GRAZING ECOLOGY OF BARNACLE GEESE

(*Branta leucopsis*) ON ISLAY

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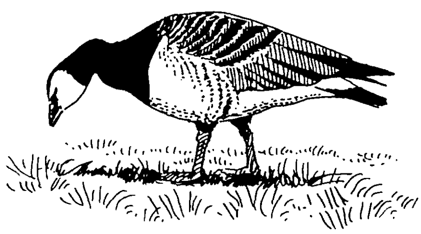

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ABSTRACT

A large increase in the number of Barnacle Geese wintering on the Inner Hebridean island of Islay has brought them into conflict with local agriculture. These geese were found to cause major widespread losses in the availability of grass to farm stock in the early spring. On areas which suffered particularly high levels of goose grazing, there were also substantial reductions in silage yield. The geese caused further loss in yield by delaying the spring application of fertilizer. Goose grazing did bring about some improvement in the quality of the sward, through an increase in its protein and a decrease in its fibre content, but this benefit was negligible in comparison to the large quantitative losses. There was no doubt that the geese were having a major impact on the island's agriculture.

Several refuge areas have been set up in an attempt to reduce this agricultural impact, where grassland is being managed to support as many geese as possible through the winter. Experiments have shown that reseeding with commercial seed mixes and fertilizer application can both increase the number of geese that a specific area can support substantially. However, the high site-fidelity shown by the geese, both within and between winters, meant that this management was not greatly effective in increasing the numbers of geese using the total area of the

refuges. Improvement of grassland attracted local birds, but did not affect the distribution of birds feeding elsewhere on the island. The geese were found to be tolerant of human disturbance, and current levels of scaring were ineffective in bringing about large-scale movements of birds to the refuge areas. Birds were remaining faithful even to the most heavily disturbed area.

There was some interchange of birds throughout the winter with the rest of the Greenland Barnacle Goose population, using other sites along the west coast of Scotland and in Ireland. Changes in feeding conditions at these other sites could affect the numbers wintering on Islay, so the Islay birds must be considered as part of the whole population. Breeding success of birds using different parts of the winter range were found to differ significantly. Some evidence was found that suggested that this was due to birds which associated during the winter staying together through other times of year and therefore experiencing similar environmental conditions. More study is required before the factors affecting the numbers of geese coming to Islay are fully understood.

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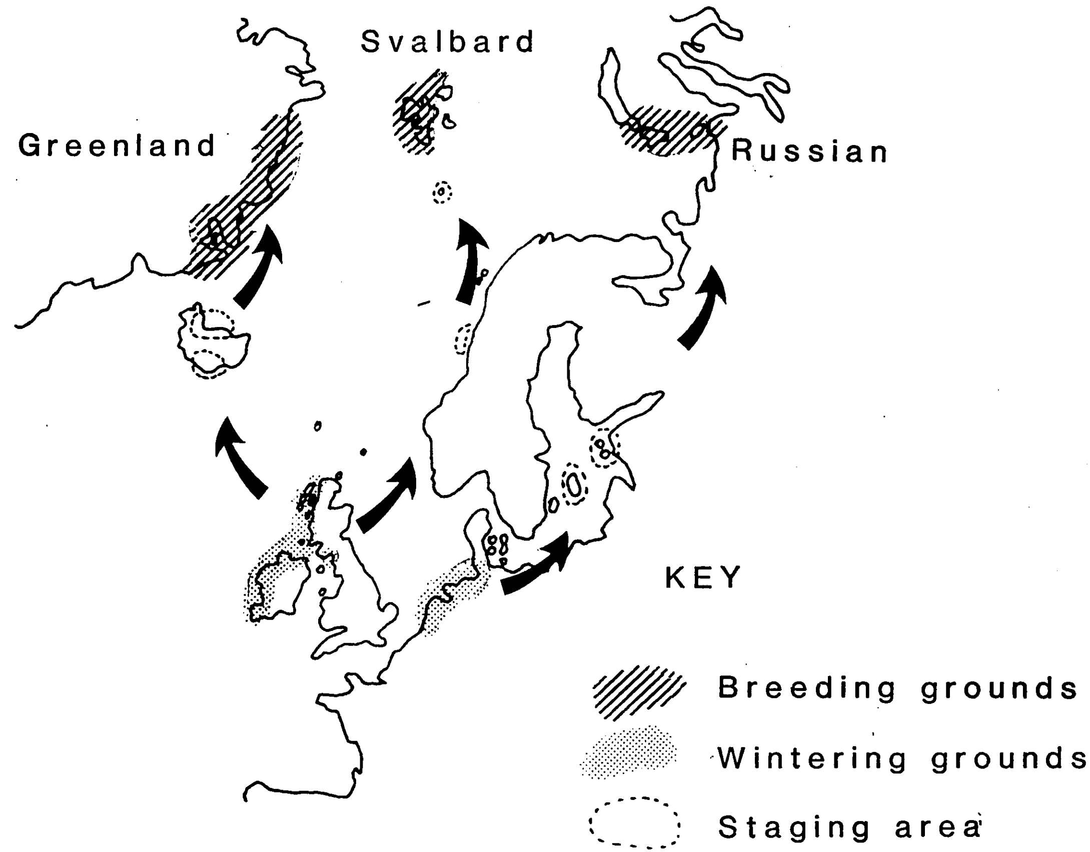
Chapter 1 : INTRODUCTION

1.1 Background to the study

There are three populations of Barnacle Geese, Branta leucopsis, in the world (Owen 1980). Their distribution is summarised in figure 1.1. The Russian population, totaling approximately 75,000 individuals (B. Ebbinge, pers. comm.), has its breeding grounds on the arctic island of Novaya Zemlaya in the far north of the Soviet Union and winters chiefly in the Netherlands. The Svalbard population, of about 11,000 birds (M. Owen pers. comm.), breeds on the Svalbard archipelago and winters exclusively on the Solway Firth in south-west Scotland. The Greenland population, of about 32,000 birds (Ogilvie 1983) breeds in eastern Greenland and winters along the western fringes of Scotland and Ireland. These birds spend about six and a half months on the wintering grounds, from mid-October to the end of April. The conservation importance of a species with such small numbers is enhanced by the fact that arctic-breeding geese in general, and the Barnacle Goose in particular, have a low breeding productivity. Only a small proportion of adults successfully raise young each year, so their ability to recover from a population crash could be poor. The need for careful management of the species is further recognised by its inclusion in Annex 1 of the European Community's Birds' Directive as a species which requires special conservation measures.

Fig. 1.1 WORLD DISTRIBUTION OF THE BARNACLE GOOSE

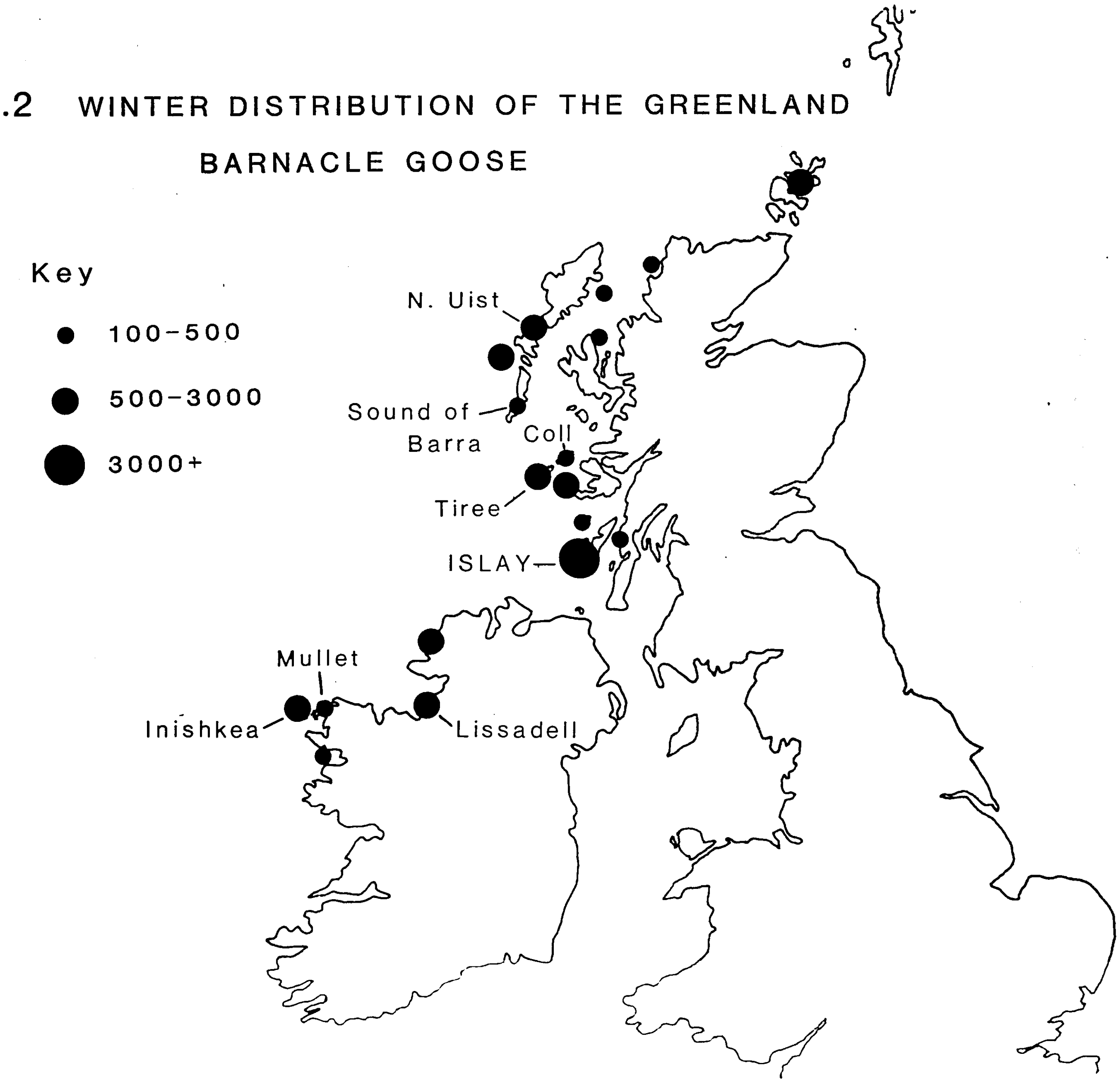


Within the last 30 years the Greenland Barnacle Goose population has become concentrated on the Inner Hebridean island of Islay. The number of geese wintering on the island has risen from about 6,000 in 1960 to a present level of around 22,000, with even greater numbers present on the island during the autumn (Ogilvie 1983; also see chapter 2). As Islay supports such a large proportion of the Greenland population of Barnacle Geese (70%) and of the whole world population (20%), it is clear that the conservation of this species on the island is of great importance.

Outside Islay, the remaining 10,000 birds in this population are scattered along the western coasts of Ireland and Scotland. Figure 1.2 shows a summary map of their winter distribution, based on an aerial survey carried out by Ogilvie (1983). It is thought that in prehistorical times the species was confined to short natural grasslands of exposed coasts (particularly machair islands) and saltmarshes (Owen 1976). The species is now primarily found on improved agricultural pasture.

The main increase in goose numbers on Islay coincided with a period of intensification of the island's agriculture. Islay's agriculture has changed from a traditional low input crofting base, to a high input mixed agriculture. Farming on the island is primarily stock-based, with a mix of sheep, and dairy and beef

Fig 1.2 WINTER DISTRIBUTION OF THE GREENLAND BARNACLE GOOSE



cattle, though a few arable crops are also grown. Most of Islay's 54,000 hectares of arable land is rye grass- (*Lolium perenne*) dominated grassland, and of this

2,780 hectares are intensively managed rotational leys (DAFS 1977). These grasslands are usually reseeded every five years, and are used primarily for silage production. Two silage cuts are usual, one in mid-June and a second in September. The grasslands are also used for grazing farm stock in summer and autumn, but these are removed to allow grass to grow prior to the silage cuts. Most stock are removed from the fields and are in-wintered, from mid-November, as there is insufficient forage available to them. Barley is an important arable crop grown for sale as well as for dairy cattle feed. The stubbles can provide rich temporary feeding grounds for the geese in autumn, in years when spilt grain is abundant. Other crops, grown mainly for animal fodder, include rape and turnips, but these are little used by Barnacle Geese as feeding grounds.

It is only in the last 50 years that the agriculture on Islay has intensified. The land has a long history of crofting, but suffered considerable de-population in the late 19th century (Storrie 1981). Many crofts were merged at that time and taken up as larger farm units. These farms are now mostly managed by tenant farmers, remaining under the ownership of the island's estates. Since the

Second World War government farming policy has strongly encouraged agricultural improvements to increase food production, with grants available to farmers to carry out these improvements. As a result extensive areas of pasture were reseeded with high-yielding grasses, and large areas of marginal wetland were reclaimed. At the same time the geese came in increasing numbers to exploit an increased food supply, and came into direct conflict with the farming community.

Work by Patton and Frame (1981), comparing yields from goose-grazed and protected vegetation plots, suggests that the geese may cause substantial economic losses to the farmer. The three principal areas of concern are :-

(i) that the geese reduce food availability to livestock, especially during the spring when ewes are lambing and the value of the pasture is high.

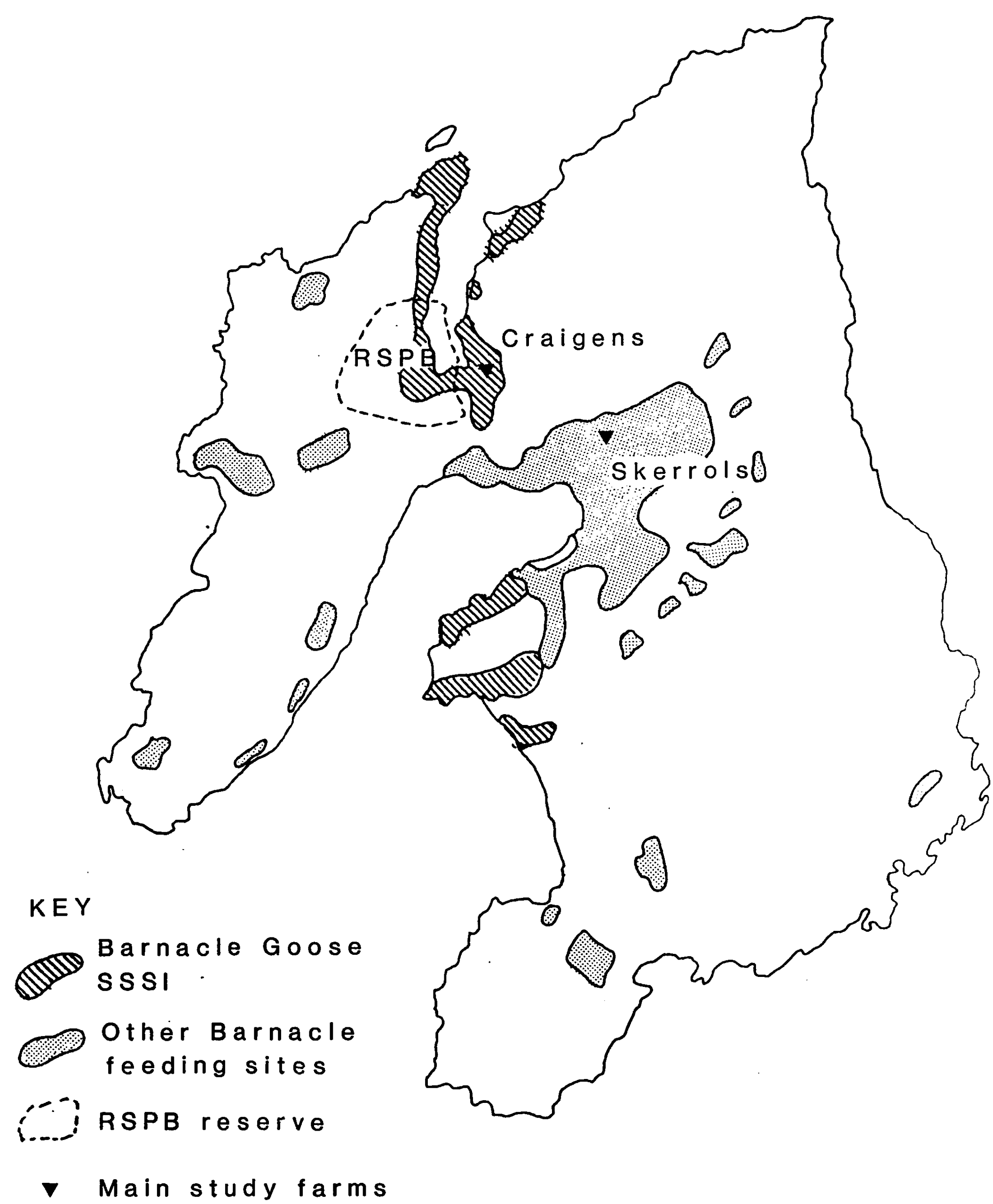
(ii) that the grazing pressure of the geese on the agricultural pastures causes a reduction in silage yield, forcing farmers to buy supplementary food to feed their stock during the winter.

(iii) that the geese prevent effective early spring fertilizer application, by consuming any extra yield that such application produces.

The increase in numbers of geese on Islay in the 1970s brought about an increase in goose shooting by the farmers and landowners, in an attempt to reduce the impact of the geese on the island's agriculture. Up to 1954 Barnacle Geese had been shot without any restriction. After the 1954 Protection of Birds Act shooting was only allowed during December and January. In response to the large population increase in the 1970s, the shooting season was extended to five months in 1976, and foreshore shooting was allowed from 1977. This resulted in a large increase in the numbers of geese being shot on Islay, so that by the late 1970s shooting was so intense that in some winters the total number of geese killed exceeded the summer's production of young birds (up to 1,500 were being shot annually). By 1980 the number of Barnacle Geese on Islay had decreased to only 13,000 individuals, from a peak of 24,000 in 1976. The increased shooting effort may not have been the only cause of this decline, but probably exacerbated the result of a succession of poor breeding seasons.

In 1981 the Wildlife and Countryside Act gave protection to the Barnacle Goose in Britain. Under the Act, shooting is only allowed under licence from the Department of Agriculture, specifically to prevent serious agricultural damage. In addition, many of the areas of land which the geese favour have been designated Sites of Special Scientific Interest (SSSIs). To provide the geese with relatively undisturbed feeding areas, farmers in these areas are given financial compensation for goose damage per

Fig 1.3 BARNACLE GOOSE FEEDING SITES ON ISLAY



grassland. The main aim was to look in detail at the relationship between the amount of goose grazing and subsequent grassland performance. Both quantitative (biomass yields) and qualitative (nutrient content) effects are examined.

Chapter 4 deals with the selection of feeding sites by the geese. It looks at different pasture management techniques, such as reseeding and fertilizing, to see how they affect goose grazing. The chapter progresses to look at Barnacle Goose feeding requirements through the winter and discusses the concept of carrying capacities of geese on the refuge areas.

Chapter 5 investigates the movements of Barnacle Geese through the winter. The first part of the chapter focuses on the ranging behaviour of the geese on Islay, and the second examines the movements of birds within the whole of the wintering grounds. Finally chapter 6 looks at the relationship between the behaviour of the geese during the winter and their subsequent breeding success.

All analyses for this thesis were carried out using the SPSS package, on the mainframe computer at Glasgow University using SPSS-X v.2.1 (SPSS Inc. 1986a), and on an Apricot Xen-Xi 20 using SPSS/PC+ (SPSS Inc. 1986b).

Chapter 2 : NUMBERS OF BARNACLE GEESE ON ISLAY

2.1 Goose counts on Islay prior to this study

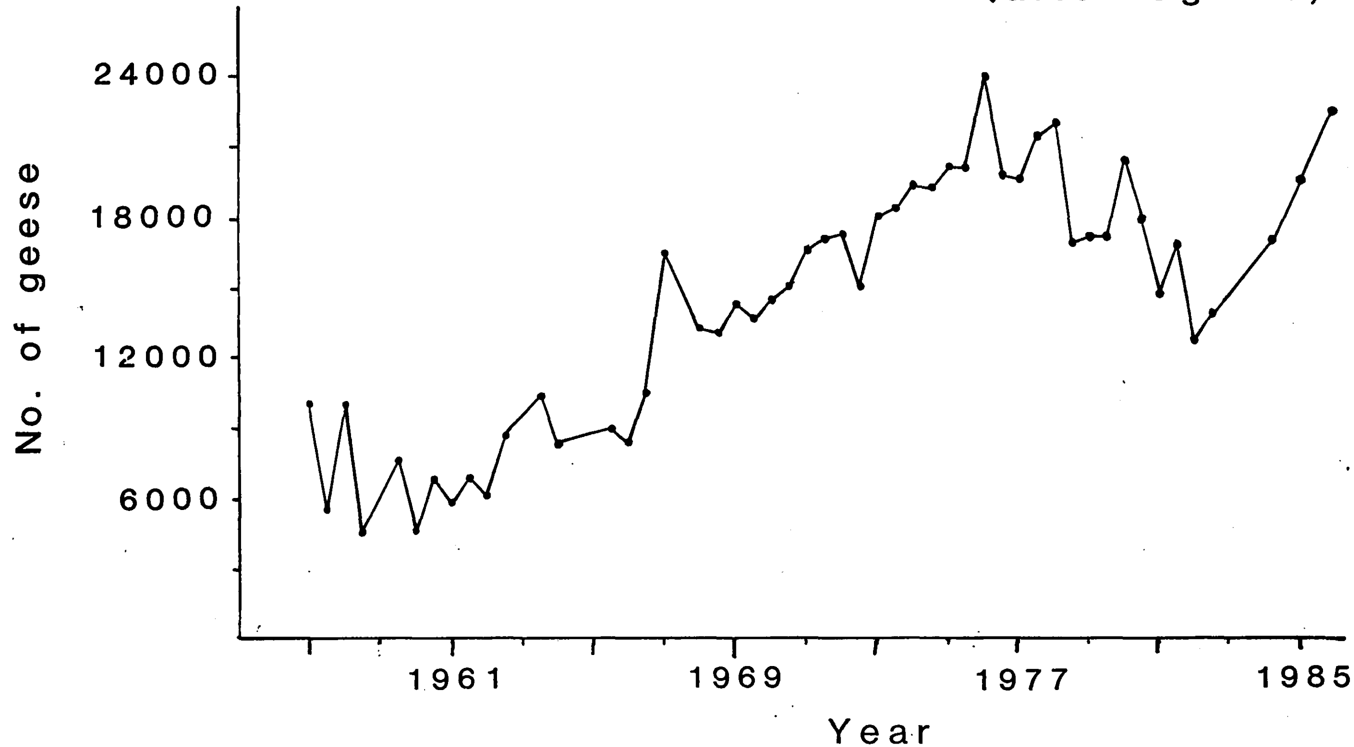
The Wildfowl Trust has been carrying out twice-yearly counts of the geese on Islay since 1952 (Boyd 1961, Ogilvie 1983). A summary of the results is given in fig. 2.1. These data clearly show the dramatic increase in goose numbers that took place in the late 1960s and early 1970s, and suggest a population decline in the late 1970s and early 1980s.

There data show the gross trends in goose numbers over the last 30 years, particularly the dramatic increase in the 1970s and decline in the early 1980s. Since 1982 the numbers have returned to their upward trend, and by 1987 were almost back to the peak 1976 level of 24,000.

Though the Wildfowl Trust counts do show the overall trends in goose numbers on Islay, they have not been carried out frequently enough to allow any detailed analysis of population changes. Differences of a few thousand birds between years can be explained by alternative hypotheses to actual population change. For example, a count in one year might have coincided with a peak of autumn passage birds which were moving through Islay to other wintering sites, or flocks may have occasionally been missed during counts. The low numbers

Fig 2.1 COUNTS OF BARNACLE GEESE ON ISLAY 1956-1987

(after Ogilvie, 1983)



recorded the late 1950s and early 1960s could have been partly due to less observer knowledge about the distribution of the geese, and also at that time the geese were more spread out over the island and therefore more difficult to count accurately.

2.2 Numbers of Barnacle Geese on Islay during this study

In the winters of 1983-6 the NCC and, in 1986-7 the Wildfowl Trust, have organised monthly counts of the geese on Islay (Bignal et al 1984-6, Ogilvie 1987). These showed the fluctuations in numbers of geese on Islay through the winter in more detail than the biennial Wildfowl Trust counts. A summary of the results, supplemented by counts made by Newton (1985), and myself, is shown in figures 2.2, 2.3 and 2.4.

1) 1984-5 (fig 2.2) : The counts suggest a marked autumn passage of birds on Islay, with two waves of migrants passing through. Peak numbers during this period were 23,200 and 22,000 for the two waves respectively. The number of geese remained stable through the winter at about 17,600, and increased slightly in spring to 18,800.

