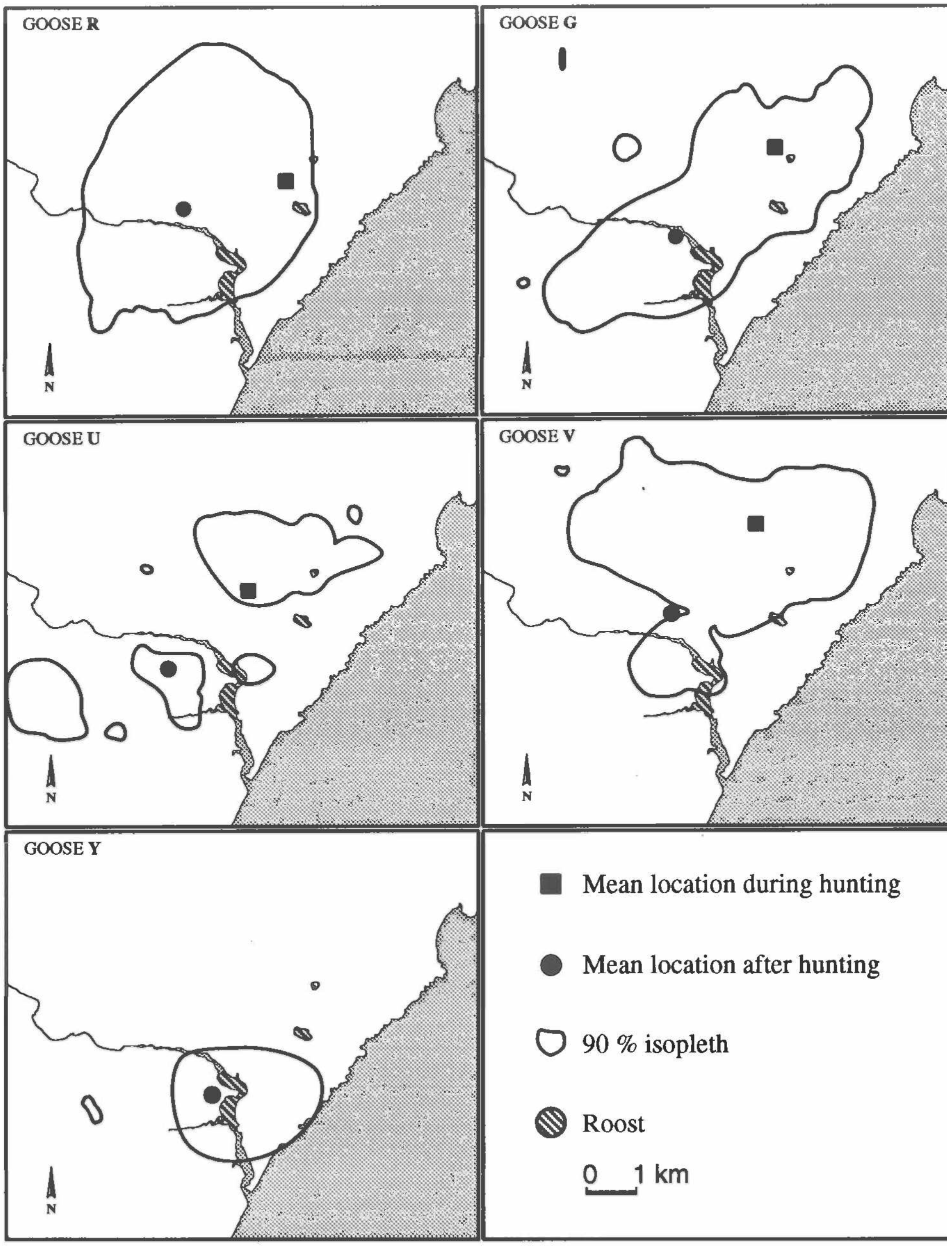

Figure 3. Seasonal home ranges (90% isopleth harmonic mean) and mean locations during and after the hunting period of five radio-marked Pink-footed Geese wintering in northeast Scotland, 1987-88.

affected by the tail-mounted transmitters (Giroux *et al.* 1990).

Pink-footed Geese concentrated their activity on only a few crop types throughout the winter and spring, and on a daily basis. Grasslands were used to the greatest extent and were even selected in late winter, confirming the importance of this habitat (Newton & Campbell 1973, Bell 1988, Patterson *et al.* 1989). In winter, Pink-footed Geese spent more than 70% of the daylight period feeding, which is similar to other goose species eating green vegetation (Owen

1972, Summers & Critchley 1990, Owen *et al.* 1992). The decrease in feeding activities in mid and late April, however, was surprising in view of the high energy demands required for migration and subsequent reproduction (McLandress & Raveling 1981). On one hand, this could limit the overall mass of the birds, thus reducing wing loading before undertaking a long flight. Alternatively, an increase in the quantity and quality of food, in this case new grass shoots (the 'spring-bite' of Fox *et al.* 1994), might allow Pink-footed Geese to satisfy their needs by feeding for shorter periods.

Observation of the largest flocks on fields of cereal stubble and potatoes, two high energy foods, indicates that it is possible to concentrate large numbers of geese in a few small areas. The longer distances travelled by geese to reach these habitats and their fidelity to these crops after disturbance show how attractive these habitats are and their potential for management. Stubble and potatoes were used in early winter but their availability rapidly decreased after ploughing. This agricultural practice, especially its timing, may therefore become a useful tool to increase or decrease the attractiveness of an area.