2) 1985-6 (fig. 2.3) : The basic pattern was similar to the 1984-5 counts, with a brief peak of just under 20,000 birds during a two day period at the end of October and then a longer second peak of around 20,000 birds during

Fig 2.2 NUMBERS OF BARNACLE GEESE ON ISLAY

WINTER 1984/5

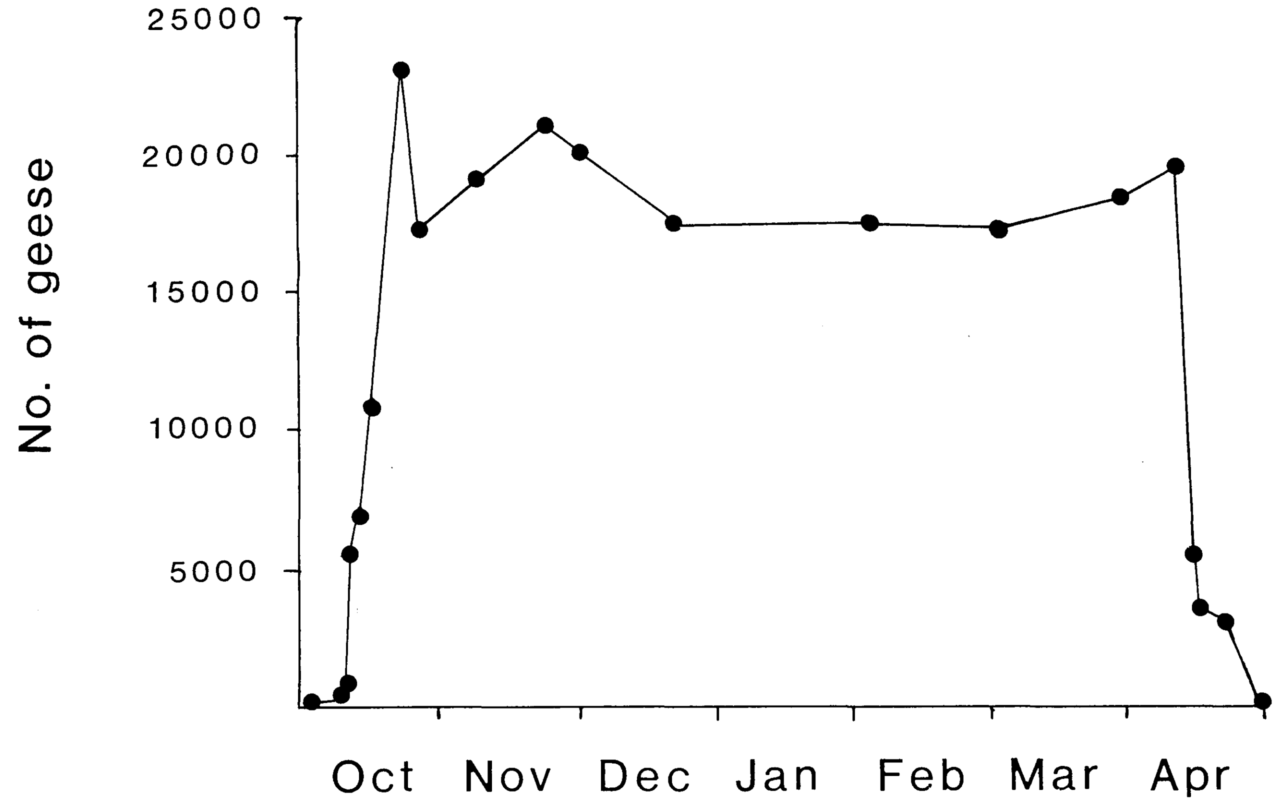


Fig 2.3 NUMBERS OF BARNACLE GEESE ON ISLAY

WINTER 1985/6

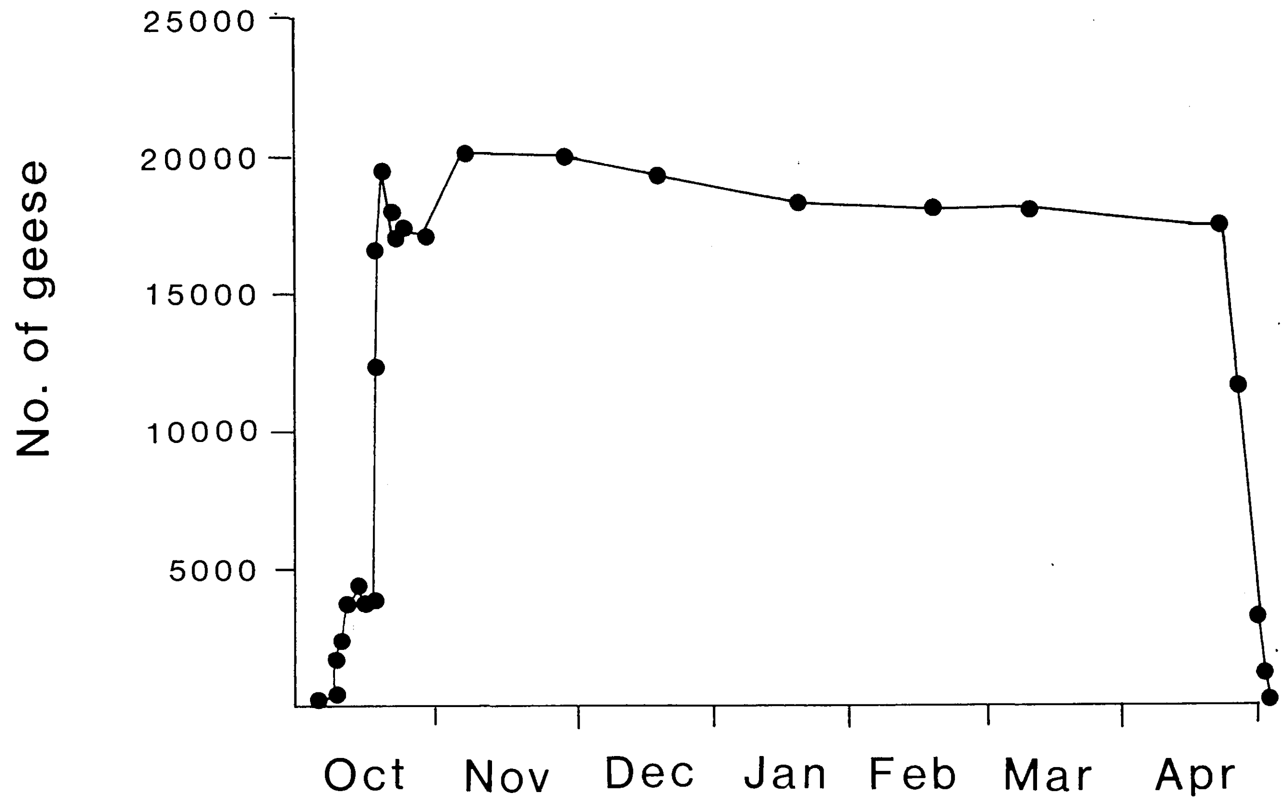
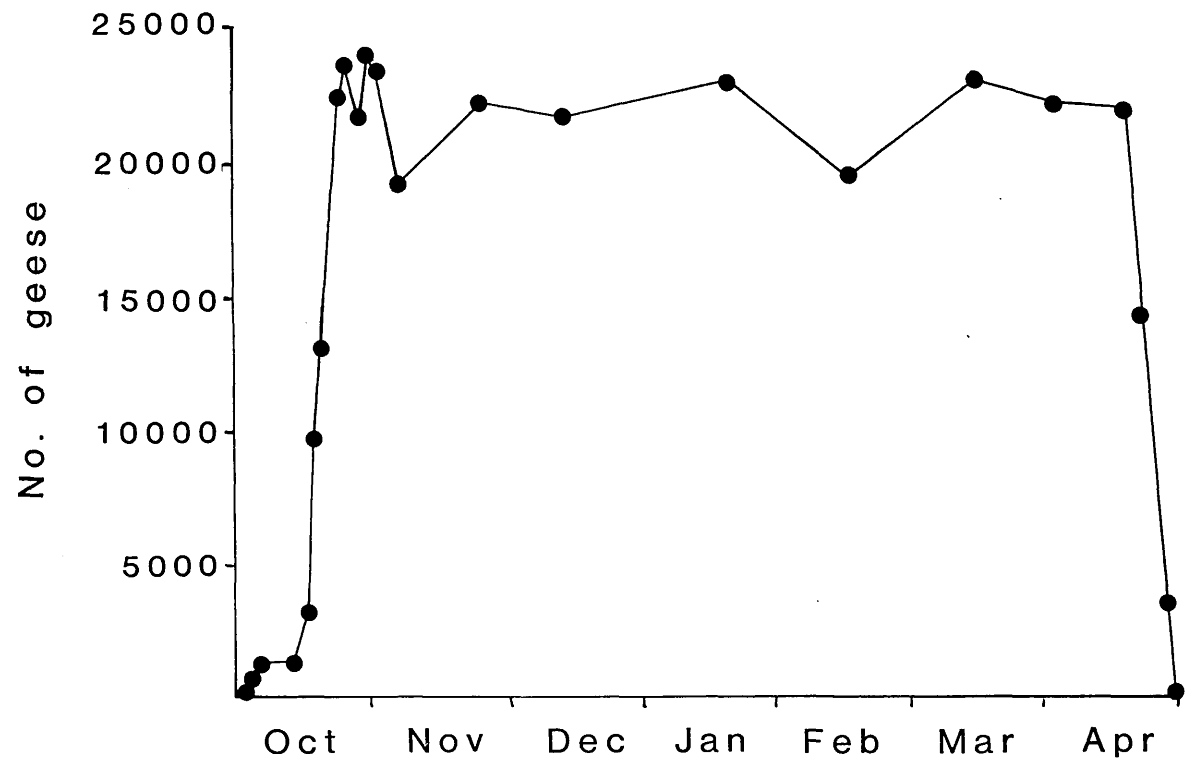


Fig 2.4 NUMBERS OF BARNACLE GEESE ON ISLAY

WINTER 1986/7



November and into December. In both years the counts suggest a period of mid-winter stability in goose numbers, though in 1985-6 this was not reached until January, and at a higher level than the previous winter (18,600). No spring influx of birds moving to Islay from other sites was recorded this year.

3) 1986-7 (fig. 2.4) : The pattern of the autumn counts during this season were similar to those of the previous two years, with an initial peak lasting for a few days in late October (24,500 birds), followed by sustained high numbers (about 23,000 geese) through November. This year, however, the numbers remained high through most of the rest of the winter, with only a single count below 22,000.

These counts suggest that the numbers of geese on Islay are stable through the winter, but there is a passage of birds moving through the island in the autumn to other wintering sites. In 1984/5 an influx of birds was recorded in the spring, but this was not detected in either of the other two years. The counts also showed that the number of geese wintering on Islay has been steadily increasing since 1984. The mid-winter counts, taken as an average of the counts made in December, January and February, for the three winters are summarised in table 2.1. Further investigation of the ideas suggested by these counts will be made in chapter 5, using the data from sightings of individually-marked birds.

Table 2.1 : Mid-winter counts and population dynamics of Islay Barnacle Geese, 1984-7.

Winter	Mid-winter count	% change from previous year
1984-5	17,600	+11%
1985-6	18,500	+5%
1986-7	21,800	+18%

Chapter 3 : AGRICULTURAL IMPACT OF THE GEESE ON ISLAY

Background and Aims

This chapter investigates the impact of Barnacle Geese on Islay's agriculture. Over-grazing of pastures by stock through the winter has been the subject of much agricultural study (Alcock 1964, Lockhart *et al*. 1969, Frame 1970, Wilman & Griffiths 1978). It has been demonstrated that if a sward is repeatedly defoliated in the late winter and early spring, the subsequent growth of the grass can be considerably reduced. Work on the potential of wild geese to cause such over-grazing was carried out in Britain in the 1960s (Kear 1965, 1970) and a further study was made in Belgium (Kuyken 1969). Both studies showed that grazing by geese on agricultural grasslands could cause significant damage when grazing continued through the spring. Patton & Frame (1981) carried out work in western Scotland, including Islay, to quantify the loss in yield attributable to the geese. They found that damage was great in areas of intense goose grazing, resulting in substantial economic losses to the farmer. They did not, however, measure the losses over a wide spectrum of goose grazing pressures. Recent work has concentrated on quantifying the relationship between the amount of goose grazing and the loss of yield (Bedard *et al*. 1986a, Bruinderink 1987), and investigating influencing factors such as climate and soil fertility in more detail. A general summary of potential goose damage to crops is given in Ruger (1984), in which it is pointed out that such damage is generally negligible in terms of the national agricultural economy. It can, however, be very important on a local scale in areas where wild geese congregate in large numbers. Islay is one such area.

This study undertook a detailed investigation of any reduction in pasture yield resulting from goose grazing on Islay, and obtained information about the other aspects of goose damage that could be of economic importance to the farmer. The specific aims were to assess the importance of three potential types of damage to pastureland that grazing by geese might cause :-

1. Reduction in the herbage available to farm stock in the spring as a direct result of simultaneous grazing by geese and stock. At this time the nutritious flush of spring growth of grass (known as the 'spring bite') is of particularly high value for feeding lambing ewes.

2. Reduction in the silage yield as a result of grazing by the geese through the winter and spring. This could have considerable economic importance, as low silage yields result in farmers having to buy in extra foodstuffs to maintain their stock through the winter.

3. Delay in the application of spring fertilizer, further

reducing yields. Many farmers on the island suggested that the presence of the geese made it unprofitable for them to apply fertilizers to the grassland in early spring, as the geese would consume any resulting extra yield.

Methods

Most of the agricultural impact work was carried out during the winters of 1985-6 and 1986-7. The study sites were chosen to examine the effects of the geese across a range of grazing intensities, but without the complication of dealing with a wide variety of grassland types. The trials were on improved pastures, as these were the fields which were of prime agricultural importance and were preferred goose feeding grounds (see chapter 4). In 1985-6 two fields were used, one at Craigens which was reseeded in the summer of 1985, and one at Skerrols reseeded in 1983 (see fig. 1.3 for the locations of these sites). In 1986-7 two fields were again used, but in this season both were at Craigens; one was the same field as had been used in the previous year, the other a field reseeded during the summer of 1986. The Craigens fields were used by large numbers of geese, as they were secluded from human disturbance and situated close to one of the main goose roosts. The Skerrols field supported fewer geese, because it was subjected to greater human disturbance and was located further from a main goose roosting site. Some work was carried out on the RSPB reserve during the 1984-5 season, on three fields; two pastures reseeded in 1984 and an old pasture which had not been reseeded during the previous ten years.

All study fields had a similar management regime. Stock were removed in late autumn. Slurry was usually spread on the fields during cold periods in January and February. The first inorganic fertilizer of the year was applied in April, to be effective in increasing grass growth only when the geese had left for their breeding grounds. The sward was left ungrazed by stock to the first silage cut in mid-June. A second cut was usually taken in mid-September, then stock were returned to graze the pastures until mid-November.

Most of the experimental work in this chapter involved the manipulation of the intensity of goose grazing on a sward and measuring the response of the grass. Exclosure cages were used to exclude geese totally from grassland plots, so that the grass growing in these ungrazed areas could be compared with that in control grazed ones adjacent. These cages had negligible effect on goose grazing outside the protected plots, as the geese grazed heavily right up to the physical barrier of the cage itself. The basic experimental design and sampling technique followed the guide-lines of Frame (1983). The exclosures were 1.5m square by 0.5 m high, made with 5cm mesh wire netting sides, two wires strung diagonally across the top, and metal Dexion angle-iron corner posts. All large herbivores were excluded. A small number of exclosures were broken into by Roe Deer during the study: the resulting grazed grass within the cage was immediately apparent, and these exclosures were excluded from the analyses.

In any study using exclosures, two major problems have to be considered. Firstly, erecting an exclosure over the vegetation may alter the micro-climate inside and hence the pasture productivity. Secondly, exclosure cages also exclude other herbivores from the plots as well as the geese. Hares, Rabbits and Roe Deer were all present in the study area. If they had been present in large numbers, they could have had a confounding effect on the results of the trials. Fortunately this was not the case. Even at their maximum observed density in the study area of 0.5 individuals per hectare (pers. obs.) Hares would still be taking about 20 kg. of grass per hectare through the winter (Southern 1964), less than 2% of that consumed by the geese. Rabbits were at a similar density to the Hares (pers. obs.), and therefore would also have been having little impact on the experiments. The third species, the Roe Deer, made only occasional visits to the study areas in small numbers (the maximum number observed in the study area was five individuals), so was very unlikely to have been having any significant effect on the experiments, except when they broke a few of the exclosure cages (which were excluded from the analyses - see above).

Ideally both of these problems could be tested by putting up exclosures of the same design as used in the main experiments in a comparable area which is ungrazed, but on Islay this is impossible, as almost all pastures are grazed by the geese at some time during the winter. Therefore, three exclosures were set up on the Craigens study fields in early May 1987, when the geese had left the island. The vegetation growth inside and outside these cages up to the time of silage cut was compared, by taking clippings in mid-June. Thus the effect of the cages without the influence of the geese could be assessed. Any observed difference between the yields from inside and outside the cages could be attributed to factors other than the geese, and would have to be taken into consideration in the interpretation of the results of the main experiments.

A further experiment was carried out to test whether the mesh size of the exclosure netting might have a significant effect on grass productivity. This provided some additional information about the potential sheltering effects of the exclosure cages. Three mesh sizes were tested; 2-inch (as used in the main experiments), 1-inch and half-inch. Three exclosures of each mesh size were erected in the Craigens study field in early March 1986. Standard grass clippings were taken from each cage (see below) to allow the production of grass to be compared, at the end of April and in mid-June.

For each exclosure and control grazed plot, the quantity and the quality of the vegetation were measured. The live grass biomass was calculated by taking clippings, using a pair of manually-operated sheep-shears, down to ground level from 25 x 25 cm. quadrats, (i) at the end of April immediately after the departure of the geese, to assess the loss of 'spring bite', and (ii) in mid-June, immediately prior to the silage cut, to assess the effect of the geese on the silage yield. The April samples were sorted to remove the dead material and weed content of the sample, to obtain a standard value of live grass biomass. This was not necessary for the silage samples, as dead material did not make up a significant part of the total biomass by that stage of the season. All grass samples were dried overnight in an oven at 80^{o}C and then weighed. All quoted weights in the results section are dry weights.

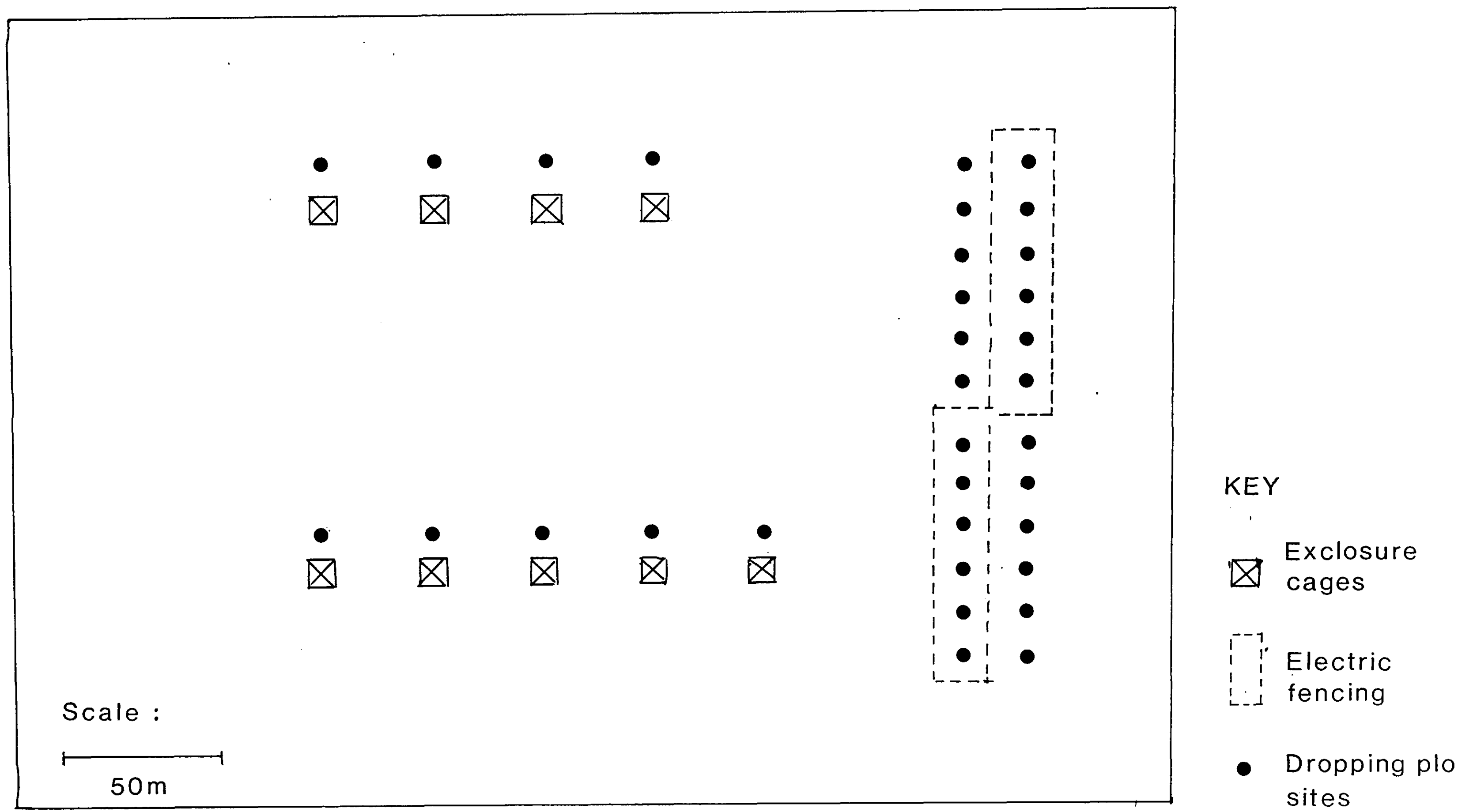
Grass quality was assessed by measuring the protein and fibre content of the samples. These analyses were carried out at the Department of Animal Husbandry at the Glasgow University Veterinary School, using an automated Kjeldahl method for the crude protein content (calculated as 6.25 x nitrogen content), and a modified acid detergent technique for fibre content (details of the methods are given in Hodgson 1983).

All the exclosures were set up in November/ early December, when the stock were removed from the fields for the winter. Monitoring the density of goose droppings showed that the geese made negligible use of the study fields before the start of the experiments.

In investigating the relationship between the intensity of goose grazing and the performance of the sward it is important that the amount of goose grazing can be measured accurately for a specific plot. Goose grazing pressure is readily measured directly by counting the density of droppings in the study plots (Owen 1971). Barnacle Geese defecate every 3-5 minutes whilst feeding on grassland (see chapter 4), so the number of droppings accumulated per unit area can be used as an index of the amount of time that the geese have been grazing in that area. Permanent dropping count quadrats (see section 4.2 for details) were set up beside each exclosure cage, and droppings were counted and removed from each quadrat every three weeks throughout the winter.

Four basic experimental designs were employed (summarised in figure 3.1). The exclosure cages were set out along two transects in each field, to allow coverage of the whole field on a regular layout. Goose grazing pressure was so uniform across the study fields that it was

Fig 3.1 Experimental design of main study fields



unnecessary to randomize the design. The four designs were :-

1. A straightforward comparison of paired plots on grazed and ungrazed pasture, using exclosure cages to protect plots from the effects of goose grazing. These cages were left in place until the silage was cut in mid-June. Ideally, they would have been taken down immediately after the departure of the geese at the end of April, to reduce the possibility of any sheltering effect during the main spring growth period. However, this was not possible as other herbivores in the area, particularly Brown Hares, Lepus europaeus, would have undoubtedly taken advantage of the abundant food in these small high biomass plots.

2. In 1985-6 exclosure cages were also erected at different stages through the winter and spring, to identify the periods when the geese cause most damage. This experiment was designed to investigate whether the effect of the geese is limited to the early spring growing period, or if it is cumulative throughout the winter.

3. In the 1986-7 season the effect of early spring fertilizer application on subsequent yield was investigated, to see whether the delay in application caused by the geese has a significant effect. In early March nitrogenous fertilizer (Nitram 32% N) was simultaneously applied at a rate of 175 kg/ha. to three

exclosure cages and to three adjacent grazed control plots, to compare yields and quality of these fertilized plots and the main experimental plots which received no early spring treatment.

4. An attempt was made to make a comparison of the intensity of goose grazing and grassland production. Comparison of yields between fields of different grazing pressures might give some useful information, but comparison of areas of different grazing pressure within the same field controls better for extraneous environmental variables, such as soil type and farming practice. Barnacle Geese generally graze uniformly across fields so the within-field variability in grazing pressure is low (see chapter 4), but their grazing activity can be manipulated by using electric fencing to partially exclude the geese from some sectors of the study fields. This was carried out by erecting two further exclosures on each of the Craigens fields in 1985-6 and 1986-7. These were 15m. by 100m. plots enclosed by a single-strand electric fence at a height of 30cm above the ground.

Results

Effect of the Geese on Grassland Yields

The yields of the grazed and ungrazed plots at the end exclosure cages and to three adjacent grazed control plots, to compare yields and quality of these fertilized plots and the main experimental plots which received no early spring treatment.

4. An attempt was made to make a comparison of the intensity of goose grazing and grassland production. Comparison of yields between fields of different grazing pressures might give some useful information, but comparison of areas of different grazing pressure within the same field controls better for extraneous environmental variables, such as soil type and farming practice. Barnacle Geese generally graze uniformly across fields so the within-field variability in grazing pressure is low (see chapter 4), but their grazing activity can be manipulated by using electric fencing to partially exclude the geese from some sectors of the study fields. This was carried out by erecting two further exclosures on each of the Craigens fields in 1985-6 and 1986-7. These were 15m. by 100m. plots enclosed by a single-strand electric fence at a height of 30cm above the ground.

Results

Effect of the Geese on Grassland Yields

The yields of the grazed and ungrazed plots at the end of April are given in table 3.1. The results show that at all sites in all years there is a highly significant reduction in yield after grazing by geese. The reduction in yield was greatest on newly reseeded fields, which tended to support the greatest numbers of geese. Even the yield on the least- heavily grazed field (Skerrols in 1986) was equivalent to only half of the potential productivity (that is without goose grazing) of that field. Clearly the geese cause a substantial reduction in the spring yield, particularly where their grazing pressure is most intense.

Table 3.1 : Effect of goose grazing on spring yield

Field	Year	Age of grass	Ungrazed g/m^2	(s.e.;n)	Grazed g/m^2	(s.e.;n)	
Craigens 1	'86	1st-yr	120.0	(12.7;6)	24.1	(0.9;15)	***
Skerrols	'86	3rd-yr	119.7	(11.5;6)	56.7	(2.2;12)	***
Craigens 1	'87	2nd-yr	93.6	(8.4;7)	24.8	(3.8;9)	***
Craigens 2	'87	1st-yr	151.7	(16.9;8)	51.3	(3.1;8)	***
RSPB 1	'85	"	40.7	(2.3;4)	9.7	(2.2;8)	***
RSPB 2	'85	"	117.1	(25.5;3)	61.0	(9.3;7)	*
RSPB 3	'85	10 yrs	15.2	(1.9;4)	8.8	(1.1;8)	***

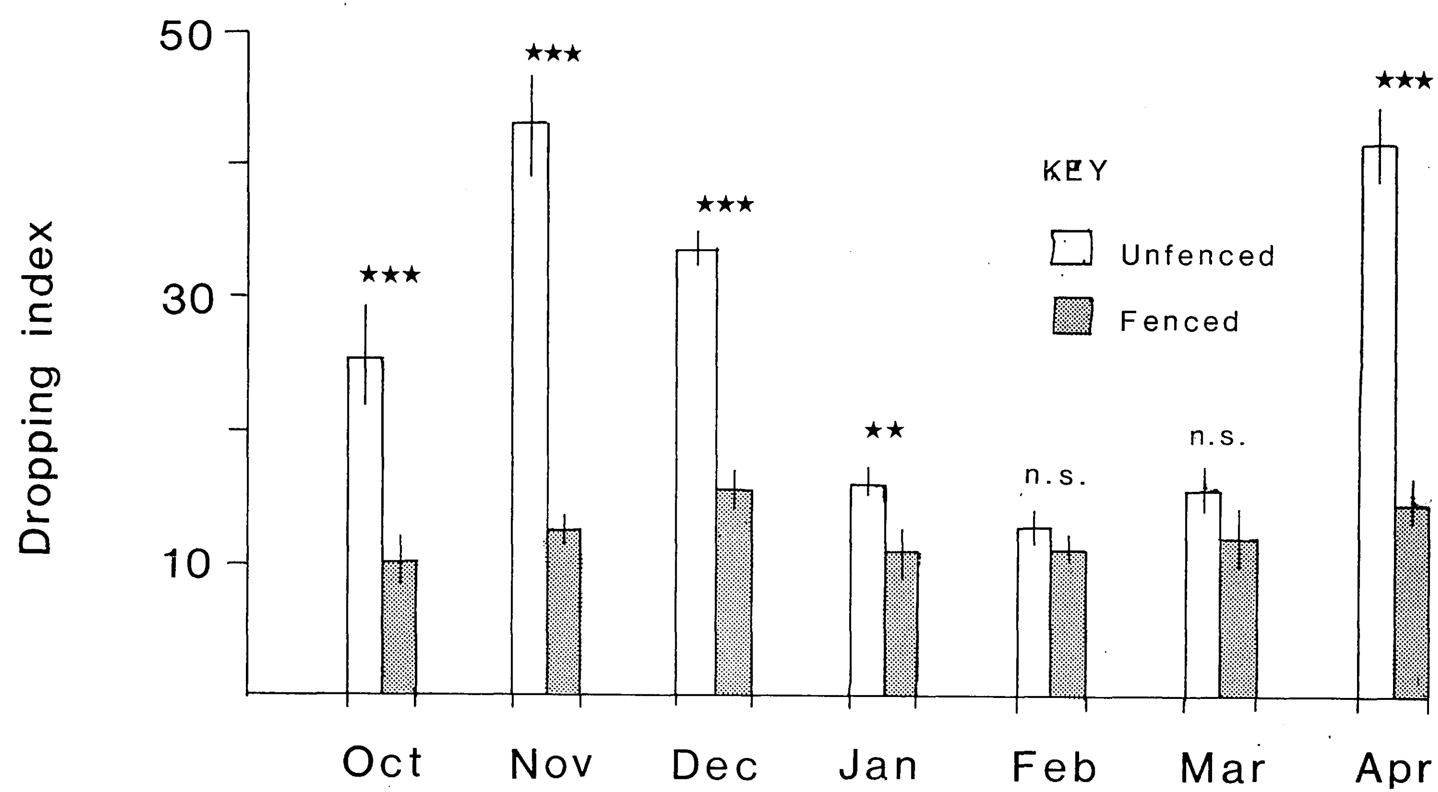
(* = $P<0.05$, *** = $P<0.001$, Students T-test; standard errors and sample sizes, n, are given in the table)

The comparatively low yields from the RSPB fields one and three, in both grazed and ungrazed plots, were almost certainly due to the dampness of these fields, which, being flat and low-lying, were frequently flooded.

The results in table 3.2 show that the grazing activity of the geese through the winter reduces the June silage yield. This yield loss is, however, rather less marked than in the spring. Again the effect is more severe on heavier grazed first-year grass. On some older pastures the reductions were not statistically significant (probabilities and sample sizes are given in the table). The marked difference in yields of the first-year pastures at Craigens in 1986 and 1987 is probably a result of differences in the climate between the two years. The spring was considerably earlier in 1987, so growth was much advanced relative to the previous year when the spring was later than average. Both silage and spring yields decline with increasing age of the pasture as well as winter goose grazing pressure. To separate the two factors more distinctly it is important to look firstly at the relationship between the intensity of grazing and yields in detail, and, secondly, to investigate the relationship between age of pasture and preferred goose grazing sites (see chapter 4).

The success of the electric fencing technique to manipulate goose grazing pressure is shown in fig 3.2. Comparison of the goose usage of the electric fenced plots and the adjacent controls shows that the grazing pressure was reduced by up to 65%. In one field in one year there were problems with grazing of these fenced plots by Roe Deer. They left large numbers of droppings in the areas

Fig. 3.2 Effect of electric fencing on goose grazing



that they had been grazing heavily, so these plots were excluded from the results.

Table 3.2 : Effect of goose grazing on June silage yield

Field	Year	Age of grass	Ungrazed g/m^2 (s.e.;n)	Grazed g/m^2 (s.e.;n)	
Craigens 1	'86	1st-yr	749.3 (79.6;6)	510.2 (19.9;26)	*
Skerrols	'86	3rd-yr	720.0 (38.1;4)	482.9 (24.9;11)	*
Craigens 1	'87	2nd-yr	871.3 (58.9;7)	830.2 (68.4;9)	n.s.
Craigens 2	'87	1st-yr	1426.0 (55.8;8)	911.3 (43.3;9)	***
RSPB 1	'85	"	664.1 (78.5;3)	420.9 (27.4;6)	*
RSPB 3	'85	10 yrs	527.7 (44.3;5)	446.4 (19.2;9)	n.s.

(*** = $P<0.001$, * = $P<0.05$, n.s. = not significant $P>0.05$, Students T-test; standard errors and sample sizes, n, are given in the table)

The results of the electric fencing experiment, showing the relationship between the amount of goose grazing through the winter and the subsequent spring yield in 1986 and 1987 are given in figures 3.3 and 3.4 respectively. In 1986 there was a strong negative correlation ($r=-0.671$, $P<0.001$, $n=42$), with the most intensively grazed plots producing the lowest yields. In 1987, however, there was a significant positive correlation ($r=0.448$, $P<0.01$, $n=49$), though this was not as strong as the negative relationship of the previous year. Goose grazing pressure accounted for 45% of the variation in yield in 1986, but only 20% in 1987 (calculated from

Fig. 3.3 Relationship between goose grazing pressure and green grass yield at end April 1986

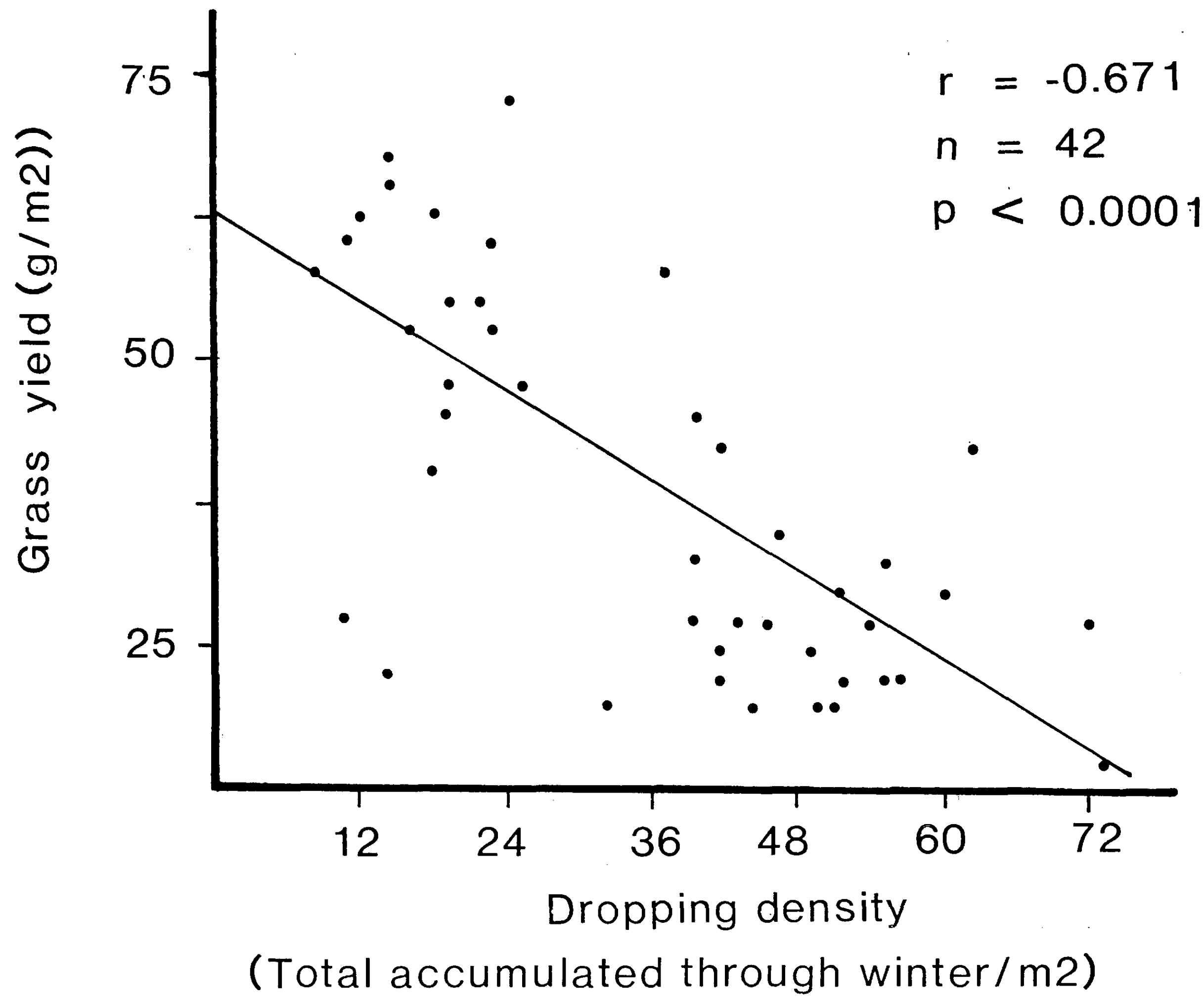
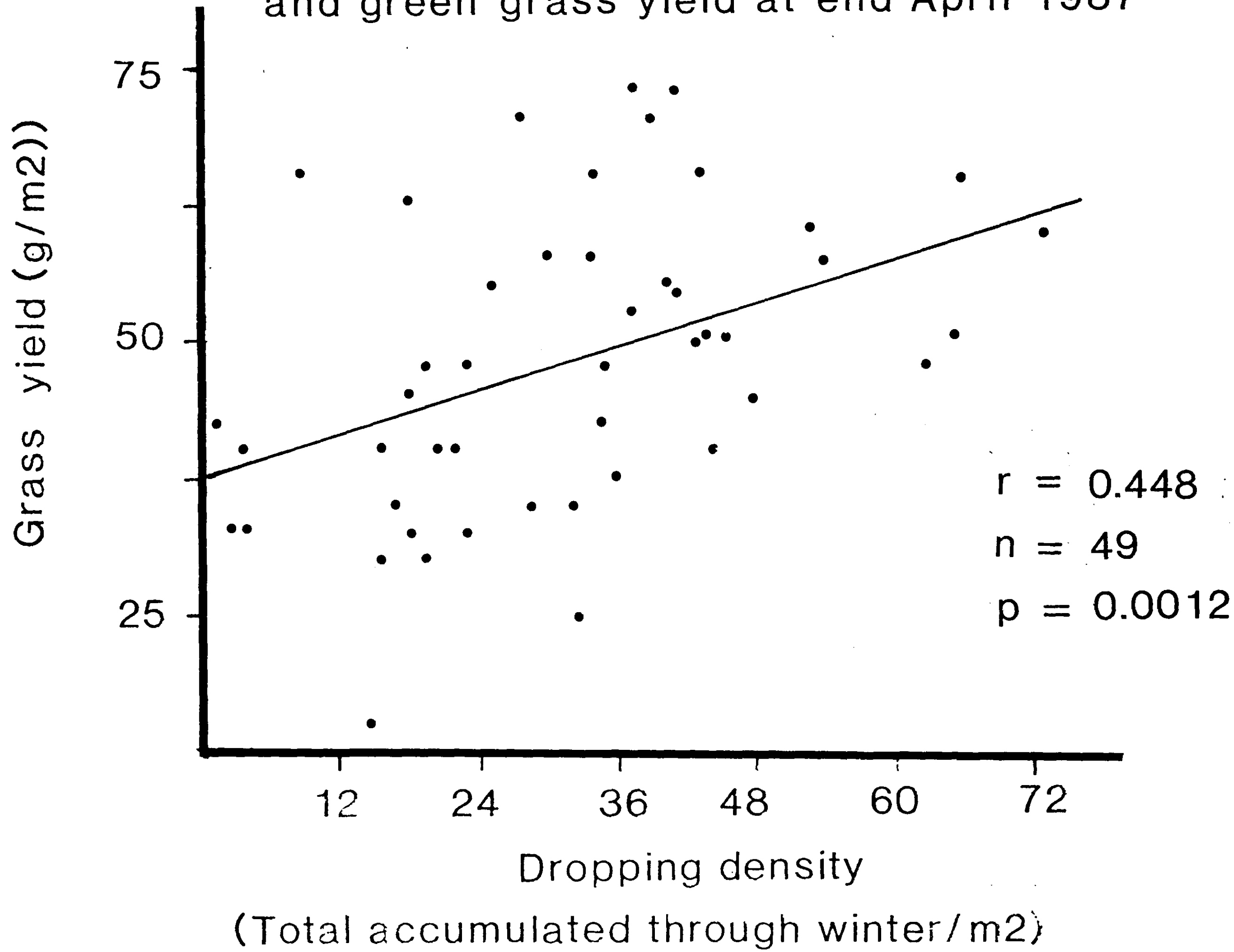


Fig. 3.4 Relationship between goose grazing pressure and green grass yield at end April 1987



r-squared values). In 1987 plots which supported the most geese through the winter gave the greatest spring yields. A comparison of the two years' data on the relationship between goose grazing pressure and spring grass yield is shown in figure 3.5, where both data sets have been plotted together. This graph illustrates that the major difference between the two years was found only in situations of high goose grazing pressure. There, the two years' data are almost completely separate, whereas in the less heavily grazed plots there is considerable overlap of data points in the two years.

The correlations between goose grazing pressure and yield were still apparent at the time of silage cut in both 1986 ($r=-0.349$, $P=0.001$, $n=113$; fig 3.6) and 1987 ($r=0.519$, $P=0.002$, $n=47$; fig. 3.7). These coefficients are not quite as high as those from the spring yields, but they are still statistically significant and are still in opposite directions in the two years. The extra data in 1986 were obtained from the control plots used in the fertilizer application experiment described in chapter 4. No grass samples were taken as part of the 1987 fertilizer experiments, so the sample sizes are smaller.

Figure 3.8 shows the effect of goose grazing on the amount of vegetation lost (calculated as the difference between the standing crops in pairs of grazed and ungrazed plots). Both years' data have been summarised on the

Fig. 3.5 Comparison of the relationships between goose grazing pressure and green grass yield at end April 1986 and 1987

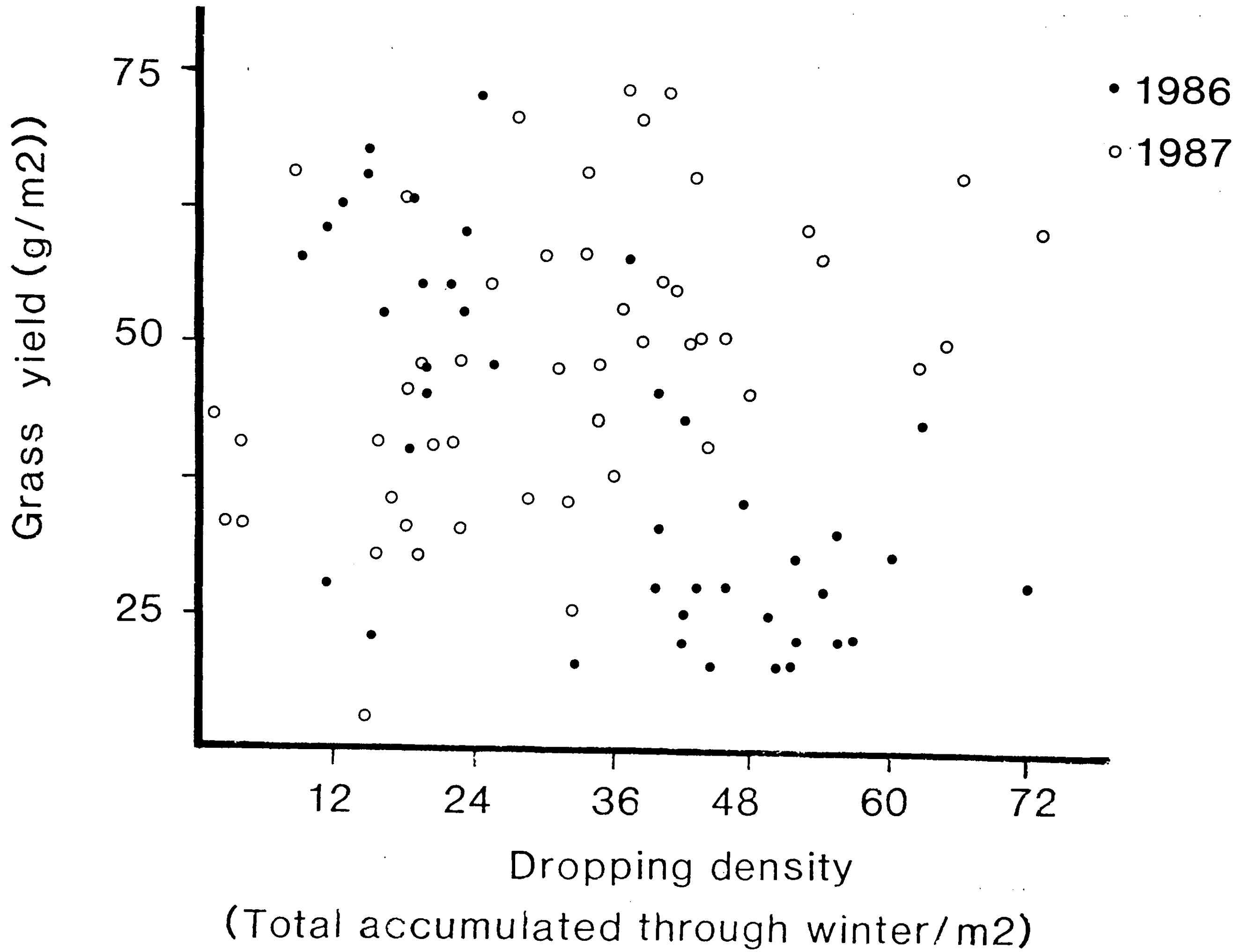


Fig. 3.6 Relationship between goose grazing pressure and silage yield in mid-June 1986

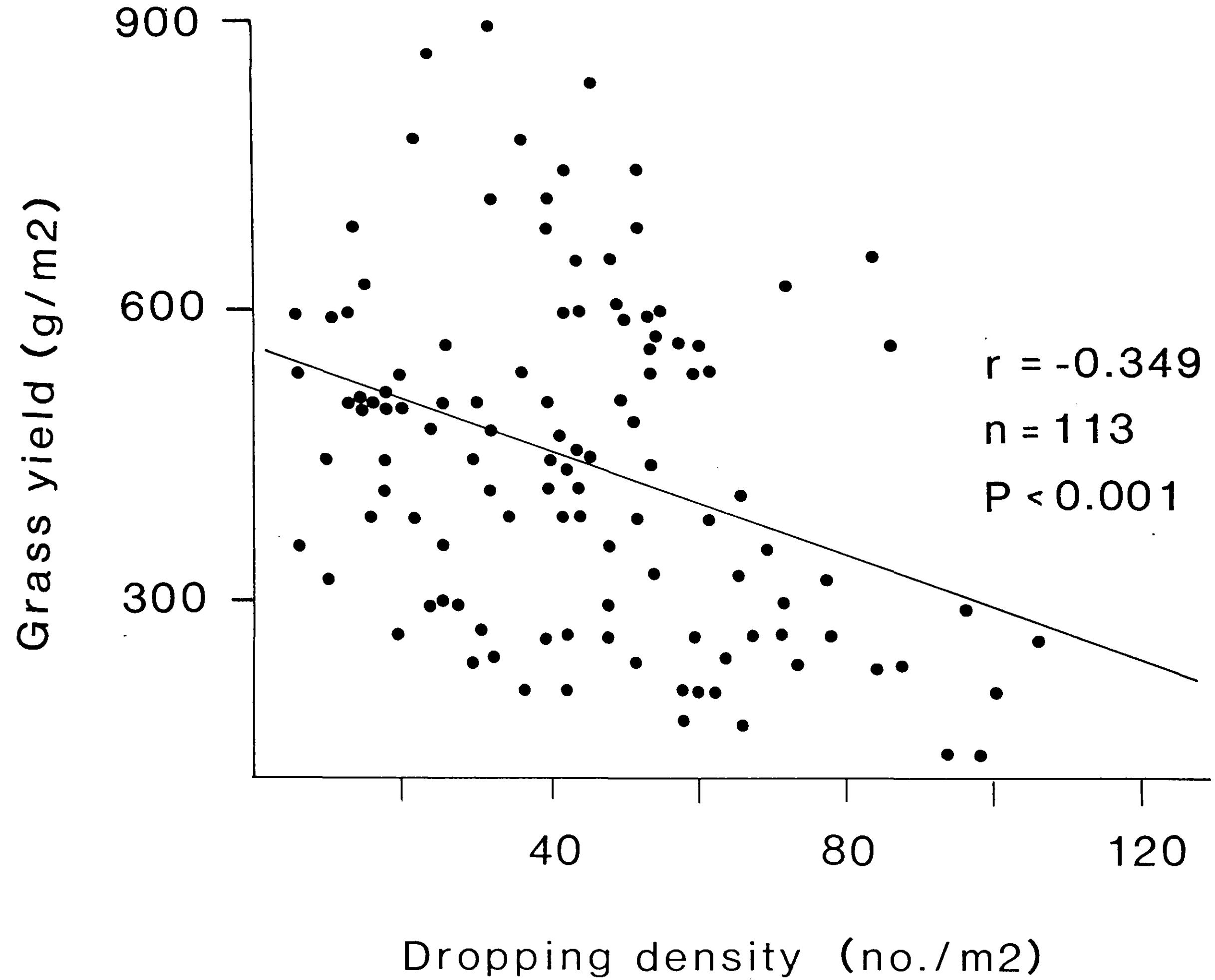


Fig. 3.7 Relationship between goose grazing pressure and silage yield in mid-June 1987

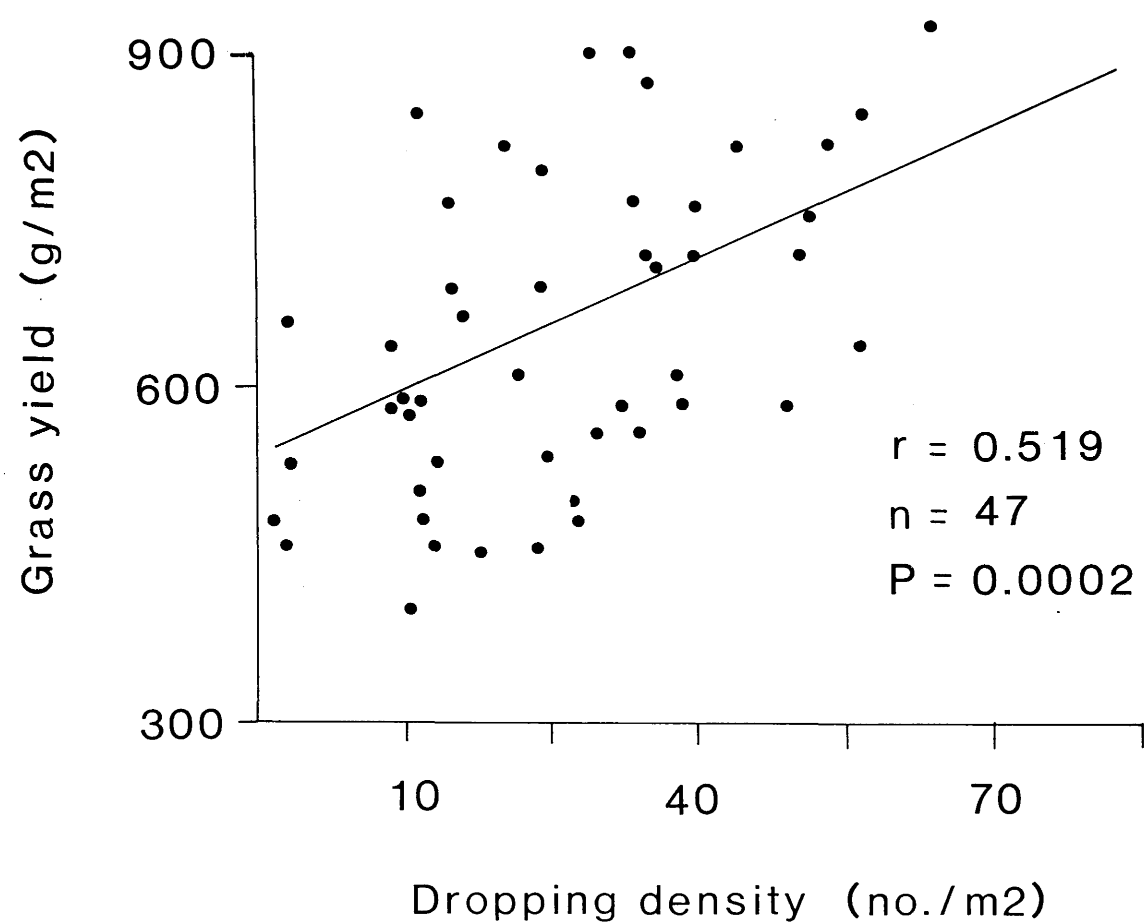
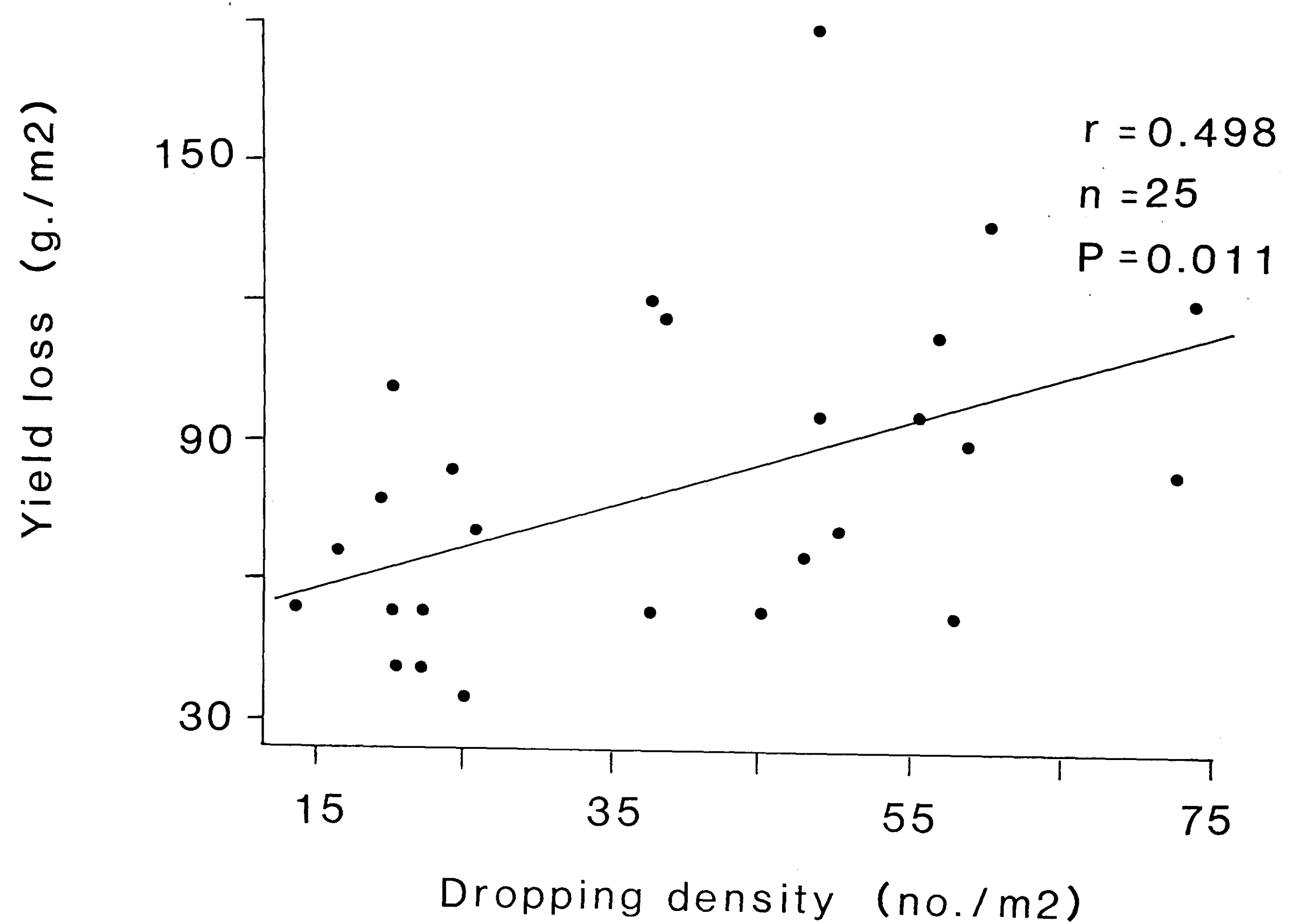


Fig 3.8 Relationship between goose grazing pressure and grass yield loss (Ungrazed plot yield - grazed yield)



graph, and exhibit a positive correlation between yield loss and grazing pressure. This correlation is statistically significant (r=0.498, P=0.011, n=25) when both years are considered together, but goose grazing still only accounts for 25% of the variation in loss of spring yield between plots.