Fields of winter barley were selected in late winter and spring, but their overall use was limited. The smallest flocks were found on winter and sown cereals which may indicate that these habitats are less preferred or may be the result of repeated scaring by farmers. The seasonal decrease in flock size observed on all crops and noted previously by Newton & Campbell (1973) results in an increasing number of smaller flocks which implies a greater effort for monitoring field use and for dispersing the birds from sensitive crops.

Considering the maximal daily distance travelled by Pink-footed Geese, crop damage is unlikely to occur beyond 10 km from a roost, a conclusion also reached by Patterson *et al.*(1989) based on flock surveys. This also indicates that management designed to attract geese to reduce grazing intensity on sensitive crops should be located within 10 and preferably within 5 km of a roost.

Pink-footed Geese concentrated their daily activity within 1 km^2 which is relatively small when compared to their seasonal activity range. Nevertheless, it indicates that small managed areas may be suitable to contain Pink-footed Geese on a daily basis.

The seasonal activity ranges of Pink-footed Geese (21–69 km^2) were much larger than the 6 km^2 reported for Brent Geese *Branta bernicla* or the few km^2 for White-fronted Geese *Anser albifrons flavirostris* (Summers & Critchley 1990, Wilson *et al.* 1991). Adult-plumage Pink-footed Geese had ranges twice as large as those of juveniles. These unpaired birds were probably sub-adults and it is unknown how their social status affects their ranging behaviour. Individual geese restricted their foraging activities within a portion of the area and had centres of activity within these areas indicating fidelity to specific sites. Similarly, Barnacle Geese *Branta leucopsis* and White-fronted Geese tended to be faithful to their feeding sites within and between winters (Percival 1991, Wilson *et al.* 1991). Overlap among individual ranges was greatest in the vicinity of the night roosts confirming the importance of these sites (Newton & Campbell 1973, Bell 1988, Patterson *et al.* 1989). It differs, however, from White-fronted Geese wintering in Ireland which split into sub-flocks, each having a small distinct activity range (Wilson *et al.* 1991).

Unlike Lorenzen & Madsen (1985) and Meire & Kuijken (1991) who reported that different feeding sites were visited sequentially by Pink-footed and White-fronted Geese, our marked birds did not return to the same km^2 with a fixed pattern. On the other hand, we noted the succession of different birds in the same fields. For instance, a poorly harvested cereal field was visited independently by four marked birds within a ten day period. Hence, even if Pink-footed Goose flocks are observed in the same field on successive days, it does not necessarily mean that the same birds are using the fields which has implications for the long term efficiency of scaring programmes.

A shift in the mean locations of the radio-tagged geese between the hunting period and thereafter was associated with a change in roosting sites from the inland lochs to the estuary (Giroux 1991). This suggests that hunting can affect the distribution of geese on the feeding grounds by influencing their use of roosting sites. A potential benefit of this distribution change is a more uniform grazing pressure over the entire area and, hence, a lower impact of geese on agricultural lands. These results differ from those of Meire & Kuijken (1991) who observed a greater dispersion of Pink-footed and White-fronted Geese in Belgium following a ban on shooting.

Special considerations are necessary for the management of Pink-footed Geese because of their particular ranging behaviour. The presence of a large managed reserve near a roost does not guarantee that geese will restrict their activities within this area, as shown at the Loch of Strathbeg in Scotland (Patterson 1991b). It could be more advantageous to establish smaller management units of 1 km^2 each scattered throughout a 100 km^2 area centred on the roost (5–6 km radius). Disturbance should be maintained at a minimum and hunting prohibited within these units.

Large areas currently in cereal production may not be needed in the future and could be converted to set-aside land (Patterson & Fuchs 1992). This could be integrated within a management unit where farmers could be compensated to manage the habitat for geese. Cereal stubble has a great potential to attract large numbers of Pink-footed Geese. Spring rather than winter cereals should be favoured because the latter are sensitive to goose grazing (Patterson 1991a) and require early ploughing. Cutting but unharvesting or partially harvesting cereals, as well as improving grasslands through fertilisation (Patterson & Fuchs 1992), could induce the geese to remain within the managed areas.

Outside the units, ploughing of cereals should be done promptly to reduce the attractiveness of the areas while scaring or hunting should be promoted to keep birds away from sensitive crops. Movements of geese between units could provide hunting opportunities with fees and/or licenses used to pay for habitat management. Although controversy exists over hunting (Mooij 1991), this should not be considered as a means of controlling numbers, but of controlling the distribution of geese. Various acoustic and visual devices have been developed to scare geese from fields (Taylor & Kirby 1990, van Paassen 1992).

Managing habitats for geese could improve their condition when leaving for the arctic, which may enhance their reproductive success and ultimately increase their numbers. This can amplify existing local problems and create conflicts in new areas. Spreading of goose flocks, however, can promote bird-watching or hunting and profit local economies. Integrated management is therefore essential in areas of goose concentrations to ensure that farmers are not affected prejudicially. We predict that the number of geese will not increase continuously because breeding areas will probably become limiting, as already shown in some arctic colonies (Cooch & Cooke 1991).

We are indebted to the Culterty Field Station of the University of Aberdeen for logistic and financial support. J-F Giroux was supported by a post-doctoral fellowship of the Natural Sciences and Engineering Research Council of Canada during this study. We are grateful to C. Thompson, W. Murray and especially E. Landa for their assistance with field work. The Slains Estate allowed access to the roosts located on their land. Finally, we thank M. A. Ogilvie and two anonymous reviewers for their comments on the manuscript.

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