A similar trend of increasing yield loss with increasing grazing pressure was found at time of silage cut (fig. 3.9), but the correlations were not statistically significant, even when both years' data were combined (r=0.313, P=0.09, n=30).

The effect of goose grazing on spring sward quality is shown in table 3.3. The geese significantly increase the protein content and so enhance the nutritional quality of the pasture.

By the time of the silage cut, the enhancement of the protein content of the sward resulting from winter goose grazing had disappeared. No significant difference was found between the protein content of the grazed and ungrazed plots in any of the study fields. The results are presented in table 3.4.

Fig 3.9 Relationship between goose grazing pressure and silage yield loss (Ungrazed plot yield - grazed yield)

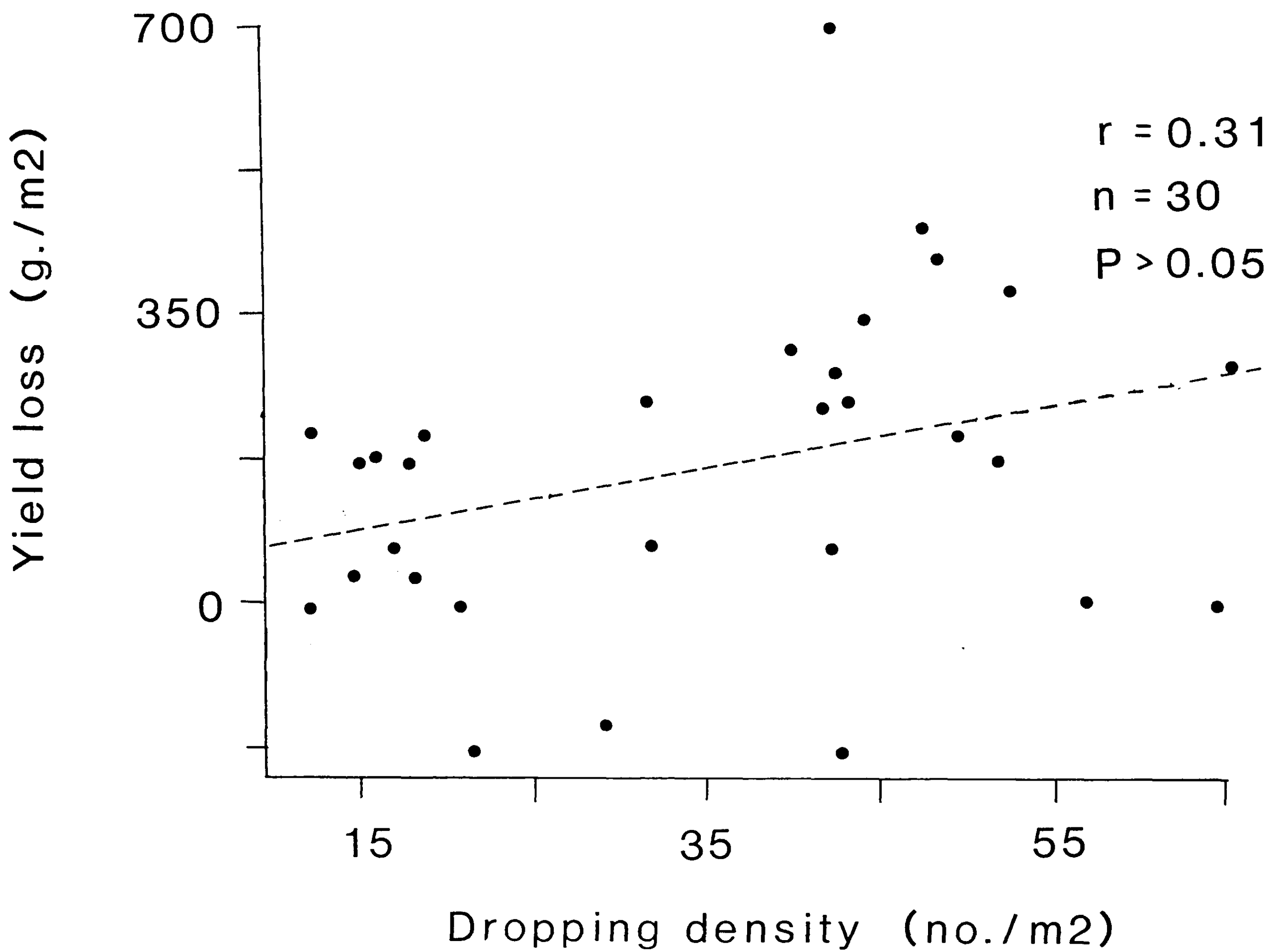


Table 3.3 : Effect of goose grazing on spring yield crude protein content

Field	Year	Age of grass	Ungrazed % dm (s.e.;n)	Grazed % dm (s.e.;n)	
Craigens 1	'86	1st-yr	19.7 (0.3;6)	25.0 (1.0;15)	***
Skerrols	'86	3rd-yr	18.1 (0.4;5)	23.3 (0.5;12)	***
Craigens 1	'87	2nd-yr	20.1 (1.2;7)	26.4 (3.6;9)	***
Craigens 2	'87	1st-yr	23.2 (0.9;10)	29.3 (0.8;8)	***
RSPB 1	'85	"	12.7 (1.6;3)	22.7 (1.3;8)	***
RSPB 2	'85	"	16.0 (1.0;4)	19.0 (0.7;8)	***
RSPB 3	'85	10 yrs	17.1 (2.8;3)	23.8 (1.4;7)	*

(%dm = % crude protein content of dry matter, *** = P<0.001, * = P<0.05, Students T-test; standard errors and sample sizes, n, are given in the table)

Table 3.4 : Effect of goose grazing on silage yield crude protein content

Field	Year	Age	Ungrazed % dm (s.error;n)	Grazed % dm (s.error;n)	
Craigens 1	'86	1st-yr	13.2 (0.6;6)	12.6 (0.3;26)	n.s.
Skerrols	'86	3rd-yr	10.4 (0.9;4)	11.9 (0.4;11)	n.s.
Craigens 1	'87	2nd-yr	12.9 (0.8;9)	12.5 (0.3;9)	n.s.
Craigens 2	'87	1st-yr	13.0 (0.9;10)	11.6 (0.5;9)	n.s.
RSPB 1	'85	"	15.9 (0.6;3)	15.9 (1.2;6)	n.s.
RSPB 3	'85	10 yrs	14.2 (1.9;5)	15.6 (0.9;8)	n.s.

(%dm = % crude protein content of dry matter, n.s. = not significant P>0.05, Students T-test; standard errors and sample sizes are given in the table)

Protein content is an important measure of sward quality, but fibre ought also to be taken into account when considering the quality of the herbage for feeding stock, as it can restrict an animal's access to the other components of the plant. The ratio of the protein to fibre content of the sward is thus a better measure of such quality. Table 3.5 gives the results of the grass analyses expressed as protein/ fibre ratios for each of the main study fields at the time of the first silage cut, showing how goose grazing affects the quality of the silage. For the first-year pastures, these results agree with those of the protein analyses taken on their own: the geese had no effect on the quality of the silage. However, on the older pastures, there was a significant increase in the protein: fibre ratio. Plots which were grazed had a lower fibre content, and hence higher protein: fibre ratio, than those which were ungrazed. Though statistically significant, this enhancement in the quality of the silage is too small to be of any great agricultural significance.

Table 3.5 : Effect of goose grazing on the protein:fibre ratio (P:F) of the silage cut

Field	Year	Age	Ungrazed P:F (s.e.;n)	Grazed P:F (s.e.;n)	
Craigens 1	'86	1st-yr	0.50 (0.02;6)	0.49 (0.01;26)	n.s.
Skerrols	'86	3rd-yr	0.35 (0.02;4)	0.43 (0.01;11)	*
Craigens 1	'87	2nd-yr	0.47 (0.02;9)	0.52 (0.02;9)	*
Craigens 2	'87	1st-yr	0.47 (0.03;10)	0.49 (0.02;9)	n.s.

(* = $P<0.05$, n.s. = $P>0.05$, Students' T-test).

Timing of Goose Damage to Pastures

The results above showed that the geese can significantly reduce both spring and silage yields. Exclosures erected for different periods during the winter provide information about when this damage is taking place (table 3.6). The results suggest that the yield reduction is a consequence of prolonged grazing throughout the winter; plots protected from grazing for the whole winter gave a significantly higher yield than those shielded from mid-March ($P<0.01$, Students' T-test - standard errors and sample sizes are given in the table), and both were significantly greater than those protected during April only (both $P<0.01$).

Table 3.6 : Spring yields of grassland plots protected from goose grazing for different periods through the winter

Period of protection	Craigens		Skerrols	
Whole winter	120.0 (12.7;6)		119.7 (11.5;6)	
From 15th March	87.0 (3.2;6)	**	-	
From 3rd April	46.1 (3.6;6)	**	70.4 (7.1;6)	**
None	24.1 (0.9;15)	***	56.7 (2.2;12)	*

(values are mean green grass biomass in grammes per sq.m (+/- s.error; sample size, ** indicate probabilities from Students' T-test between sample and the previous one from that site, ** = $P<0.01$, * = $P<0.05$)).

Table 3.7 shows that there was a similar result for the timing of damage to the silage yield. Plots protected during April gave significantly lower yields than those protected for the whole winter and spring ($P<0.05$, Students' T-test, samples and standard errors are given in the table). Thus grazing through the winter prior to these plots' protection in April must have had a significant effect in reducing silage yield.

Table 3.7 : Silage yields from plots protected from goose grazing for different periods of the winter and spring

Period of Protection	Craigens	Skerrols
Whole winter	749 (80;6)	720 (38;4)
From 3rd April	627 (43;6)	568 (30;6)
None	510 (25;26)	483 (25;11)

(values are mean green grass biomass g. per sq.m (+/ s.error; sample size)).

Effect of early spring fertilizer application

The application of nitrogen fertilizer to plots in early March increased the spring yield of both grazed and ungrazed plots (table 3.8). The increase in yield was highest inside the exclosures. It is perhaps this treatment which models most accurately how the grassland would be managed in the absence of the geese. Application of nitrogenous fertilizer to goose grazed swards did give a significant increase in yield, but the size of this increase was much less than that recorded on ungrazed plots which were fertilized. The geese were removing most of the extra yield produced by the fertilizer on the plots to which they could gain access.

Table 3.8 : Effect of early spring fertilizer application on spring yields

Treatment	Ungrazed g/m^2 (s.error;n)	Grazed g/m^2 (s.error;n)
Fertilized	357.1 (38.3;3)	83.0 (11.4;3)
Control	151.7 (16.9;8)	51.3 (3.1;9)
	***	**

(***, $P<0.001$, **, $P<0.01$, Students' T-test)

There was still a significant difference between the yields of the fertilized and unfertilized samples at the June silage cut ($P<0.05$, Students' T-test), though the differences were proportionately much reduced (table 3.9). Control ungrazed plots had almost compensated for their lack of earlier nitrogen application.

Table 3.9 : Effect of early spring fertilizer application on silage yields

Treatment	Ungrazed g/m^2 (s.error)	Grazed g/m^2 (s.error)
Fertilized	1642.7 (72.6;3)	1076.3 (53.9;3)
Control	1426.0 (55.8;8)	911.3 (43.3;9)
	*	*

(*, P<0.05, Students' T-test)

The results of the experiment to investigate the shelter effect of the exclosure cages are given in table 3.10. The exclosures erected after the departure of the geese in early May showed no significant difference in silage yield to the grazed plots (P>0.05, Students' T-test), suggesting that the exclosures themselves had no significant effect on the performance of the grassland. This conclusion is supported further by the fact that the differences in silage yields between grazed and protected plots on some fields were not significantly different (for example the plots on Craigens field 1 in 1987). Had the exclosures been having a shelter effect or if other herbivores were affecting the results, this lack of a significant difference would be difficult to explain.

Table 3.10 : Effect of the exclosure cages on silage yield

	Yield at silage cut g/m^2 (s.error;n)
Grazed plots	911.3 (130.0;9)
Control exclosures (erected after goose departure)	826.4 (153.9;3)

(no significant difference, P>0.05, Students' T-test).

The results of the experiment to investigate the effect of using different mesh sizes for the exclosure cages are shown in table 3.11. There is clearly no significant difference in the grass yields from the three sizes of exclosure mesh (oneway ANOVA: F ratio=0.012, P=0.99, 2 d.f., n=3 for each mesh size).

Table 3.11 Spring yields from exclosure cages of different mesh sizes

Mesh size	Mean grass yield (g/m^2)	(s.error;n)
2-inch	85.0	(14.0;3)
1-inch	86.7	(9.2;3)
1/2-inch	87.0	(3.3;3)

Discussion

Impact of the Barnacle Geese on Islay's agriculture

The results have shown that Barnacle Geese can have a very significant effect on Islay's agriculture. Experiments using exclosure cages showed that the major effect of the geese was to reduce the yield of the grassland. It is very unlikely that the cages themselves were contributing significantly to the estimates of yield loss, for four main reasons :-

1. No differences in yield were found between unexclosed control plots and ones which had cages erected on them after the geese had left the study area in the spring. If the cages were affecting the grassland micro-climate and hence grass growth, a difference would have been expected.

2. In conditions of low goose grazing pressure, no significant difference in silage yield was found between grassland plots which had been open to grazing all winter and those which had been protected by the cages. Again, a difference would have been expected if the cages were improving the conditions for grass growth.

3. Other herbivores were unlikely to be affecting the results as they were present in the study areas in much lower numbers than the geese, and hence were only

contributing to a small proportion of total herbage consumption.

4. An experiment investigating the size of the cage mesh found there to be no significant difference in grass yield from the plots protected by the three different sizes of mesh tested, even though the smallest (half-inch mesh) could have been thought to have a much greater potential sheltering effect than the size used in the main experiments (2-inch).

The yield loss was greatest in the early spring, when farmers would have had lambing ewes grazing the fields to take off the nutritious flush of spring grass growth. The presence of grazing Barnacle Geese meant that as much as 80% of this spring growth was unavailable to farm stock. The magnitude of this spring yield loss was greater in areas of heavier goose grazing pressure, but was still highly significant on less heavily grazed fields. The total spring yield reductions, of between 0.5 and 1.0 tonnes per hectare, on lightest and heaviest-grazed fields respectively, represent substantial losses to the farmer. These losses are not quite as great as the maximum of 1.5 tonnes per hectare recorded by Patton and Frame (1981), but they are of the same order of magnitude.

There was also a marked reduction in silage yield in fields grazed heavily by the geese. The maximum loss measured was of 30% of the potential grass production, up to 5 tonnes per hectare. This loss would force the farmer to either have a larger area of land producing silage, buy in extra foodstuffs for stock, or cut the number of stock on the farm. All three could have a major impact on the farm economy. As with the spring yield, the trend was for greater loss in areas of higher goose grazing pressure, though the correlation was not statistically significant. These results agree closely with those found during a study of the impact of winter grazing on agricultural grassland in the Netherlands (Bruinderink 1987). Bedard and Gauthier (1986b), however, found a much stronger correlation between yield loss and goose grazing pressure, working on Snow Geese on their spring staging areas in Canada. This is probably explained by the timing of the exposure of the grasslands to goose grazing. The Canadian study was confined to a few weeks in the spring, rather than prolonged grazing through the whole winter.

As with the spring yield loss data, the results are in general agreement with those of Patton and Frame (1981). Their maximum silage loss of 9 tonnes per hectare was not quite reached during this study.

Ydenberg and Prins (1981) showed that goose grazing could bring about an enhancement of the protein content of a sward. In this study goose grazing was found to bring about considerable increases in the protein content of the sward at the end of April. This would make the grass more nutritious to farm stock, but the increase is by no means sufficient to compensate for the quantitative loss of biomass. The total protein content of the grazed sward is still much lower than that of the ungrazed grass, even though it is at a significantly higher concentration.

By the time of the first silage cut in mid-June, this protein enhancement brought about by goose grazing was no longer apparent, so the geese had no effect on the quality of the silage.

Early spring application of nitrogenous fertilizer to grazed and ungrazed swards showed that the geese were consuming most of the extra grass that this fertilizer produced. Thus the geese were causing further reduction in the availability of grass to farm stock. If the geese were not present, the fertilizer could be applied earlier and spring yields increased. With the geese present, however, the agricultural benefit of such application was minimal. This delay in application did not have such a major effect on the silage yield though. It is still a factor which should be taken into account in the assessment of the total goose impact on agriculture.

It is important to know when the geese are causing the agricultural damage, so that the most effective period to protect grasslands can be identified, and the most effective management strategy for the refuges designed. Kear (1965) found that damage caused to grassland by goose grazing only took place after March, suggesting that winter grazing had no significant effect on spring grass growth. If this were so on Islay, then effort to reduce the impact of the geese, such as scaring and the improvement of food supplies on the refuges, could be concentrated in the spring. However, the results of this study contradicted Kear's finding, as swards which were exposed to goose grazing through the winter only (that is ones which were grazed through the winter then protected by cages in the spring) had significantly lower spring yields than those protected through the whole year. This might be explained by the pattern and intensity of grazing, since Kear's work was based on experimental clipping and the use of captive birds, rather than a wild grazing regime. Grazing pressures in her experiments were also rather lower than those recorded on Islay during the current study. It is clear that on Islay the damage caused by the geese is a cumulative effect of grazing through the whole winter. A similar result has been found in recent work in the Falkland Islands (A. Douse, pers. comm.).

There is no doubt, from the results of the exclosure trials, that the geese were having a very large effect on grassland production, but the poor correlation between yield loss and goose grazing pressure showed that other factors were influencing yields as well. This fact is demonstrated most clearly by comparing the relationship between the spring yield and goose grazing pressure in 1986 and 1987. There was a significant correlation between the variables in both years, but they were in the opposite direction. This difference is most likely due to differences in the climate between the two years. In 1986, when spring temperatures were lower than average, the lowest spring yield was found in the area of highest winter goose grazing pressure. The geese were limiting net production of the pasture right until their departure at the end of April. In 1987, however, the relationship was rather different, with lower spring yields at lower grazing pressures. It was notable that most of the variation between the two years occurred in areas of high goose grazing pressure. In 1987 it would appear that the grass was out-growing the consumption by the geese, particularly in the areas of highest grass productivity, which also supported the most intense goose grazing pressure. Hence the highest grass yields came from the most heavily grazed plots.

The interaction between weather conditions and the impact of the geese was also found to be of great importance to the response of the sward to goose grazing by Bruinderink (1987). In a comprehensive study of the factors affecting goose damage to pastureland, he found temperature to be the most important factor affecting the magnitude of the impact of the geese. In cold winters damage was reduced, as less of the grass was available to be consumed and the geese moved south to alternative feeding areas.

In the first part of this chapter three main aspects of potential goose damage were suggested. In areas of most intense goose grazing evidence was found to support all three of them :-

a. There was a reduced spring yield, reducing the spring bite availability to farm stock on all experimental fields.

b. The silage yield was also much reduced through the winter grazing of the geese in areas of heavy goose grazing pressure.

c. Loss of spring yield was further increased by the delay in application of fertilizer.

At the present time farmers on the SSSIs are receiving substantial payments from management agreements to provide the geese with relatively undisturbed feeding sites and attract birds away from the non-refuge areas. Thus many of the farmers in the most heavily goose-grazed areas are receiving some form of income to offset economic losses to the geese. However, many farmers outside these refuge areas undoubtedly suffer damage to their pastures by the geese, but receive no remuneration at all.

There is much scope for further work to look in more detail at the response of the sward to grazing by geese. In particular, longer-term monitoring to look at the interaction of yield loss with weather conditions would be useful. More intensive work on the response of the individual grass plants to grazing through the winter and spring would help to explain why such damage is being caused. One aspect of potential goose damage that this study did not investigate, but which could be of some economic importance, is the possibility that goose grazing increases the rate of weed establishment in a sward. The result of this would be that reseeding of the fields would have to be undertaken more frequently. This would need to be assessed by carrying out a detailed study of the vegetation dynamics of the sward in relation to winter goose grazing.

Chapter 4 : FEEDING ECOLOGY OF BARNACLE GEESE ON ISLAY

Aims

The aims of the feeding ecology work were to identify the main goose feeding habitats, and to look at the basis on which any selection of these might be taking place. Goose grazing pressures were measured on a variety of differently managed pastures, and feeding behaviour of the geese recorded. It was intended to investigate the basic patterns of habitat preference and use these to suggest management techniques that might be used to increase the numbers of geese using the refuge areas. Thus answers to four specific questions were sought :-

1. What sites do the geese select for feeding? It has been suggested by Ydenberg and Prins (1981) that the time that Barnacle Geese graze a sward correlates primarily with the productivity of that sward. Thus any management technique which increases the productivity of a pasture, such as **reseeding** with high-yielding seed mixes and application of **fertilizers**, should also increase its level of goose grazing. Work by Owen et al. (1977) using captive Barnacle Geese supports this idea, and shows that geese select swards of high protein content. Owen (1975) using field trials at Slimbridge showed that White- fronted Geese, *Anser albifrons*, graze preferentially on pastures that have received nitrogenous fertilizer application. In

the current study, experimental treatments were made to improve pastures using reseeding and fertilizer application, to see whether they increased the level of goose grazing. Owen (1972) and Madsen (1986) have shown that, though food supply is of prime importance in a goose's selection of feeding site, **disturbance** can have a strong modifying effect, so it was also important to investigate this factor in this study.

2. Can the feeding preferences outlined above be exploited to increase the goose usage of the refuges?

3. Can selection of feeding sites be explained in terms of the behaviour of the geese? Optimal foraging theory predicts that they will show a preference for feeding where they can maximize their net food intake rate (Charnov 1976). It was aimed to discover whether the feeding rates of the Islay Barnacle Geese reflect the feeding site preferences that were being exhibited.

4. What are the food requirements of a Barnacle Goose through the winter? Using this information the theoretical carrying capacities of the refuges can be calculated, to see how many geese they might be capable of supporting.

This chapter has been divided into two sections. The first deals with questions one and two, investigating the grassland types that the geese are using. Section 4.2 looks in more detail at the feeding behaviour of the geese to answer questions three and four, about goose feeding rates and food requirements.

Section 4.1 Selection of feeding site by the geese

Methods

Habitat Selection by the Geese

The habitat selection of the geese was assessed in three ways :-

i) The main basis of this work involved the measurement of **dropping density** in a series of experimentally-managed fields. The density of droppings was measured in a series of permanent quadrats (Owen 1971). Each quadrat was a circle of one metre radius, marked by a small central peg, and droppings were counted and removed at 3-4 week intervals. Removal ensured that droppings were not double-recorded, and provided the most accurate method for counting droppings (Bedard and Gauthier 1986b). It is unlikely that this removal would have had any significant effect on the sward, as the amount of nutrients that the droppings provide is insignificant in comparison to the nutrients that the pastures receive in the form of inorganic fertilizer (Kear 1963). Some studies of goose ecology have found the droppings to give a significant fertilizer input to the vegetation, but these have generally been confined to work in low-nutrient environments such as the arctic tundra (Bazely & Jeffries 1985). Fifteen quadrats were allocated per field, positioned at random along transect lines. The transects (three per field) were chosen subjectively in relation to any directional factors which might affect goose grazing pressure. The number of droppings per unit area were used as an index of the goose grazing pressure. Additional information on the amount of time that the geese have grazed the area was obtained by multiplying the number of droppings by the dropping interval (measured as the time between successive droppings).

ii) **Direct counts** of geese were made in these same experimental fields, to compare the results with those obtained from the dropping counts, and over the wider area of the RSPB reserve and its neighbouring farms. Counts were made regularly at least twice per week by the warden (Moore 1985, 1986 & 1987) and myself. During the late winter and spring of 1987 these were extended to daily counts over the reserve and its neighbouring areas, as part of the radio-telemetry study (see chapter 5). The data from all these counts allowed comparisons to be made with the results from the dropping density plots. The counts were particularly useful in providing information about habitat use of the birds over a wider area than the dropping plots.

iii) **Radio-telemetry** of ten birds caught on the RSPB reserve in January 1987 allowed the monitoring of the habitat usage of these birds. This work gave some more information about habitat use by the geese. Each time a radio bird was located, the habitat it was using was recorded. This provided an unbiased method of making spot observations on individual geese and hence to calculate the proportion of locations which were recorded for each habitat. Details of the methods used in this telemetry study are given in chapter 5.1.

1) Reseeding experiments

Two main types of grassland were used in the study; areas reseeded within the previous three years (recently improved pasture), and areas which had not been reseeded in the last ten years (old pasture). Adjacent fields of grassland of different age but equivalent size and topography were chosen, so that the samples could be paired. The dropping densities in eight of these paired fields were measured through the three winters of 1984/5 to 1986/7, to allow comparisons of goose grazing pressure to be made between years. Of these fields, two (totaling 28.1 hectares) were reseeded in the summer of 1984, two (24.5 ha.) in summer 1985, and two (28.5 ha.) in summer 1986, while the remaining two (22.6 ha.) remained as old pastures through all three winters. Block A fields were reseeded in the summer of 1984, so they allow the comparison of the relative use of a reseed in its first three winters. Block B fields were reseeded in summer 1985, so were old pasture in the 1984/5 season, and reseed in 1985/6. Block C fields were reseeded in summer 1986, so were old pastures for the first two winters, and reseed in the last. Block D fields remained as old pasture in all three years, so are a useful control. This allowed between-winter comparisons of goose grazing pressure on the fields to be made before and after reseeding, as well as within-winter comparisons of different pasture types. All fields in this part of the study were used primarily for silage-making, and were not grazed by farm stock from November to the end of June. Reseeding was carried out using commercial agricultural seed mixes, dominated by rye grass, Lolium perenne, which are used widely on the island.

2) Fertilizer experiments

All fields chosen for these experiments were relatively well-drained: many other fields in the study area could not be used, as they were too wet to allow tractor access, which was necessary to apply the fertilizer. Three fields were chosen to receive extra applications of fertilizer in the 1985-6 season. Two trials were used, one an application of extra inorganic nitrogenous fertilizer (Nitram, 32% nitrogen), the other an addition of lime. In both, the fertilizer was applied in 10m wide strips across the field, with each strip interspersed by a 10m wide untreated control strip. The grazing pressure was measured using dropping plots, with 15 plots in fertilized strips and 15 in the untreated controls.

The nitrogenous fertilizer was applied at a rate of 125 kg/ha. to two fields; one a recently reseeded pasture, and one older grassland which had not been reseeded in the last ten years. Two applications were made, one in mid-October and one in late February (around the T-Sum 200 date: this date is calculated as the date on which the sum of the positive maximum daily temperatures since January 1st of that year exceeds 200 Celsius - it is used in agricultural terms as a measure of the time after which the climatic conditions are such that the grasses are able to utilise the extra nutrients for increased growth). The experiment was repeated in the 1986-7 season, but using Nitrochalk (25% nitrogen) rather than Nitram (as this is less susceptible to leaching and remains available to the plants for a longer period), and applying it at an increased rate of 175 kg/ha. In October 1986 the ground was sufficiently dry to allow tractor access to one of the damper improved pastures on the reserve (a 1984 reseed), enabling autumn fertilizer trials of the same design to be carried out on this field also. A repeat spring application was not possible.

Only a single application of lime was made, in July 1985, to an old pasture (not reseeded in the last ten years). Lime does not usually affect the short-term yield as much as nitrogenous fertilizer, but it can have a 'sweetening' effect on the sward, and increase the soil pH.

3) Effect of disturbance on goose grazing

This was investigated by monitoring the accumulation of droppings on a series of plots placed at a range of distances (25-1000 metres) from two potential sources of disturbance to the geese; (a) a minor road, which crosses the reserve and has a traffic density of approximately 50 cars per day, and (b) the main RSPB reserve farm buildings, which are used actively on a daily basis to house and feed cattle and are thus subject to much human disturbance. The plots were arranged in transects, each of five one-metre radius quadrats running perpendicular to the gradient of disturbance.

Measurement of biomass available to the geese

It had been hoped to monitor the amount of grass available to the geese in the study fields through the winter by using a spectrophotometer to measure green biomass (Mayhew et al, 1984). This could have provided information about why the geese preferred some areas over others and tested the hypotheses that they graze in relation to the amount of standing crop and the productivity of the pasture. Unfortunately the weather conditions required by this machine, (uniform cloud cover without any precipitation), were very infrequent on Islay during the winter, and the machine itself proved to be unreliable. Monitoring of actual food availability through the winter was, therefore, not possible.

Using data from the dropping counts and the grass clippings taken at the end of April (see chapter 3), it was possible to calculate an estimate of the total net primary production of the sward through the winter. Estimates for digestibility have been derived from Owen (1980).

Amount of grass taken by the geese per unit area = No. of droppings per unit area x mean dropping weight / (1-digestibility)

Total winter production = biomass taken by the geese + biomass remaining at the end of April.

The grass clippings also provided some information about the quality of the sward. Their protein content was analysed using a modified Kjeldahl method (see chapter 3).

Results

Effect of reseeding on goose grazing

1. Dropping density data : table 4.1 shows the within- and between- year comparisons of goose grazing on the experimental field blocks. The attractiveness of newly reseeded pasture to the geese is shown by (i) the large increase in dropping density (and therefore goose grazing pressure) that occurred when a field was reseeded (comparing data on the same field block between years), and (ii) the comparison of dropping densities of reseeded and old grassland blocks in the same year. The magnitude of the increase in goose grazing pressure following reseeding declined each winter, as the total cover of recently reseeded grassland in the area increased. This is primarily a result of the amount of improved pasture available to the geese. In 1984-5 only 28 ha. of the RSPB's grassland were less than five years old, but by 1986-7 this had increased to 81 ha. The geese appear to be spreading their grazing around the reserve more, rather than increasing in numbers. This hypothesis is supported by the goose counts on the reserve, which do not show any significant increase over the three winters despite the increasing area of improved pasture (Moore, 1985-7).

Table 4.1 : Annual variation in winter goose grazing pressure on pastures of different age

	Use in 1984/5	Use in 1985/6	Annual change	Use in 1986/7	Annual change
Block A (1984 reseeds)	95.5 (6.5)	64.6 (1.9)	-32%	59.0 (1.6)	-9%
Block B (1985 reseeds)	43.8 (6.0)	73.1 (3.9)	+67%	49.7 (1.7)	-32%
Block C (1986 reseeds)	39.8 (4.2)	40.4 (2.1)	+2%	62.6 (1.7)	+55%
Block D (old pastures)	39.8 (4.2)	40.4 (2.1)	+2%	31.3 (2.4)	-23%

(underlined values indicate a field block in its winter immediately following reseeding : all values, except % change, are mean no. droppings per sq.m accumulated through the winter (+/- standard error); sample size = 30 plots for each field block).

The seasonal pattern of the use of reseeded and old pasture is shown in fig. 4.1. Both show a rather similar pattern of heavy autumn use, a decrease in mid-winter and a slight and steady increase in spring. These generally reflect the numbers present in the Gruinart study area (Moore, 1986). The selection for reseeded pasture (expressed as the difference between the grazing pressures on the old and new pastures) is strongest in the autumn (see fig 4.1).

2. Count data ; The count data on habitat use are summarised in table 4.2 below. Like the dropping density data, they too show that geese have a strong preference for reseeded pasture. When the area of each habitat type is taken into account, these data show that over the reserve as a whole, extensive use is made of older pastures.

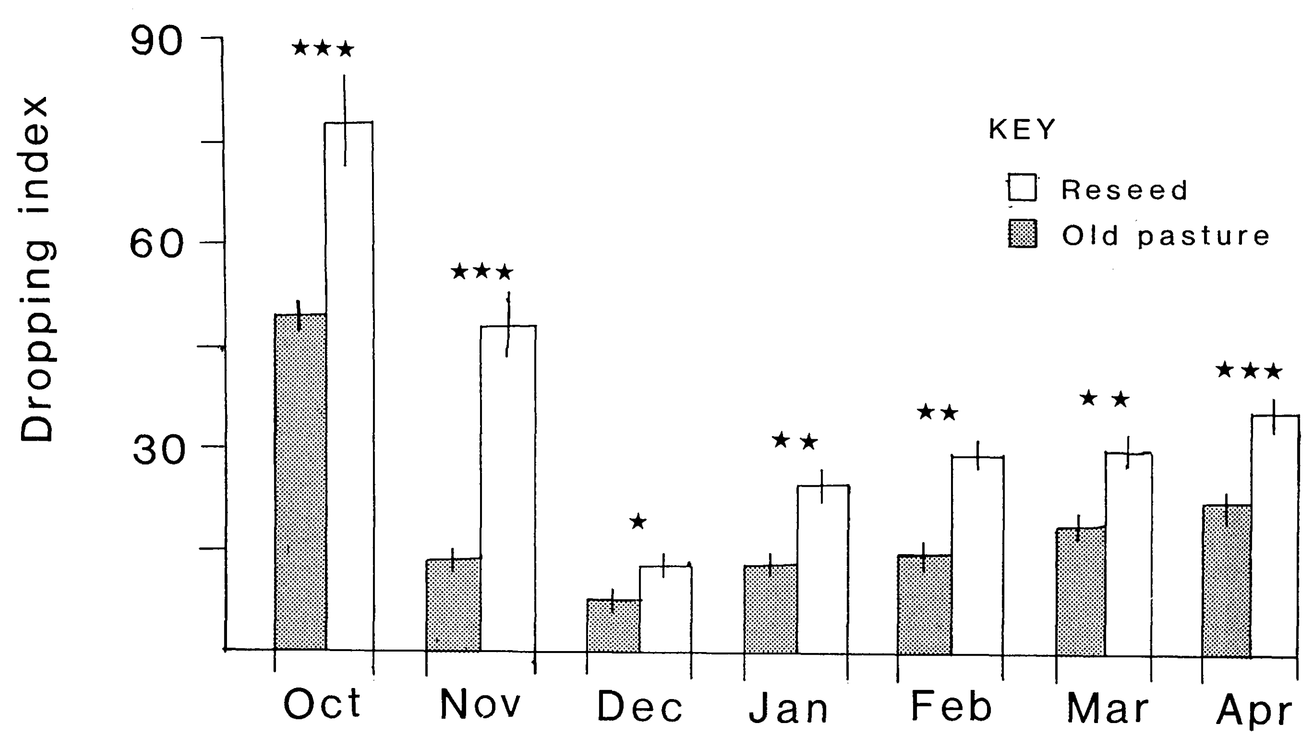
Table 4.2 : Habitat use of Barnacle Geese on the RSPB reserve, measured from direct counts

	Area (ha)	1984/5	1985/6	1986/7
1984 reseeds	28.1	1344	988 (-26%)	650 (-34%)
1985 reseeds	24.5	606	1135 (+87%)	826 (-23%)
1986 reseeds	28.5	332	490 (+48%)	1024 (+110%)
Old pastures	300	293	361 (+23%)	243 (-33%)
Saltmarsh	25.0	-	-	172

(underlined values indicate a field block in its winter immediately following reseeding : counts are expressed as goose-days per hectare, with the annual change for each block given in brackets).

The correlation between the count data and the dropping densities in the main study fields was high ($r=0.762$, $n=28$, $P<0.001$). There were a few fields, however, where the discrepancy between the counts and the dropping densities was considerable. Two factors probably account for this: firstly, in well-hidden fields, birds may sometimes be missed during the counts, and secondly, the

Fig. 4.1 Effect of pasture age on seasonal pattern of goose grazing



counts are all made in daylight, so they take no account of night-feeding.

3. Radio-telemetry data ; Table 4.3 shows that the radio-telemetry work, like that of the dropping plots and the direct counts, demonstrated that the geese were exhibiting a preference for recently reseeded pasture. The selection is not as strong, however, as that shown by the dropping densities and the counts. This is explained by the timing of the radio study; it was carried out during January to April, excluding the autumn period when selection for reseeded pasture is strongest (see fig. 4.1, discussed above, on the seasonal pattern of use of the different pasture types). The preference for 1984 reseeds which the radio birds showed resulted primarily from their site of capture: the birds were originally caught at the north end of the RSPB reserve, adjacent to the 1984 reseeds. The 1985 and 1986 reseeds were located slightly further from most of the birds' core range areas. The individual goose daily feeding patterns which underlie this selection are discussed in chapter 5.

Table 4.3 : Habitat records of the birds carrying radio-transmitters, 1987.

Pasture	No. fixes	% of fixes	% of area	Preference
1984 reseed	204	31.1	6.6	4.71
1985 reseed	75	11.5	5.8	1.98
1986 reseed	46	7.0	6.7	1.04
Old pasture	314	47.9	70.6	0.68
Saltmarsh	16	2.4	5.9	0.41

('Preference'=% fixes/% area, chi-squared test, for the null hypothesis that the birds occur randomly in relation to the area of habitat available; $X^2 = 699.9$, $P<0.001$, 4 degrees of freedom).

The counts and radio-telemetry fixes give data on the habitat usage of the geese over a wider area than the dropping plots, and also provide information about habitats, such as saltmarsh, which could not be measured effectively using dropping plots. None of the three methods provided any data about another habitat which might be of some importance to the geese as a feeding site, the barley stubble fields. None of these was located in the main study area, so a quantification of their use was not obtained. There were generally only a few of these fields, and they were used irregularly by the geese in large numbers in the autumn.

Effect of Fertilizer Application on Goose Grazing Pressure

The results of the fertilizer application experiments are summarised in table 4.4, comparing total winter goose grazing pressure on fertilized and unfertilized strips. In 1985/6 no significant difference was found between the total winter use made by the geese of the treated and untreated strips in either of the two fields which received additional nitrogen, nor in that to which lime was applied ($P>0.05$, Students' T-test; $n=15$ for each treatment). In 1986/7, however, when a more persistent nitrogen fertilizer was used at a greater application rate, a significant increase in goose grazing was found on the old and damp improved grasslands (see table 4.4 for details of the statistical tests). There was still no significant difference in the goose usage of the fertilized and unfertilized strips of the dry improved pasture. The ineffectiveness of the fertilizer on goose grazing on the dry recently improved pasture was probably due to a super-abundance of nitrogen in the soil at that time, as the field was known to be rich in nutrients (Anon 1986). The relatively high use of the older pasture in the nitrogen experiment deserves some comment, as its total winter use was almost as high as some areas of recently reseeded pasture. This is mainly attributable to its close proximity to a major roost (on the mudflat adjacent to the field).

Table 4.4 : The effect of fertilizer application on goose grazing pressure

		1985/6		1986/7	
1. Nitrogen Application					
Recent improved pasture (dry)	- fertilized	55.0 (3.7)	ns	43.9 (2.4)	ns
	- unfertiliz.	54.2 (2.9)		37.4 (2.8)	
Old pasture	- fertilized	65.2 (2.4)	ns	66.6 (2.4)	**
	- unfertiliz.	65.0 (2.5)		46.2 (2.2)	
Damp recent imp pasture	- fertilized	-		80.2 (3.0)	**
	- unfertiliz.	-		57.4 (2.2)	
2. Lime applic.	- treated	46.8 (3.4)	ns	-	
	- untreated	45.6 (2.8)		-	

(all values are mean no. of droppings per sq.m accumulated through the winter (+/- standard error); sample size = 15 plots per treatment).

The lack of any response shown by the geese in 1985/6 suggests that the treatments were not effective in that year. The grass analyses showed this to be true, with no significant difference in the protein content of the fertilized and unfertilized swards (P>0.05, Students' T-test; n=7). It is possible that the ambient temperatures following the nitrogen applications were too low to bring about a response in the sward. Alternatively, the Nitram used in 1986 was much more water- soluble than the Nitrochalk used in 1987, and would therefore have been more susceptible to leaching out of the soil.

The differences in the seasonal pattern of goose grazing pressure on fertilized and unfertilized strips in 1986/7 are shown in figs 4.2 and 4.3. Fig. 4.2 shows the pattern on the old pasture, which received two fertilizer applications, one in mid-October and one at the end of February. The geese showed very strong selection for the fertilized strips in November and December, but by January there was no significant difference in dropping density between the two treatments. After the second application, the fertilized strips were used significantly more by the geese then the unfertilized ones in April.

Fig. 4.3 shows the seasonal pattern of goose grazing on the damp improved pasture, which received only one fertilizer application, in mid-October. As on the old pasture, the geese showed a strong preference for fertilized strips in November and December, but thereafter there was no significant difference in the dropping densities recorded on the two treatments. No data on the seasonality of goose grazing pressure from the 1985/6 season, nor from the dry improved pasture in 1986/7 have been presented, as no significant differences were found between fertilized and unfertilized strips through the whole winter.

Effect of Disturbance on Goose Grazing Pressure

Two sources of disturbance were investigated to look

Fig. 4.2 EFFECT OF FERTILIZER APPLICATION ON GOOSE GRAZING

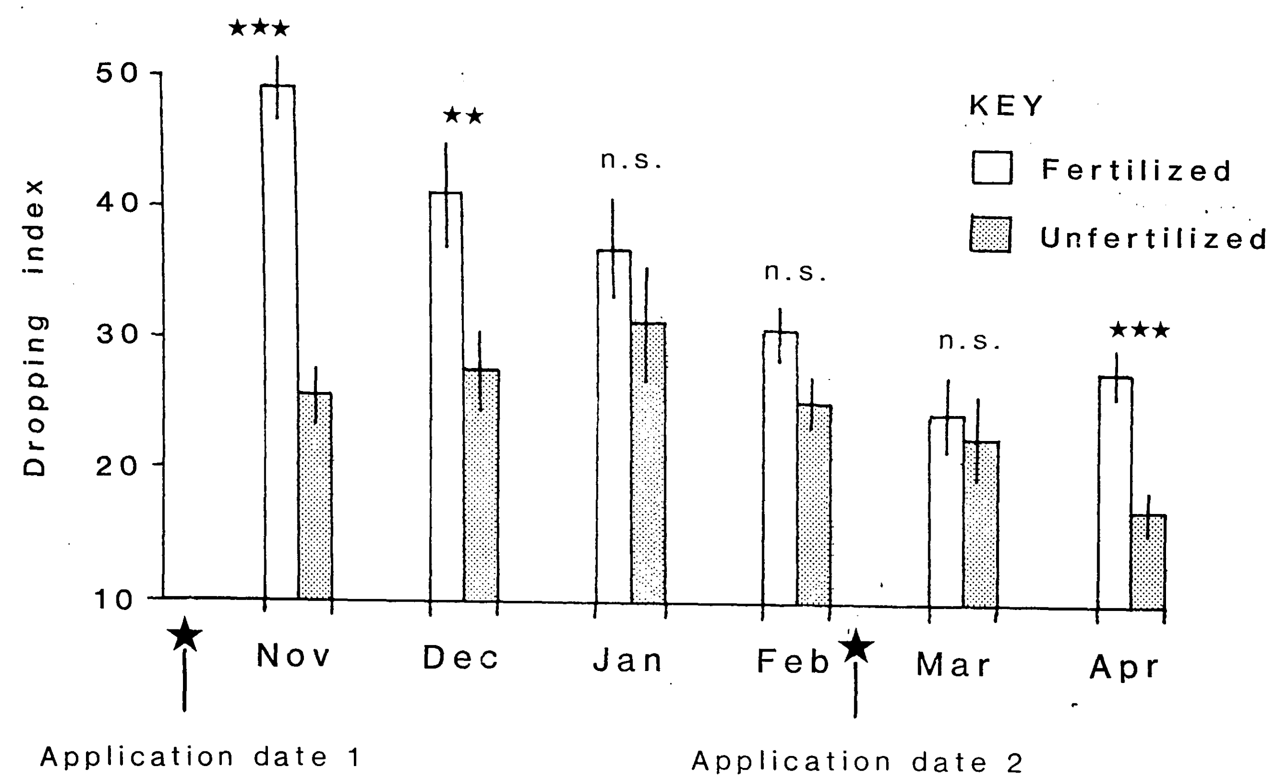
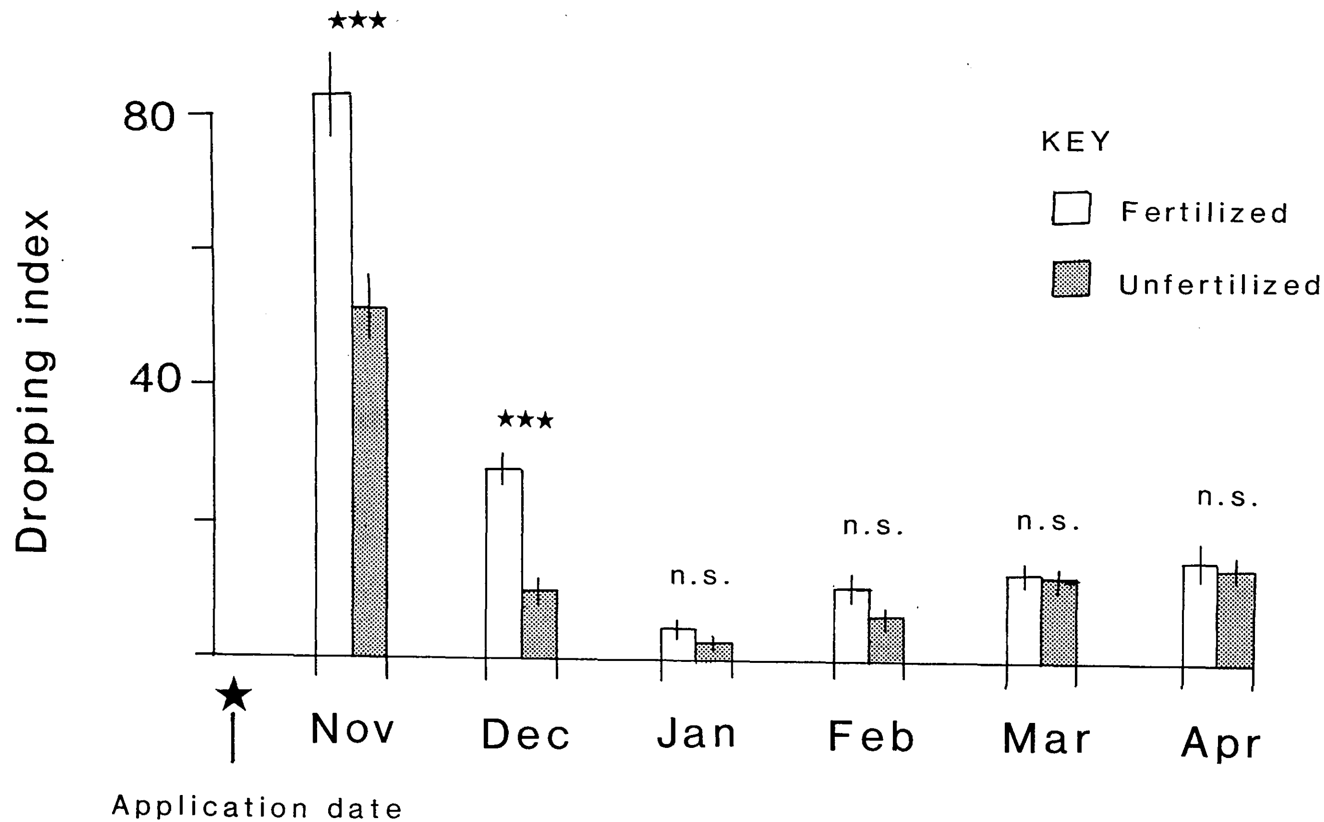


Fig. 4.3 Effect of autumn fertilizer application on goose grazing



at their effect on goose grazing. Firstly, the effect of proximity to a road on goose grazing pressure is shown in fig. 4.4. The goose usage, as measured by the number of droppings accumulated per square metre through the winter, of plots at varying distances from a minor road (about 50 cars per day) is expressed as a percentage of the maximum usage of the field. While usage is reduced at close proximity to the road (50m), the graph soon levels off. The effect of a second source of disturbance, proximity to active farm buildings, is illustrated in fig. 4.5. It shows the geese to have a similar pattern of high tolerance to the source of disturbance.

Fig. 4.6 shows the seasonal pattern of goose grazing pressure on two sites, at either end of the disturbance gradient. One site was 30m from a minor road, ie relatively disturbed, and the other 1km from the nearest source of human disturbance, and hence relatively undisturbed. The disturbed site showed a rather different seasonal pattern of use to the undisturbed one. It supported more goose grazing during the mid- winter period, when food supplies are short at more preferred less disturbed sites. In comparison the undisturbed site showed a minimum goose grazing pressure in mid-winter and peaks in autumn and spring.

Fig.4.4 Effect of proximity to road on goose grazing

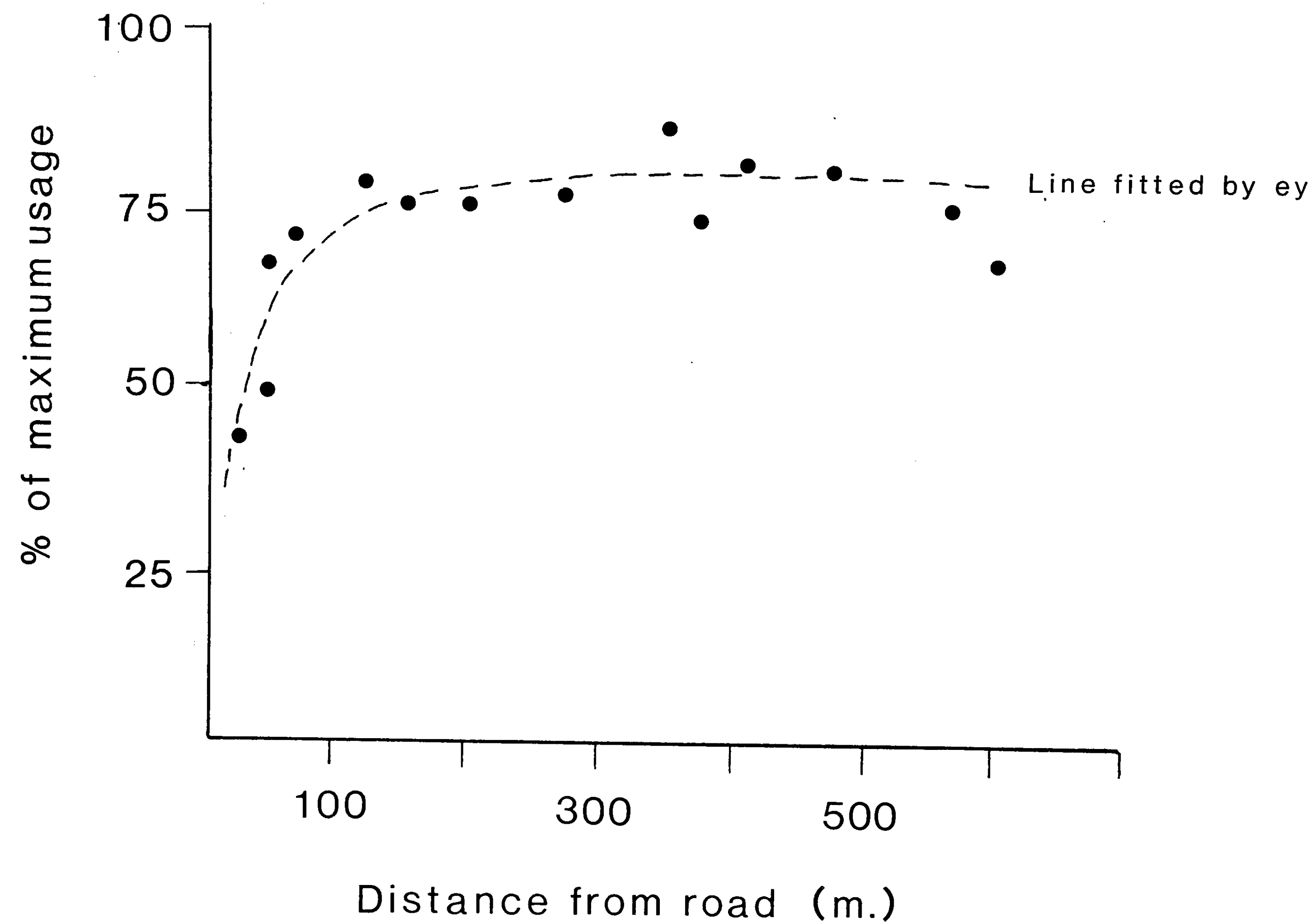


Fig. 4.5 Effect of proximity to farm buildings on goose grazing

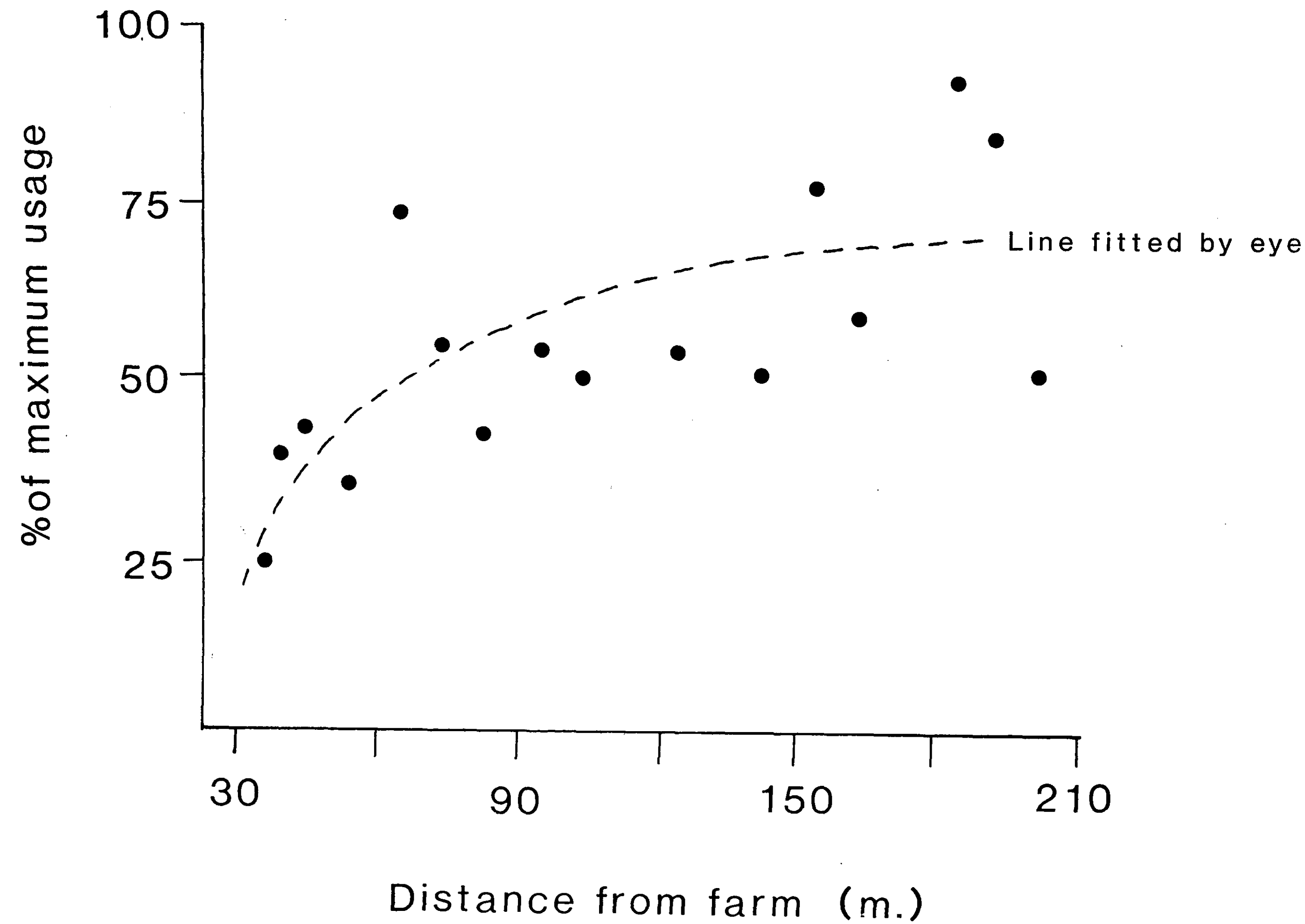
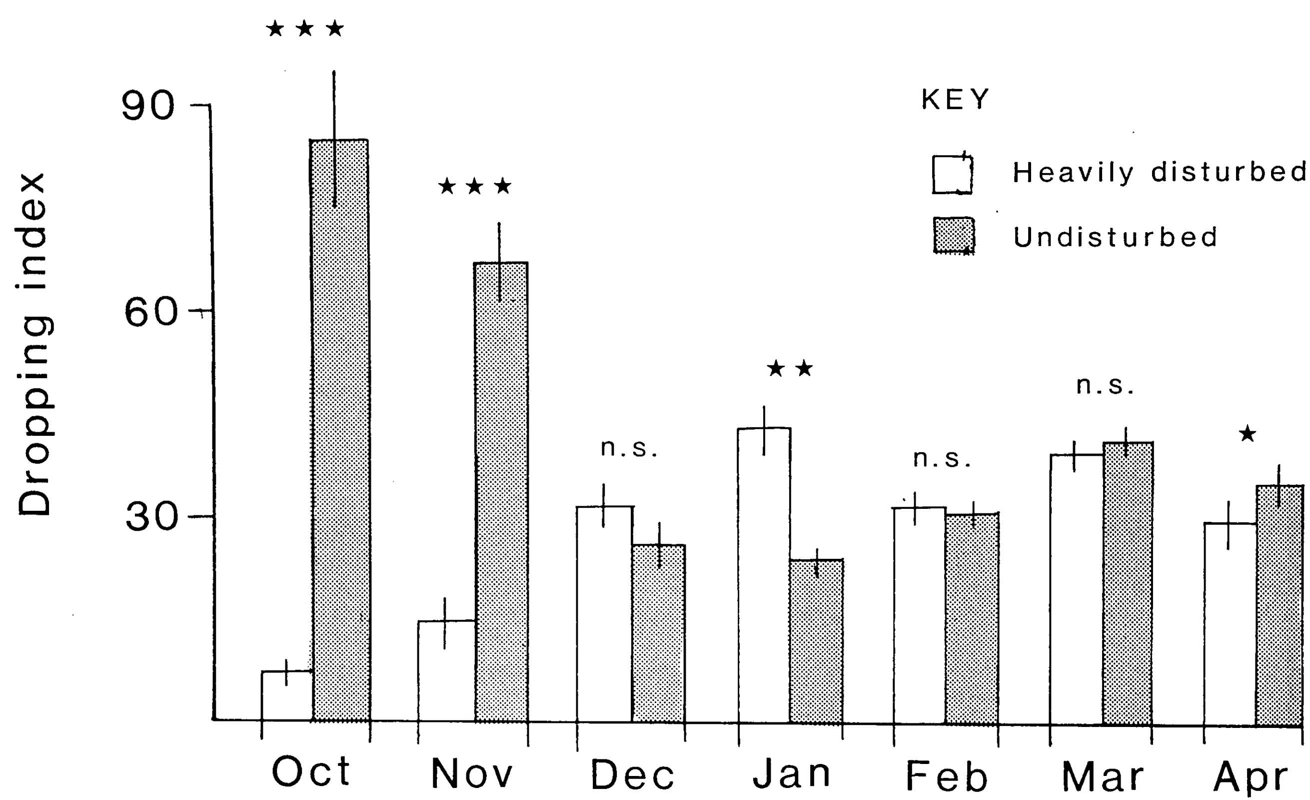


Fig. 4.6 Effect of disturbance on seasonal pattern of goose grazing



Grass Quantity and Quality of Pastures of Different Age

Table 4.5 summarises the data on the quantity and quality of food available to the geese in newly reseeded and older pastures. It has been shown above that the geese exhibit a strong preference for feeding on new reseeds (see dropping index in table 4.5). The table 4.5 shows that this selection is not readily explained in terms of standing crop of the sward, its protein content or the total winter grass production. The only consistent significant difference between reseed and older grass was the lower standing crop on the reseed at the end of April, which presumably resulted from the heavier goose grazing pressure that it supported.

Table 4.5 : Comparison of the April standing crop, protein content and total winter production of a reseeded and an old pasture

	April standing crop (g/m^2)	Protein content (% dm)	Total win production (g/m^2)	Dropping index ($no./m^2$)
1984-5				
Damp reseed	14.2 (8)	22.7% (8)	95.3 (8)	95.5 (30)
Old pasture	25.6 (6)	19.0% (8)	59.4 (6)	39.8 (30)
	***	*	***	***
1985-6				
Reseed	24.1 (15)	25.0% (15)	63.6 (15)	46.5 (18)
3-year old	56.7 (12)	23.3% (12)	72.2 (12)	18.3 (30)
	***	n.s.	*	***
1986-7				
Reseed	24.8 (9)	29.3% (9)	67.7 (9)	49.9 (15)
2-year old	51.3 (8)	26.4% (8)	70.0 (8)	21.4 (15)
	***	*	n.s.	***

(% dm = % protein content of dry matter, *** - $P<0.001$, * - $P<0.05$, n.s. - $P>0.05$, Students' T-test)

Section 4.2 : Feeding behaviour of the geese

In the previous section it has been established that the geese show a strong preference for feeding on newly reseeded pastures. The main purpose of this section is to investigate whether this selection can be explained in terms of the feeding behaviour of the geese on different grassland types. It is a general rule that animals will forage where they can maximize their net food intake (Charnov 1976), though the particular element of the diet on which this decision is based may vary seasonally and between individuals (Pyke et al. 1977). In this chapter the feeding rates of the geese were investigated, to see whether they differed between pasture types and to see how they were affected by other factors such as a bird's social status. The section also deals with the food requirements of the geese through the winter and develops the concept of carrying capacities of the refuge areas, to see how much grassland the geese theoretically need to accommodate them through the winter.

Methods

Barnacle Geese are animals of open, short pasture, and thus their feeding behaviour is readily observable. The population on Islay have the added advantage that they contain many individuals marked with uniquely-coded plastic rings (see chapter 6). By recording the bird's identity, variables such as the bird's age, sex and breeding status can be included in the analysis and be used to help explain the feeding behaviour. The feeding ecology of geese in winter has been the subject of many studies. The basic techniques of this work follow those of Owen (1972) in his classic study of the White-fronted Goose at Slimbridge, in south-west England. Four basic measures of feeding behaviour were recorded in the field :-

1. Dropping interval ; this was measured as the time between successive droppings. The rate of dropping production is known to be closely related to food intake rate (Owen 1972). Observations were made where possible using ringed birds as the focal individual, so that their status was known. Bedard and Gauthier (1986b) suggested that this measurement of dropping interval can be biased towards shorter intervals when birds are frequently moving from view (as longer intervals are more likely to be abandoned when the focal bird disappears into the flock). They proposed the use of an alternative method, which they called the 'hourly block' technique. Observations are made for a total of one hour per sample, starting on a randomly chosen focal bird, and changing to another when that bird moves from view. This gives an unbiased measure of the number of droppings produced per goose per hour, but provides no information about individual birds of known social status. As this potential bias was thought to be negligible in this study (as observation bouts on each goose were usually considerably longer than the dropping interval), the traditional method of Owen was used.

2. Peck rate ; this is a direct measure of feeding rate, but is very much dependent on the height of the vegetation. The geese peck less frequently when the grass is long. This is shown in table 4.6 below, where vegetation has been classified according to the height that it reaches up the bird's leg.

Table 4.6 : Relationship between peck rate and an index of vegetation height

Vegetation height class	Mean peck rate (pecks/min.)	Standard error	Sample size
1 (shortest)	199.3	2.4	70
2	192.2	1.5	447
3	182.6	1.9	153
4	151.0	5.0	13
5	128.2	6.6	12
6 (tallest)	97.6	22.0	5

(Analysis of variance of peck rate by vegetation height class : $P<0.001$, $F=30.50$, $n=699$).

Peck rate can be a useful immediate measure of feeding intensity, once allowance has been made for the effect of vegetation height. Only peck rates on grassland of vegetation height class less than 4 were included in the analysis. The peck rate was measured as the number of pecks in a minute observation period.

3. Pace rate ; this is thought to be a measure of food availability, with birds moving faster over poorer pastures (Teunissen et al., 1985). It is recorded as the time taken for a goose to walk 20 paces, and converted to the number of paces made per minute.

4. Activity budgets ; these were constructed primarily to calculate the amount of time that the geese spent feeding. Scans of feeding flocks were made every 10 minutes through the day, recording the behaviour of between 100 and 200 individuals. Each was assigned to one of the following nine categories; feeding, preening, drinking, resting (head on back or under wing), walking, alert (neck stretched out), standing, sitting and socially interacting. These provided information on how the birds were allocating their time on the various pasture types.

5. Night feeding ; during the first winter of the study it was noticed that the geese were occasionally present in the feeding fields during the night. If any night-feeding was taking place regularly, it was important that it could be included in the food intake calculations. Therefore, observations were made at night, using an image-intensifier. The poor resolution of the image-intensifier meant that it was only the flock activity scans that could be made at night, so they provided the only direct measure of nocturnal foraging behaviour. The radio-telemetry study provided some additional information on the behaviour of the geese at night. Fixes of the birds at night were obtained at least three times per week during the four months of this work (January to April 1987 - see chapter 5 for the details of the methods used), which enabled the habitats that the birds were using to be monitored, particularly noting whether the birds were present on the main sandbank roost sites or on the feeding fields.

Daily food intake of the geese

The average daily food intake of the geese was calculated using the following method (after Owen 1972 and Ebbinge _et al_. 1975) :-

Daily food intake = Daily faecal output / (1-digestibility of the food)

The daily faecal output is simply a product of the mean dropping weight and the number of droppings produced per day. The latter is calculated from the dropping interval (described above), and the length of the feeding day, which was calculated from observations of the morning and evening flights to and from the roost sites, as the time during which more than half the total number of birds were present in the feeding fields.

Daily faecal output = no. of droppings produced per day
x mean dropping weight
= length of feeding day / dropping
interval x mean dropping weight

Allowance has to be made for the droppings excreted at the roost during the night when at the roost-site. Work on Barnacle Geese in Holland (Ebbinge et al. 1975) found that they excreted about 25 droppings per night. Owen (1975) calculated that a full Barnacle Goose gut would contain 14.4 g. dry weight of grass, equivalent to about 20 droppings. Observations from Islay suggest that the geese there have a similar night-time production to the Dutch birds, but as the geese roost almost exclusively on tidal mudflats it is difficult to obtain a reliable figure. Hence,

Daily food intake = (LFD / DI + 25) x DWT / (1 - DIG)

(where LFD = Length of feeding day, DI = dropping interval, DWT = mean dropping weight and DIG = digestibility).

Samples of droppings were collected each month, and dried and weighed to obtain a mean dropping weight. Digestibility values are taken from Owen (1980). This technique gives a rather crude measure of daily food intake, but can still be useful. Its main shortcoming is that it assumes that digestibility values are uniform across the groups being compared, as these criteria are calculated from whole population means. It is rarely possible in the field to specifically identify droppings to the individual being observed, and hence to calculate digestibility on an individual basis. The calculation of daily food intake is also complicated by night-feeding, which could provide a major supplement to the daylight consumption. The nocturnal observations using the image-intensifier and the night fixes of the birds carrying radio transmitters allowed some account to be taken of the latter.

A detailed investigation of the response of the geese to different feeding conditions would require the use of grazing trials with captive geese (such as carried out by Owen _et al_. 1977), and is beyond the scope of this study. The approach of the current work aimed to identify the characteristics of a preferred goose feeding area, followed the 'macro' level of study discussed by Madsen (1986), rather than a detailed 'micro' study of the precise mechanisms of food selection. The aim was to obtain basic measures of goose feeding rates, to allow comparison between habitats and individual birds to be made, and hence to make suggestions about how pastures might be managed to attract more geese.

Results

Effect of pasture age on the behaviour of the geese

A summary of the variation in the three goose feeding rate parameters with pasture age is given in table 4.7. The analysis of variance demonstrates that, of the three parameters, only peck rate shows any significant relationship with the age of the pasture. Generally the geese peck less frequently on younger pastures. Details of the results of the statistical analysis are given in the table.

Table 4.7 Effect of Pasture Age on Goose Feeding Rates

Age of pasture		Dropping interval (secs)	Peck rate (pecks/min)	Pace rate (paces/min)
< 1 yr		263.4 (5.2;119)	178.3 (2.0;230)	34.8 (0.7;180)
1-5 yrs		261.3 (4.9;175)	186.9 (1.7;318)	34.1 (0.7;291)
> 5 yrs		271.1 (8.5;62)	198.8 (2.5;93)	34.6 (1.0;81)
ANOVA :	F ratio	0.026	16.50	0.096
	Prob.	0.975	<0.001	0.908
	n	297	297	297

(all figures in main table are means (+/- standard errors; sample size).

The results of the flock time budgets are given in table 4.8. The behavioural categories have been simplified into three groups ('Feeding', 'Comfort'- preen, rest, sit, stand - and 'Vigilance' - alert). When account was taken for the time of year, by including the month in a two-way analysis of variance, no significant difference was found between the birds' behaviour patterns on the different age classes of pasture (ANOVA $P>0.05$, $n=551$). The geese do appear to be spending a smaller proportion of their time feeding on the newly reseeded grassland, but this is explained primarily by the different seasonal pattern of use of this habitat. They tend to graze the reseeds particularly heavily in the autumn and spring, when the days are longer and so they do not need to feed so intensively.

Table 4.8 : Effect of pasture age on goose time-activity budgets

Age of pasture	Time-activity budget (% of time in each activity)		
	Feeding	Comfort	Vigilance
< 1 yr	85.9 (0.59;270)	7.6 (0.51;270)	2.9 (0.26;270)
1-5 yrs	89.0 (0.77;225)	5.7 (0.73;225)	1.6 (0.12;265)
> 5 yrs	90.7 (1.03;56)	3.7 (0.77;56)	1.3 (0.16;56)

(all figures in table are means (+/- standard errors; sample size)).

Effect of Goose Status on Feeding Rate

Section 4.2.1 showed that pasture age has no significant effect on goose feeding rate, apart from peck rate. The calculations to produce those results were based on population averages, but as most of the feeding observations were made on individually-marked birds, it is possible to look in more detail at some of the other factors affecting goose feeding rate. Table 4.9 gives a summary of the effects of age, sex, breeding and pair status on the three measured parameters of feeding rate. The analysis of variance below the main table summarises the results and highlights the significant relationships.

Night-feeding by Barnacle Geese on Islay

There are three sources of information about the importance of night-feeding to the Islay Barnacle Geese. Firstly, direct observation of flocks feeding at night, using an image- intensifier. Night-feeding flocks were observed on several occasions during the study, but only during December, January and February. The results of the time budget are given in table 4.10, where again the data have been summarised into three behavioural classes. They show clearly that when birds are feeding at night they are feeding actively, spending as great a proportion of their time feeding as during daylight. No significant difference in behaviour pattern was found between daylight- and night-feeding flocks, apart from birds allocating slightly less time to vigilance at night.

Table 4.9 Effect of Status on Barnacle Goose feeding rate

	Dropping interval (seconds)	Peck rate (pecks/min)	Pace rate (paces/min)
1) Age			
Adult	265.6 (3.1;419)	187.6 (1.2;693)	33.9 (0.5;503)
Yearling	256.5 (10.6;11)	179.9 (6.0;30)	33.8 (1.9;25)
Juvenile	220.9 (11.5;20)	198.9 (8.5;29)	41.0 (2.4;22)
	*	***	**
2) Sex			
Female	276.8 (4.4;193)	189.7 (1.8;303)	34.8 (0.7;227)
Male	254.1 (3.9;254)	188.0 (1.5;445)	34.0 (0.6;334)
	*	n.s.	n.s.
3) Breeding status			
Non-brdr	263.9 (3.0;455)	187.2 (1.2;793)	34.3 (0.4;559)
Breeder	262.7 (9.9;20)	204.4 (5.2;30)	34.6 (1.7;24)
	n.s.	*	n.s.
4) Pair status			
Unpaired	281.6 (11.2;33)	185.8 (3.6;62)	36.0 (1.4;54)
Paired	262.2 (3.2;393)	190.5 (1.2;635)	33.9 (0.5;476)
	**	n.s.	n.s.

ANOVA table :	F	P	F	P	F	P
Age	5.03	0.013	13.07	<0.001	8.99	0.002
Sex	6.03	0.015	0.50	0.483	2.82	0.094
Breeding st.	0.33	0.565	3.80	0.052	0.91	0.340
Pair status	7.48	0.007	0.27	0.606	0.10	0.752
Sample size	279		279		279	

Table 4.10 : Time budgets of goose flocks during daylight and at night between December and February

	Time-activity budget (% of time in each activity +/-SE)			
	Feeding	Comfort	Vigilance	Other
Day (n=231)	90.5 (.47)	4.5 (.41)	1.9 (.12)	3.2 (.19)
Night (n=31)	92.4 (1.1)	4.3 (.94)	0.6 (.10)	2.6 (.33)
	n.s.	n.s.	**	n.s

(** = P<0.01, n.s.= not sig, P>0.05, Students' T-test, n = no. of flock scans).

These observations, however, were confined to flocks feeding under bright moonlight, as this was the only time that the image- intensifier worked effectively. The data from the birds fitted with radio-transmitters gave a better indication of the frequency of night feeding. The relative proportions of birds located on the main roost-sites and on the feeding fields during the period January to April 1987 are given in table 4.11 which show that night-feeding accounted for only 6.9% of the nocturnal fixes. The geese were spending a large majority of the night on the roosting grounds. Again, night-feeding was only recorded during the mid-winter period (January and February), and only in conditions of bright moonlight. When the birds were night-feeding, they were usually found in fields in close proximity to the roost-site.

Table 4.11 : Locations of nocturnal fixes of radio birds

	No. of fixes	% of total
At roost site	188	93.1%
Night-feeding	14	6.9%
Total	202	

The daylight activity budgets provide a third source of data on night-feeding by the geese. If night-feeding were widespread amongst the geese, one might expect a lunar rhythm to be apparent in the daylight feeding activity, with less time spent feeding during the day around full moon when conditions for night- feeding would be particularly suitable. Table 4.12 shows the results of an analysis of variance to test this hypothesis, controlling for the season (as the percentage of time spent feeding varies seasonally - see below). The table shows that there is some variation in the proportion of time spent feeding with the state of the moon, but this is not significant when comparing across all three seasons. In autumn and winter the birds are spending a greater proportion of their their daylight hours feeding at the time of the new moon compared to the full moon, as would be predicted if night-feeding were important to their total food intake. The opposite was found to be true, however, in the spring (hence the highly significant interaction between season and moon state in the ANOVA - see table 4.12). The birds were spending a very large proportion of their time feeding during daylight throughout the lunar cycle. Even around the full moon period there was little reduction in diurnal feeding activity.

Table 4.12 : Variation in the proportion of time that the geese spent feeding with the state of the moon

	MOON STATE		
SEASON	FULL	1/4 - 3/4	NEW
Autumn	85.3 (43)	85.6 (77)	94.8 (4)
Winter	87.0 (132)	89.8 (74)	95.8 (44)
Spring	91.7 (77)	88.5 (10)	82.5 (109)

ANOVA of % time feeding by season and moon state :

	F-ratio	P	d.f.
Main effects			
Season	7.19	0.001	2
Moon	0.76	0.466	2
2-way interactions			
	17.60	0.0001	4

Daily Food Intake of the Geese

Table 4.13 shows the results of the daily food intake calculations. The data have been calculated for each month through the winter, to look at the seasonal pattern of intake as well as the overall total. There is considerable variation in the daily food intake through the winter, primarily reflecting the amount of daylight feeding time available to the geese. The feeding rate parameters do vary with the season (particularly the rate of food intake : an analysis of variance with month was highly significant, $P<0.001$, $F=8.29$, d.f.=6, n=475), but the doubling of the length of feeding day between mid-winter and spring has the greatest influence on the daily food intake.

Table 4.13 : Seasonal variation in daily food intake parameters

	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Food intake/hour (g.dry wt./hr)=F	17.1	17.1	15.6	15.7	15.8	17.4	23.4
Length of feeding day (mins) =L	645	557	467	440	535	693	894
% of day spent feeding =A	87.0	84.7	86.5	89.0	92.9	91.3	82.5
Daily food intake (g.dry wt./day) = F x L x A	160	135	105	103	130	183	287

The total winter food requirement of a Barnacle Goose on Islay, calculated by multiplying together all the daily intakes, is approximately 30.4 kg. (dry weight) of grass. Taking estimates of food availability in terms of winter grassland production (from section 4.1), the number of geese that such pastures could support through the winter, ie, the field carrying capacity, can be calculated. In the following calculations the maximum observed goose grazing pressure has been used, to obtain an estimate of the maximum number of geese that an area could sustain, its maximum theoretical carrying capacity :-

Winter food requirement of a goose = 30.4 kg.

Pasture net primary production = standing crop in spring + biomass consumed by geese through winter (see section 4.1)

= 95.3 g/m^2

Theoretical carrying capacity = Net production/goose requirement

= **31.3 geese/hectare.**

There is a second, alternative route for calculating a theoretical maximum carrying capacity, based on direct conversion of the maximum observed dropping density to grazing pressure :-

Dropping interval = 263.5 seconds

Therefore, 1 dropping = 263.5 goose-seconds

Max. dropping density = 95.5 droppings/m^2

Hence, carrying capacity = dropping interval x dropping density

= **34.7 geese/hectare**

These estimates of maximum theoretical carrying capacity can then be compared to the present density of geese using, for example, the RSPB reserve. The figure of 11.0 geese/hectare on the latter (calculated from data in Moore, 1987) is clearly considerably below the potential number of geese that the reserve might support if feeding conditions were made as attractive as those on the most heavily grazed field on the reserve. Indeed, if the actual carrying capacity of the reserve as a whole were to increase to the maximum theoretical value, it would support 12,000 - 13,900 birds, in comparison to the present winter average of 4,400. The total area of the refuges could theoretically support approximately 55,000 geese, or more than twice the present population level on the whole island. These figures are, however, based on maximum values. Their realism and relevance to goose management on Islay are dealt with in the discussion below.

Discussion

Selection of Feeding Site

All three methods of assessment of habitat use (dropping density, direct counts and radio-telemetry) showed the geese to have a strong preference for newly reseeded fields over older pastures. Reseeding a field can increase the number of geese grazing on it by as much as 120%, though this increase is partly dependent on the availability of other reseeds in the area. On the RSPB reserve, for example, the magnitude of the increase in goose grazing following reseeding has declined slightly as the total area of reseeded grassland in the vicinity has increased, over the three winters of the study. Even so, reseeding can still bring about a substantial increase in the number of geese grazing on a field.

Fertilizer application was another pasture management technique that increased the numbers of geese grazing on a field in some situations. Both autumn and spring applications could bring about a significant increase in the level of goose grazing, so this might, in addition to reseeding, be a useful management technique that could increase the numbers of geese using the refuge areas. Unlike reseeding, however, the benefits of fertilizing were not found over all fields. Some sites of particularly high nutrient status showed no significant effect of fertilizer application on goose grazing.

Similar results on the response of grazing geese to reseeding and fertilizer application were found by Owen in a study of White-fronted Geese in SW England (1972, 1977). The findings of the current study were in broad agreement with the ideas which Owen put forward regarding pasture management for geese, though they highlight particularly the benefit of frequent reseeding.

No immediate straightforward explanation was found to explain why the geese were exhibiting such a strong preference for reseeded pasture over older swards. No consistent correlation was found between how much the geese were grazing on a sward and that sward's standing crop, protein content, or total winter productivity. There is need for detailed work using captive birds to test the assumptions that have been made in this study, particularly that of constant digestibility by the geese of grass from pastures of different ages. Detailed work on the digestive strategies of geese feeding on these different pastures is necessary to answer fully the question of why the geese were exhibiting such strong preferences for newly reseeded fields.

Disturbance was found to be of little importance to a Barnacle Goose's selection of feeding site. This contrasts with results from several other studies of goose feeding site selection, where geese were shown to be very sensitive to human disturbance (for example Owens 1977, Madsen 1986). However, during the three years of this study there was little general shooting disturbance. In the face of increased human disturbance the geese may revert to the pattern of sensitivity to disturbance shown by other goose species.

Other factors which have not been investigated in this study may also have had some influence on goose feeding site selection. Proximity to a suitable roost site is an important requisite of a goose's environment, and can have a strong influence on the distribution of some species (for example Pink-footed geese in Scotland, Newton et al. 1973). On Islay almost all the potential goose feeding areas are within 10km. of a roost site, so availability of such sites is not limiting their use of areas on Islay. The foraging range patterns that the geese show in relation to their roosting site are discussed later in chapter 5.

The abundance of predators was very unlikely to be of any significance to the Islay geese, as natural predation rates are very low. The only natural predator of the geese is the Peregrine, Falco peregrinus, and this species takes very few geese in its diet, preferring the abundant Curlew, Numenius arquata, and Lapwing, Vanellus vanellus, that are available (pers. obs.). Occasional remains of Barnacle Geese have been found around Ferret burrows (pers. obs.), but it is unlikely that they take anything other than sick or injured geese.

Feeding Behaviour

The approach used in this study was to concentrate fieldwork effort on obtaining data on the basic established measures of goose feeding rate (Owen 1980), to compare these between the different pasture types. The rate of dropping production is a reliable measure of food intake, provided digestibility of the food and dropping weight are constant across the groups being compared. No significant difference was found between any of the pasture types. The activity budgets also showed there to be little difference in the behaviour of the geese on different ages of grassland. No significant difference in pace rate between the pastures was found, suggesting that the quality of pasture in terms of food availability did not differ. A significant difference was found in peck rate, with birds pecking more slowly on younger swards. These results suggest that the geese are able to attain the required intake rate on the newly reseeded pastures with less pecking effort. As mentioned earlier, more work needs to be done to test the assumptions of constant digestibility before any firm conclusions can be drawn about the mechanisms of feeding site selection.

The social status of a goose had considerable effect on its feeding behaviour. The age of the bird had a significant effect on all three feeding rate parameters, with younger birds having a shorter defecation interval, and faster peck and pace rates. Three possible explanations could account for this apparent increased feeding rate in first-winter birds. Firstly, they might have a higher nutrient requirement than adult birds, as they are not yet at their full adult weight. Secondly, the difference may be explained by the young birds having a lower digestive efficiency, and hence need to take in more food to maintain their nutritional demand. The third, and perhaps most likely reason, is that the young birds may have a poorer ability to select nutritious foods, and so are eating a lower quality diet than the adults. Owen (1976) has provided some evidence that this might occur.

The sex of a goose has a significant effect on its defecation rate, though not on peck or pace rates. Females were found to have a longer interval, suggesting that they were feeding at a slower rate than the male geese. This seems unlikely, and the difference is probably better explained by a difference in digestive strategies between the sexes. Different nutritional demands of the female (for example laying down reserves for the production of eggs) may make it more profitable to retain food in the gut for a longer period and extract more nutrients from it.

The only parameter to vary significantly with breeding status of the goose was peck rate. An explanation is not immediately obvious, but it might result from the need to feed more actively as they have to spend more time attending to their offspring. Adult males with families are known to spend more time vigilant than those with no young, (Black 1986). Pair status of the bird only showed a significant relationship with defecation interval, with unpaired birds having a longer interval than those with a mate.

A highly significant difference was found between the feeding parameters in different seasons. They all reflected the low food intake in mid-winter, when daylength is short and food availability is low, and the large increase in intake in the spring (up to twice the daily intake recorded during the winter). In April the birds were taking considerably in excess of their nutritional requirement (Drent 1978), so they must be accumulating reserves, either for their forthcoming migration or for future breeding.

The total winter food requirement of an Islay Barnacle Goose, calculated from the daily food intake values, is approximately 30.4 kg. dry weight of grass. This agrees closely with work on Barnacle Geese in the Netherlands (Ebbinge et al. 1975).

There is an inherent assumption of the above calculations that there is no significant intake of food at night. In some species of wildfowl night-feeding can contribute to a substantial portion of the total food intake. Nocturnal feeding has been recorded as being of importance to Barnacle Geese in the Netherlands (Ebbinge et al. 1975). Observations on Islay using an image-intensifier showed that when geese were in the feeding fields at night, they were feeding actively, but it was only possible to make such observations under full moon. Radio-telemetry allowed the location of birds at night without such bias, and showed that birds were seldom present in the feeding fields, and then usually only under conditions of bright moonlight and in the mid-winter period (December to February). Further evidence for the low importance of night-feeding to the total food intake was obtained from the daylight time- activity budgets. Some variation was found in the proportion of time spent feeding in relation to the state of the moon, but much time was still allocated to daylight feeding around the full moon. If night-feeding were particularly important, one would expect the geese to show a more pronounced lunar rhythm of daylight feeding activity, as found, for example in the Wigeon, Anas penelope, (Mayhew 1984). Thus it is unlikely that night-feeding had much influence on the total winter food intake of the geese. This is perhaps surprising, considering that Islay is free from foxes and other potential ground predators of the geese. On

Schiermonikoog, a small island off the Dutch coast which is similarly fox-free, night-feeding is frequent (Ebbinge et al. 1975). The Svalbard Barnacle Goose population rarely feed at night during the winter (Owen pers. comm.), though these birds do occur in an area in which they could be subject to fox predation. Night-feeding may, however, be an important supplement to the food intake of the Islay geese at some times, for example in mid-winter when the length of the daylight feeding day is short, or when disturbance pressure during the day is high.

Calculations of maximum carrying capacities have shown that refuges could theoretically support considerably more geese than at present. For example, if the whole of the RSPB's 400 hectares of arable grassland were grazed by the geese as heavily as the most intensively-used field on the reserve, then the reserve could support approximately 13,000 birds through the winter. Extrapolating up to the entire extent of the refuges, about 55,000 geese could be accommodated on these areas. Thus the refuges could theoretically provide sufficient food for all the Islay Barnacle Geese. The very high intensity of goose grazing on Islay is illustrated by the fact that these maximum recorded grazing pressures are higher than that recorded in the literature for any other goose species feeding on grassland. Even at the Wildfowl Trust refuge on the Solway the Barnacle Goose grazing pressure has only been recorded up to 4400 goose days per hectare (Owen 1977), compared to this 6500 goose days per hectare maximum on Islay.

It is clear from the counts of geese on the RSPB reserve that the distribution of the geese is rather more complex than can be explained by straightforward food availability. As the area of newly reseeded grassland, and hence food supply, on the reserve has increased over the three winters of this study, the numbers of geese have remained more or less constant (Moore 1987). More birds were not moving into the area to exploit an increased food supply. Instead, the geese local to the reserve appeared to be concentrating on these improved grasslands. Other factors must be holding goose grazing pressure below its theoretical maximum. Thus the concept of carrying capacity seems to be redundant with regard to the management of the geese on Islay. Account needs to be taken of the range behaviour of individual geese through the winter, to gain further insight into why they do not seem to move in to exploit new areas of improved feeding. Chapter 5 continues to look at this problem in detail, in an investigation of the movements of individual geese.

Chapter 5: MOVEMENTS OF GREENLAND BARNACLE GEESE IN WINTER

Aims

This chapter investigates how Greenland Barnacle Geese exploit their winter range. The first section deals with the movements of birds within Islay. It examines the factors which affect a Barnacle Goose's range on the island. The aim was to establish whether there is any pattern to the way in which the geese use Islay, and to look at the factors underlying any such pattern. The work on the selection of feeding site by the geese in chapter four showed that the geese were not exploiting improved feeding grounds as much as might be expected. Birds remained widely dispersed over the island, despite improvements in the management of the refuges and in particular the RSPB reserve for the geese. It was intended to look at the foraging ranges and site fidelity of individual geese, to see how they responded to changes in grassland management, and to investigate what other factors affected their movement patterns on Islay.

The second section looks at the movements of Greenland Barnacle Geese within the whole winter range of the population. Aerial surveys by Ogilvie (1983) have shown that as much as 60% of the Greenland Barnacle Goose population spends the winter on Islay. The rest are scattered along the west coasts of Ireland and Scotland, with few sites holding more than a few hundred birds (see map in chapter 1). This section investigates how the birds using Islay relate to the remainder of the population. Any management plan for the geese on Islay needs to take into account the behaviour of the whole Greenland population. Observations were made on ringed birds to see if the Islay birds form a distinct sub-group, or if there is mixing with the rest of the population. Improvement in the feeding conditions for the geese on the refuges on Islay might, if the birds are highly mobile, lead to an increased number of birds moving to Islay from other parts of the range and exacerbating the conflict with agriculture.

Section 5.1 Movements of Barnacle Geese within Islay

Methods

Approximately 1,500 Greenland Barnacle Geese have been marked with individually-coded engraved Darvic plastic leg rings, as described by Ogilvie (1972). These can be read in the field at distances of up to 400m. The majority of the geese were caught during the summer moult at two sites in Greenland, in 1984 and 1985 (Cabot & Newton 1984, Newton 1985b), with an additional 302 caught using cannon-nets on Islay in January 1987. The origins of all the ringed birds in the population are summarised in table 5.1. An estimate of the number of individuals still alive in April 1987, based on the assumption of a 10% annual survival rate, is also given.

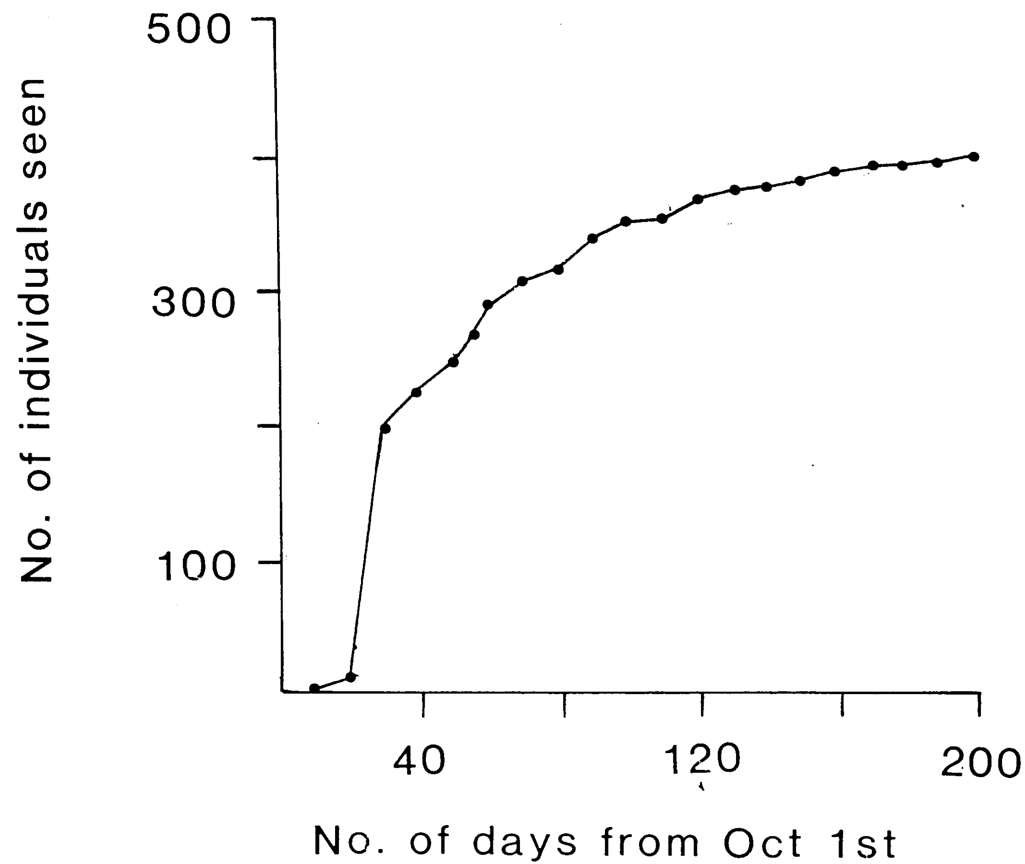
Table 5.1 : Origins of the ringed birds in the population

Ringing site and date	No. of individuals originally marked	Approx. no. individuals still alive in Apr 1987
E.Greenland (July 1984)	640	460
E.Greenland (July 1985)	115	90
W.Ireland (winters 1970-87)	c.500	200
Islay (January 1987)	302	295
Svalbard /Solway (1970-1983)	-	10
TOTAL	c.1570	1055

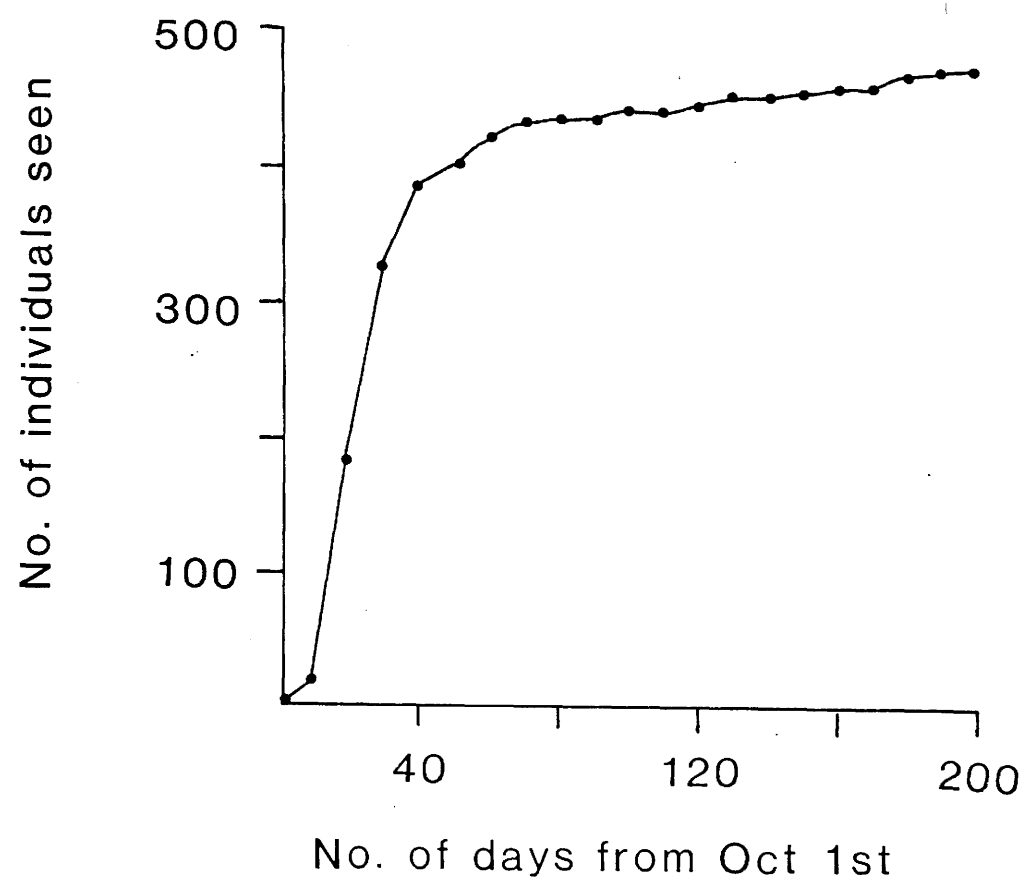
Each of the sites that the geese used on Islay was checked for ringed birds at least once every two weeks, to ensure a full coverage. The main goose areas were usually visited every 3-4 days. The comprehensiveness of the coverage of the island is demonstrated by the cumulative frequency diagrams in figure 5.1, which show that only a very small number of new individuals were recorded after the initial period of the winter, in any of the three winters. The time taken to reach the plateau was slightly longer in 1984/5, as observer coverage was poor up to the end of October.

Fig. 5.1 Cumulative frequency diagrams of number of ringed individuals seen through the winter of :-

a) 1984/5

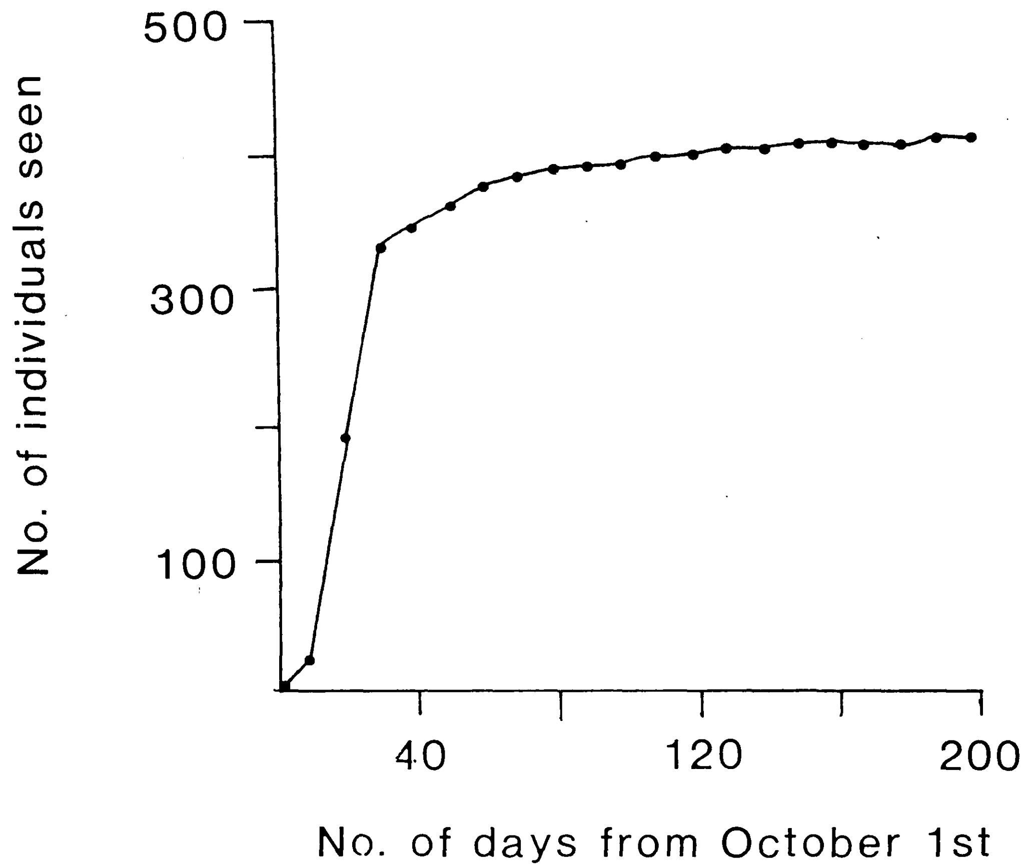


b) 1985/6



500
300
100
No. of individuals seen
40
120
200
No. of days from Oct 1st

c) 1986/7


500
300
100
No. of individuals seen
40
120
200
No. of days from October 1st

For each sighting of a ringed bird the following details were recorded:- (1) the exact location, (2) date and time, (3) habitat, (4) the bird's mate, or if it were unpaired, (5) whether the bird had any juveniles associating with it, that is whether it had successfully brought any young back to the wintering grounds, (6) the flock size, and (7) the bird's abdominal profile index (Owen 1981).

It was intended that the abdominal profile index would enable the physical condition of the birds to be monitored through the winter. The cannon-net catch in January 1987 allowed this technique to be tested, comparing the profile index, assessed in the field within 10 days of the catch, with direct measures of condition (weight/wing length^3) obtained from the catch birds. The condition indices of each of the the profile classes are summarised in table 5.2. No significant difference in condition was found between any of the four profile classes that occurred in the catch ($F=0.169$, $P>0.05$, ANOVA, $n=301$), showing that the field profile index was not a good measure of individual body condition. Owen (1981) showed that this technique could detect gross differences in condition between large samples, for example comparing a whole population in different years. However, the data presented here showed that the method was too insensitive to be used to compare the condition of individual birds at one specific time in the winter. Therefore no further analysis of the profile data was carried out.

Table 5.2 : Comparison of body condition assessed by profile index in the field with biometrics in the hand

Profile class	Condition index (weight/wing^3) Mean (+/- S.E.)	Sample
2	2.69 (0.05)	28
3	2.69 (0.02)	160
4	2.69 (0.03)	66
5	2.59 (0.07)	3

Any records for which the ring had not been read with certainty have been discarded from all analyses. Before the data were analysed, they were weighted according to the coverage that particular sites received during each winter. This weighting was based on the ideal that the number of sightings at any site would be a direct proportion of the number of ringed individuals using that site. This proportion, if coverage were perfectly uniform, would be equal at all sites. Therefore, if the number of sightings and the number of ringed birds at each site is known, the actual sightings can be weighted to keep this proportion constant :-

No. of sightings at site = NSIGHT

Mean count " " = COUNT

% of birds ringed " " = %RINGED

No. ringed birds at site = COUNT x %RINGED = NRINGS

Weighting factor = NSIGHT / NRINGS

The percentage of ringed birds at each site was calculated by taking a sample of the proportion of marked birds from each flock of geese encountered at that site. Each sample was taken by scanning through a flock and recording the number of individuals which were carrying rings. Any bird whose legs could not be seen clearly was excluded from the sample. It was important to obtain a representative sample from the whole flock, so in the analysis only samples which comprised more than a third of the sample flock, or contained more than 500 individuals, were included. The results were weighted for flock size to avoid bias in sampling from small flocks which tend to be easier to sample because legs are less obscured by other birds, (pers. obs.).

Preliminary multivariate analyses of the ring sightings were carried out to examine the data to see if there were any major patterns in the way in which the geese were using feeding sites on Islay, or whether the geese were simply moving around the island randomly. Prior to these analyses, the data for each of the three winters were arranged into two-dimensional matrices, holding the number of times each bird was sighted at each site, and weighted for coverage as described above. An example of the layout of the matrix is given below :-

		Site number					
		1	2	3	4	5	6 ......
	AAA	0	0	2	1	3	0
	AAD	3	1	0	1	0	0
Bird	AAF	4	4	4	0	0	0
	ABA	6	0	0	0	0	1
	ABB	0	0	0	2	6	1
	.						
	.						
	.						

(numbers in matrix = weighted no. of times that individual was seen at that site)

Cluster analysis, using Ward's method (Ward 1963, SPSS Inc. 1986) was used to describe the patterns in the data and classify the sites on Islay into groups according to the individual birds which used them. Sites which were used by similar groups of birds were grouped together. The compositions of these site groups were then investigated, to see :-

(i) how many birds were using each of them (calculated as a product of the number of ringed birds classified to them and the proportion ringed, as described earlier),

(ii) the fidelity of individuals to the groups within a winter,

(iii) the fidelity of individuals to the groups between winters,

(iv) whether the individuals in each group associate at other times of year away from the wintering grounds. Samples of birds were ringed in two different areas of Greenland in 1984 and 1985, so the data were tested to see whether they dispersed randomly across the wintering grounds or remain in association. Some further observations of ringed birds on the spring staging grounds in Iceland provided some more data on this subject: this is presented and discussed in chapter 6.

Further investigation of the between-year tenacity of individual birds to these groupings was made using principal components analyses, to see whether individuals occurred at the same group of sites in consecutive years, or whether they changed their site usage pattern. Birds which were seen less than ten times during a winter were excluded from both the cluster and principal components analyses, to avoid anomalous groupings of individuals with little information recorded (that is birds with low numbers of sightings).

Detailed examination of the ring sightings data was made to look at the factors affecting the pattern of site use by the geese. Two parameters were used as measures of goose range, both of which were calculated from data obtained from the sightings of ringed birds :-

1. Home Range Area ; calculated using the harmonic mean method of Dixon and Chapman (1980). This facilitates the identification of core areas of the birds' ranges, as well as their total range, by allowing the definition of contour boundaries to describe a certain proportion of an individual's range (Kenward 1987).

2. Inter-sighting distance ; this is calculated as the distance between successive sightings of the same individual. It is a useful additional measure, as it expresses the distance that an individual regularly moves within its home range.

These parameters were analysed in relation to the birds' age, sex, pair and breeding status and which site group on the island (defined by the cluster analysis discussed above) that it was using.

Radio-telemetry work

Additional work on the range behaviour of the geese using radio-telemetry was carried out during January - April 1987, following the successful cannon-net catch on Islay. Two-stage 14 g. radio- transmitters supplied by Biotrack (Kenward, 1987) were fixed to ten birds, with Evostick glue and cotton thread attaching them to the central two pairs of tail feathers. Their movements were followed from the day after the catch (January 3rd) to their departure from the wintering grounds at the end of April. No evidence was found to suggest that the catch disrupted the birds' pattern of behaviour. Fixing the radios to the tail feathers had the advantage that they would be moulted out with the feathers in summer, so would not be carried by the birds for much longer than they were being used in the study. Birds were located at least once each day on their feeding grounds. A minimum of three locations per week were also obtained for each bird on the roost at night. Three particular parameters were investigated; (a) distances moved between feeding sites in different days ('between-day distance'), (b) distances moved between feeding sites on the same day ('within-day distance'), and (c) distance moved between the roosting and the first feeding site of the day ('roost-feed distance'). Searches were also made for birds on the feeding grounds at night, to obtain information to complement the night-feeding activity budgets, to assess the importance of nocturnal food intake (see chapter 4.2).

Results

Preliminary analysis using clustering

The cluster analyses of all three winters' data showed clearly that there were groups of birds which use certain groups of sites. The dendrograms showing the relationship between the sites for all three winters together, and for each winter separately are given in figs 5.2 to 5.5. The map in fig. 5.6 summarises the geographical locations of these groups over all three winters. Though the exact boundaries of the site groups varied slightly between years, there was generally a high consistency in the pattern of the results in all three winters. This consistency between years is clear from the similar structure of the dendrograms, and is further supported by the results of the principal components analyses. The scores from these analyses were correlated using Spearman Rank correlation, and showed that the similarity between years was high. The correlation between the 1984/5 scores with those of 1985/6 was 0.65 ($P<0.001$, $n=115$), and 1985/6 and 1986/7 0.57 ($P<0.001$, $n=217$).

The numbers of geese using each site group, calculated from the numbers of ringed individuals using them and the proportion of ringed birds, are given in table 5.3.

Fig. 5.2 Cluster analysis dendrogram of Barnacle Goose sites on Islay (all 3 years)

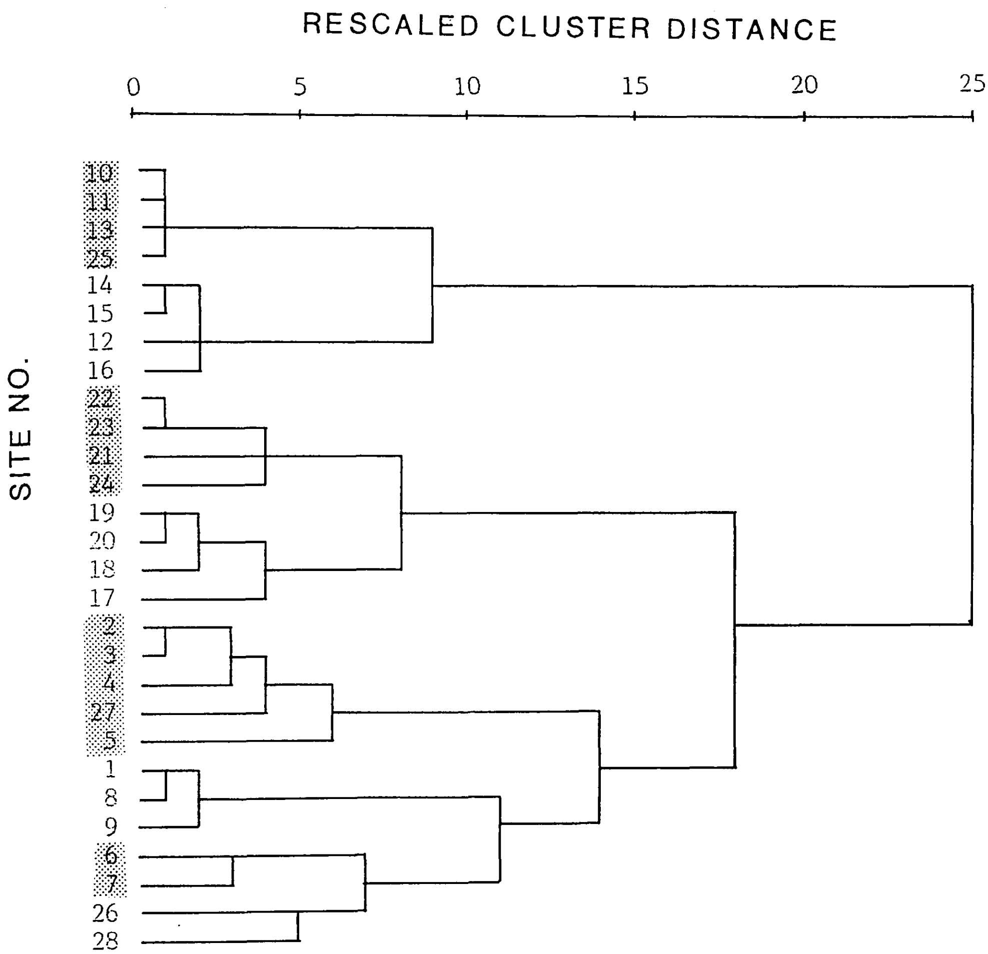


Fig. 5.3 Cluster analysis dendrogram of Barnacle Goose sites on Islay in 1984/5

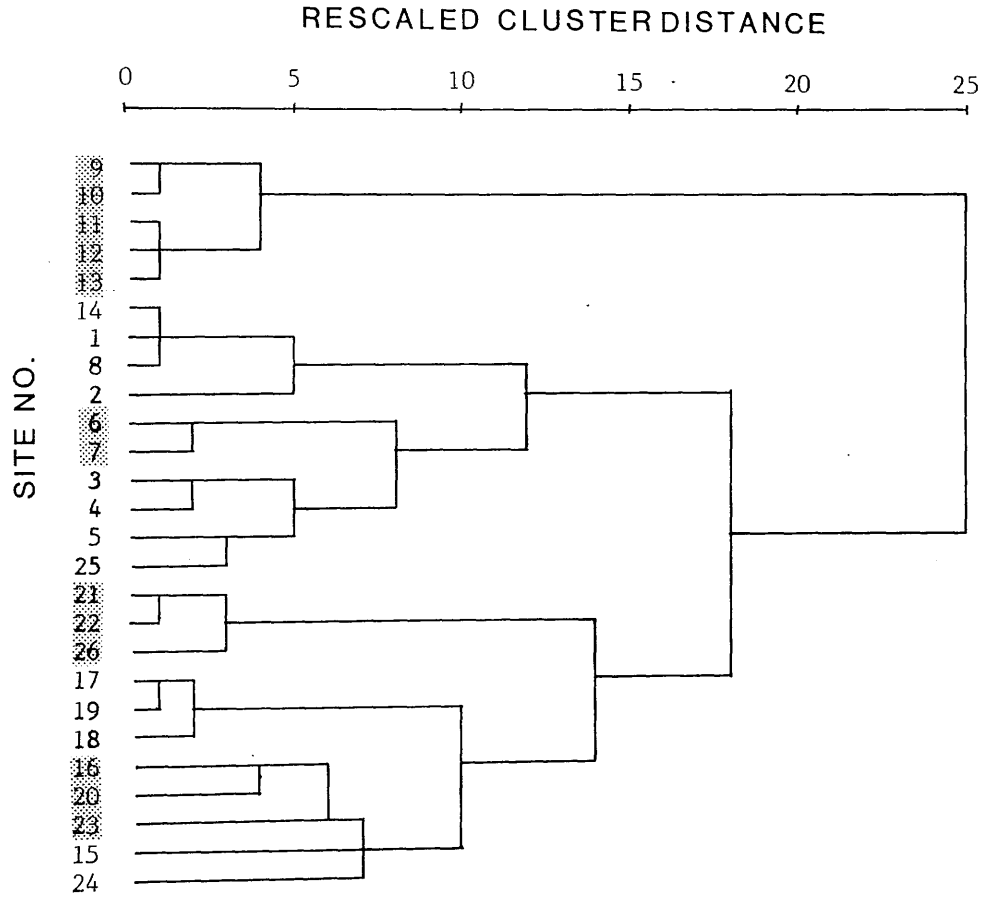


Fig. 5.4 Cluster analysis dendrogram of Barnacle Goose sites on Islay in 1985/6

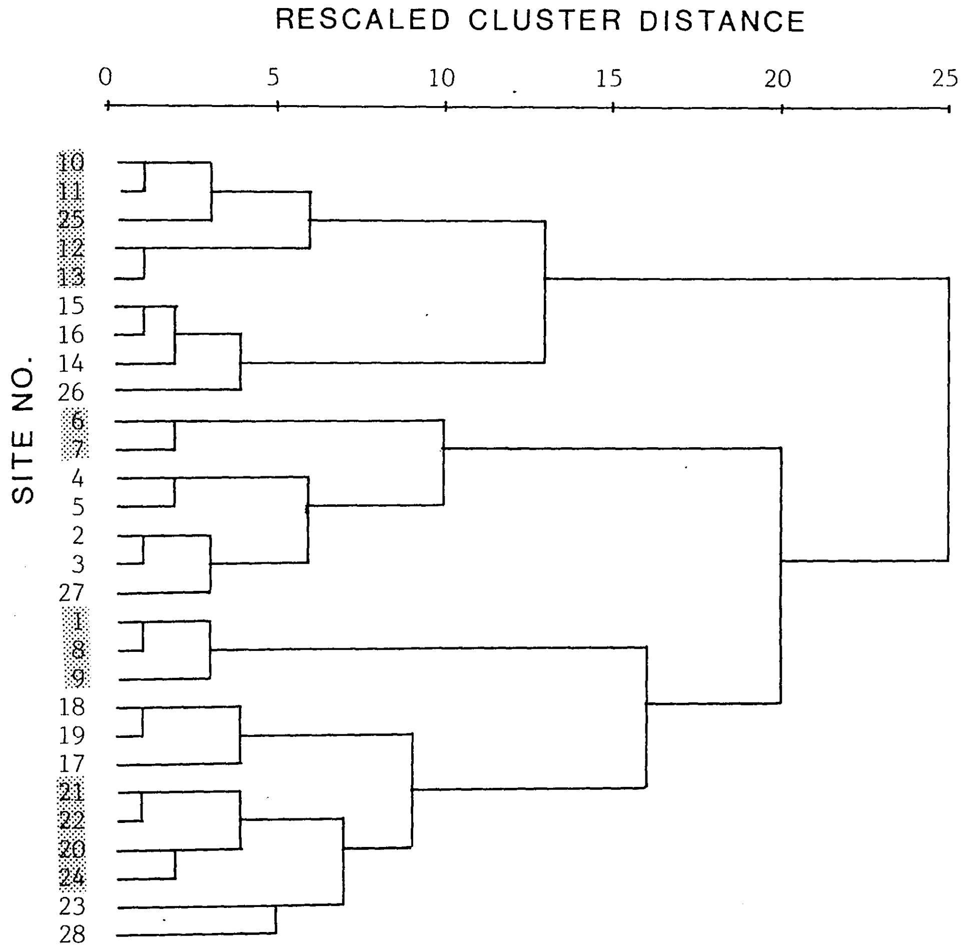


Fig. 5.5 Cluster analysis dendrogram of Barnacle Goose sites on Islay 1986/7

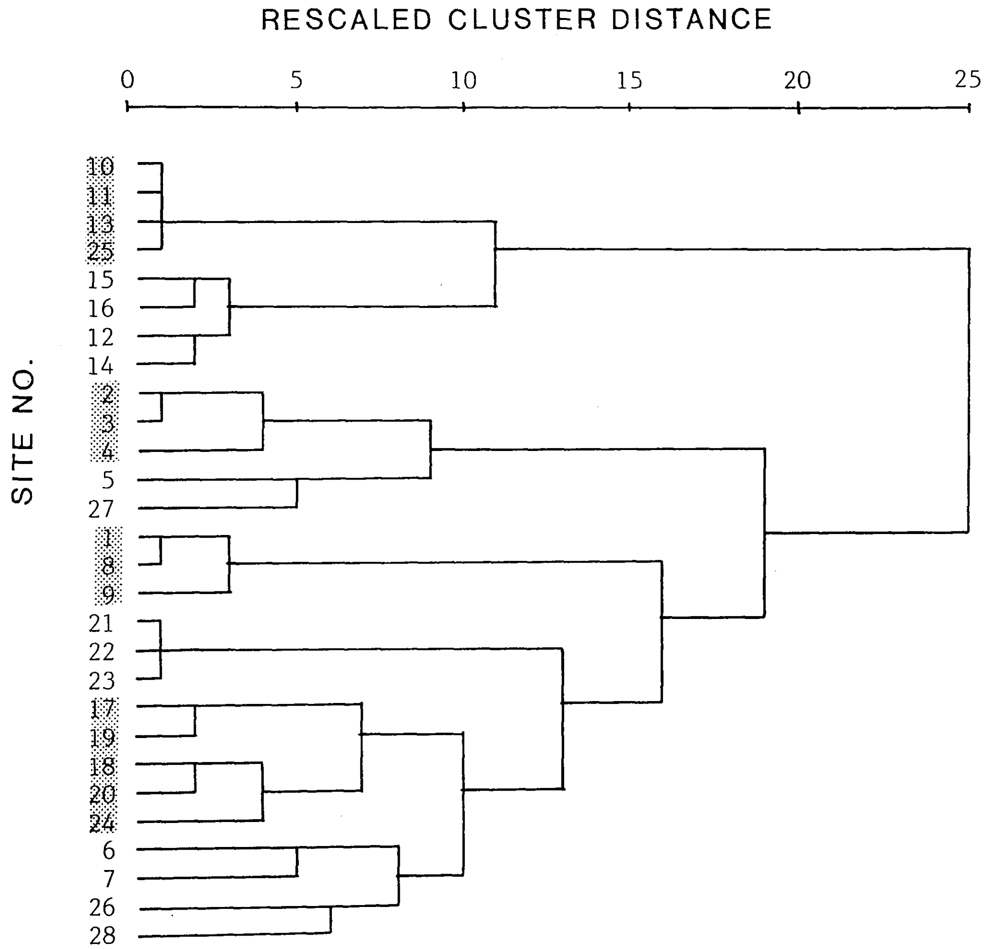


Fig. 5.6 CORE GROUPS OF BARNACLE GEESE ON ISLAY

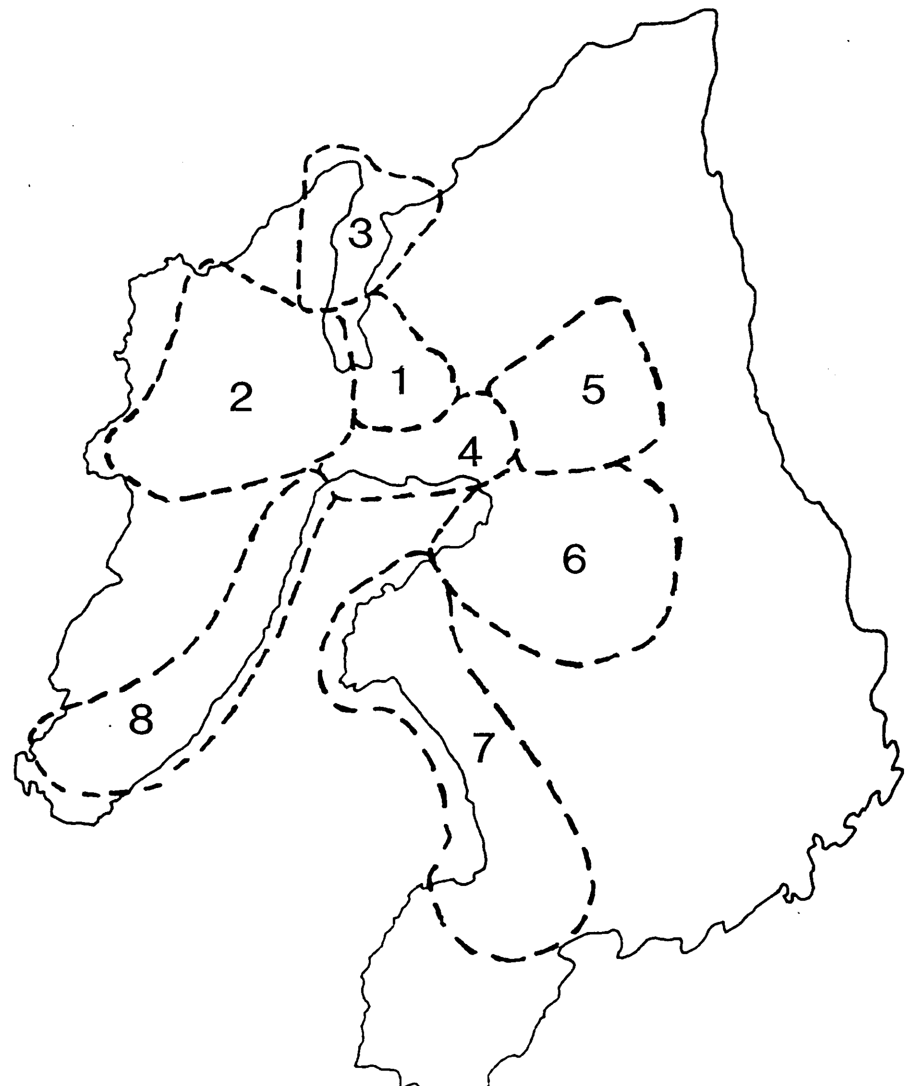


Table 5.3 : Numbers of geese in each site cluster group

	Year		
Site group	1984/5	1985/6	1986/7
1	3,340 (68)	4,384 (89)	3,466 (81)
2	6,709 (128)	6,606 (128)	7,305 (397)
3	2,643 (54)	2,928 (86)	3,360 (80)
4	1,205 (14)	1,807 (45)	1,883 (44)
5	4,765 (48)	3,154 (54)	2,504 (37)
6	2,254 (21)	1,197 (19)	2,497 (19)
7	3,944 (51)	2,666 (41)	3,893 (40)
8	719 (15)	534 (11)	841 (12)
Total	(399)	(473)	(654)

The fidelity of individuals to each of the site groups within a winter is summarised in table 5.4. Fidelity has been expressed as the percentage of sightings of each bird in its main (most frequently recorded) site group. Thus a value of 75% indicates that that bird was recorded in its main group for 75% of its sightings, and at other sites in other groups for the 25% occasions. The large majority of the birds were spending most of their time within a single group. There was significant variation in fidelity between the groups though, some site groups having birds which were very faithful to them (see table for the results of the ANOVA).

Table 5.4 : Fidelity of marked individuals to their site group within a winter

Site group	% of sightings in main site group 1984/5	1985/6	1986/7
1	78.1 (39)	68.3 (48)	78.2 (55)
2	83.7 (56)	76.3 (68)	84.1 (242)
3	68.4 (13)	72.7 (69)	75.8 (62)
4	57.6 (9)	59.2 (43)	68.3 (40)
5	48.1 (13)	57.8 (35)	59.5 (31)
6	55.7 (11)	51.0 (7)	48.6 (11)
7	65.5 (32)	53.3 (22)	60.0 (33)
8	-	54.8 (3)	38.2 (6)
F-ratio	10.60	8.35	21.17
d.f.	6	7	7
P	0.0001	0.0001	0.0001
Number of individuals	153	295	480

The fidelity of individuals to the site groups between consecutive winters is shown in table 5.5. Fidelity has been expressed as the percentage of individuals using the same, adjacent and more distant site groups as the previous winter. No significant difference was found between the fidelity in the two pairs of winters (1984/5 with 1985/6, and 1985/6 with 1986/7: $P>0.05$ using X^2 test), so all the data have been grouped together. It is clear that a large majority of the birds return to the same site group in subsequent winters, as suggested by the results of the principal components analyses discussed above. When the birds do move to new groups they usually just move to the adjacent group rather than to one more distant from their original one. As found for the within-winter fidelity, there were significant differences between the fidelity of birds to the different site groups. Generally the site groups with a larger percentage of highly faithful individuals within a winter were the same ones which had larger numbers of individuals faithful between winters.

Table 5.5 : Fidelity of marked individuals to their site groups between consecutive winters

Site group	Same site group	Moved to adjacent gp	Moved further than adjacent gp
1	73.4	14.6	12.0
2	77.3	10.0	12.7
3	61.3	31.3	7.4
4	63.4	14.9	21.8
5	57.9	17.1	25.0
6	39.4	51.5	9.1
7	52.6	13.2	34.2
8	24.0	20.0	56.0
Total	67.0	17.0	15.9

(X^2 = 163.3, 14 d.f., P<0.0001)
No significant difference between years for any of the site groups (X^2 P>0.05)

Further evidence supporting the hypothesis that there is some structure in the Barnacle Goose population on Islay comes from the winter distribution of marked individuals from different parts of the breeding range. Table 5.6

shows clearly that there are significant aggregations of birds from different areas of Greenland in different parts of Islay in the winter. The distribution of the birds is non-random, and highly consistent between years.

Table 5.6 : Ratios of the numbers of individuals in each site group from the two catching sites in Greenland

	Ratio of Orsted Dal : Traill O birds	
Site group	1985/6	1986/7
1	3.00	3.50
2	5.11	7.21
3	6.33	6.63
4	0.78	0.95
5	2.30	3.13
6	2.50	2.33
7	2.50	13.00
8	2.00	0.50
Total	2.81 (n=274)	3.74 (n=360)
X2	27.52	45.38
d.f.	7	7
P	0.0003	0.0001

Distances moved by birds between sightings

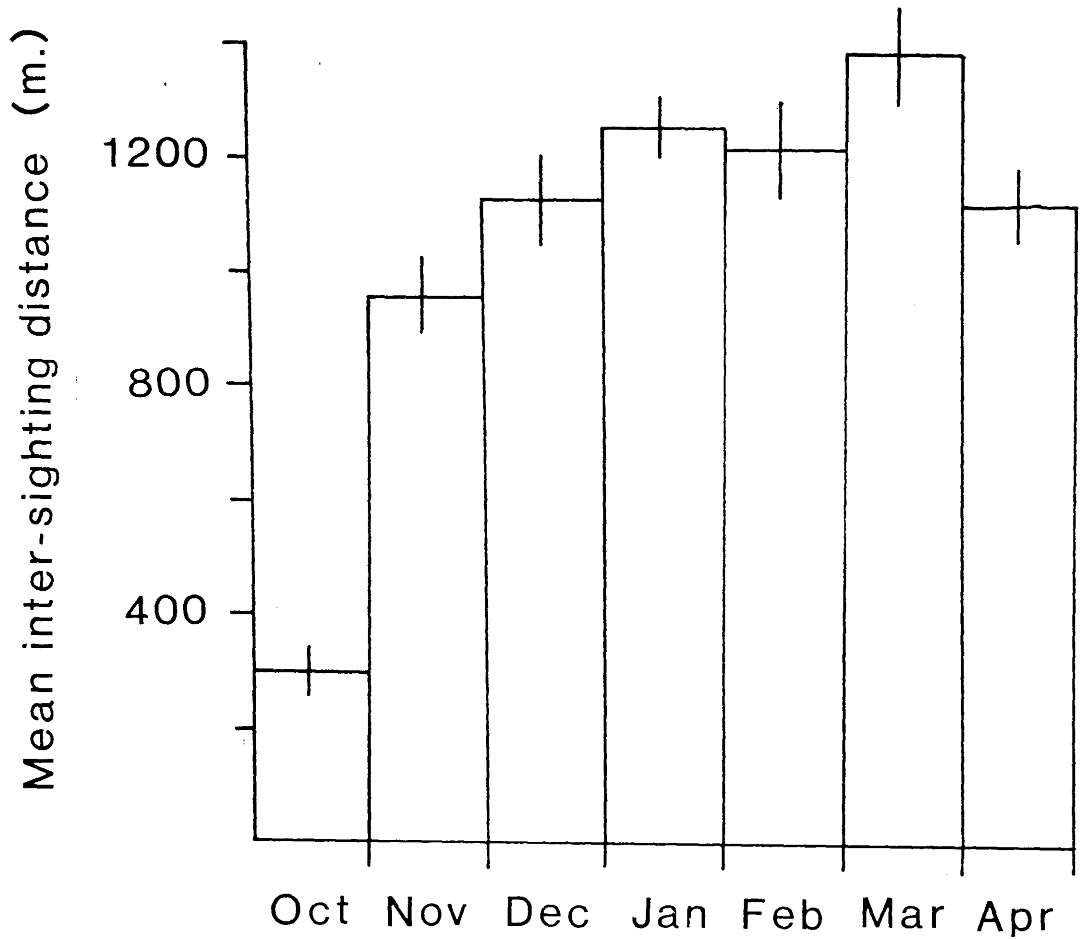
The overall population derived mean of the inter-sighting distance, calculated from data from all three winters, was 1.0 km. (sample=13,858). This provides further evidence to support the hypothesis of high site-fidelity suggested by the cluster analyses. In the statistical analysis these means have been derived from a logarithmic transformation of the data, as the distribution is positively skewed. Most birds tended to move only short distances between sightings.

The radio-telemetry work enabled a validation to be made of this technique. Using ring sightings, there is a potential bias in the data due to the fact that it is not always possible to read a bird's ring over the bird's entire range. The radio- fixes, however, provide an unbiased method of location of marked individuals. These birds allowed a validation of the use of the ring sightings to estimate home range areas to be made. The high correlation between the estimates of a bird's range calculated from the radio fixes with that from ring sightings of the same bird ($r=0.71$, $P<0.001$, $n=8$) showed that any bias in the sightings data set was not having a significant effect on the inter-sighting distance results.

Figure 5.7 illustrates the seasonal variation in the goose movement patterns. There was highly significant variation in the distances moved between months (ANOVA, $F=180.2$, $P<0.001$, 6 d.f., $n=13{,}858$). The geese were moving much shorter distances in the early autumn, with inter-sighting distance increasing through the winter and decreasing slightly in the spring immediately before the geese migrated north.

As suggested by the preliminary multivariate analyses,

Fig. 5.7 Seasonal variation in goose movements



birds showed fidelity to their movement pattern of the previous winter. Correlation coefficients of inter-sighting distances of individual birds seen in two consecutive winters were 0.471 ($P<0.05$, $n=99$) and 0.467 ($P<0.05$, $n=187$) comparing the winters of 1984/5 with 1985/6, and 1985/6 with 1986/7 respectively. Only birds seen on more than 10 occasions during a winter were included in the analysis, to ensure that a sufficient sample to describe each individual's range behaviour reliably had been obtained.

The analyses of site group fidelity within- and between- winters was found to be variable between the site groups. Table 5.7 shows that the movements of birds using the groups also differed significantly (the results from an ANOVA, controlling for year are given in the table - the large F-ratio for site group shows that this is a major factor affecting the movements of the birds). As mentioned earlier, all distances have been log-transformed to approximate to a normal distribution prior to analysis.

Table 5.7 : Variation in goose movements between individuals using each of the site groups on Islay

Site group	Mean distance moved between sightings (metres)	95% c.l. Lower	95% c.l. Upper	Sample size
1	657	616	700	2295
2	733	708	758	7355
3	1018	951	1089	1984
4	1059	990	1133	1618
5	1609	1493	1733	1437
6	1428	1257	1621	530
7	1941	1786	2109	1331
8	2673	2002	3556	146

TWO-WAY ANOVA, controlling for year

Site group	117.1	7	<0.0001
Year	8.1	2	<0.0001
2-way int.	12.9	14	<0.0001

In chapter 4 it was found that a bird's feeding behaviour was much affected by its social status. Table 5.8 shows how the same measures of social status affect goose movement patterns over their foraging range. Significant relationships were found between a bird's movement and its age; yearlings moved significantly further than either adults of juveniles. A similar correlation was found with breeding status (birds with families moved less far than those without).

Table 5.8 : Effect of social status on goose movements

	Mean inter-sighting distance (m.), (sample size)
1) Age	
Adult	1032.8 (15774)
Yearling	1366.5 (305)
Juvenile	916.0 (571)
	***
2) Sex	
Female	1012.3 (7591)
Male	1053.6 (8793)
	n.s.
3) Breeding status	
Non-breeder	1053.6 (14833)
Breeder	897.8 (1782)
	***
4) Pair status	
Unpaired	1085.7 (1243)
Paired	1032.8 (15472)
	n.s.

(*** = $P<0.001$, n.s. = $P>0.05$, Students' T-test for two-sample tests, one-way ANOVA for three- sample).

The movements of the birds carrying radio transmitters have been summarised in table 5.9, where again the means have been derived from logarithmic transformation as the data are skewed in their distribution. Of the 10 radios originally fitted, one failed immediately after release and two birds moved from the main study area, so comprehensive data were only obtained from seven individuals. These comprised five adults, all of which were paired but had no young, and two juveniles, which remained part of family groups to their departure at the end of April. The radio-tracking work was carried out during January - April in a single winter, and all birds were caught on the RSPB reserve, which explains why the mean between-day distance moved by the radio birds was smaller than that from the ring sightings data (which covered all three winters and the whole of Islay).

Table 5.9 : Movements of radio-transmitter birds

	Between-day (metres)	Within-day (metres)	Roost-feed (metres)
Adult non-breeder	775 (331)	380 (221)	1049 (236)
Juvenile	538 (113)	345 (67)	779 (82)
	***	n.s.	**

(*** = P<0.001, ** = P<0.01, n.s.= not significant, P>0.05, Students' T-test, nos in brackets = sample size)

Home range area

The harmonic mean method of home range area estimation (Dixon & Chapman, 1980), allows the definition of contours to calculate the area covered by a certain proportion of an animal's range. The results presented here include the total feeding range (enclosing 100% of the locations of an individual goose), the major part of its range (90%), and its core range (50%). Table 5.10 gives a summary of the means for each of these range classifications. The sample sizes are 924 individual ranges for each range class.

Table 5.10 : Barnacle Goose feeding home range area summary

% of total range	Mean area (km^2)	Standard Error
100	24.0	0.23
90	21.8	0.17
50	8.6	0.03

These overall population means illustrate that the geese were foraging within a relatively small area, in comparison with the 540 $km.^2$ of pastureland that is available to them on Islay. The birds' site fidelity is further emphasised by the size of the core range. The birds are spending, on average, 50% of their time in an area of only 8.6 km^2.

The birds used in the radio-telemetry study, enabled a validation of the home range results to be made, by comparing the ranges of the birds carrying radio transmitters calculated from radio fixes with those of independent ring sightings of the same birds. The correlations between these two values for each bird were very high for the total (100%) and major (90%) range parameters ($r=0.94$ and 0.96 respectively, $P<0.01$ for both, $n=7$). Clearly the ring sightings gave a reliable estimate for these two parameters. The relationship between the core (50%) range areas derived from the two methods was not so close ($r=0.44$, $n=7$, $P<0.05$). This was probably a result of the low variability between individuals for this parameter. The large majority of the birds had a very similar core range area; the variation in range size is over a very small range of values, hence it is difficult to establish any close correlation with the estimates obtained from the two methods.

The ring sightings provided insufficient samples to calculate individual home ranges on a seasonal basis, so the only data on the seasonal variation in range size was obtained from the radio-telemetry work, over the period of January to April 1987. The results are summarised in table 5.11. No significant difference was found between all three range parameters by month, (ANOVA, $P<0.05$, $n=7$), but the trends show an increasing total and major range area to a peak in March then decreasing in April. There was little seasonal trend in the core home range area, suggesting that even though the geese are ranging more widely later in the winter, they are still concentrating at least half of their foraging in the same small core area. As with the inter-sighting distance data from the radio-telemetry work, the results are restricted to the January - April 1987 period and are concentrated mainly on the RSPB reserve.

Table 5.11 : Seasonal home range areas of radio-transmitter birds

Month	Mean 100% range (SE) (km^2)	Mean 90% range (SE) (km^2)	Mean 50% range (SE) (km^2)
January	9.9 (1.7)	9.8 (1.6)	7.1 (0.2)
February	10.4 (1.3)	10.4 (1.3)	7.8 (0.4)
March	13.1 (2.1)	13.0 (2.0)	8.0 (0.4)
April	8.8 (2.8)	8.8 (2.5)	6.9 (0.3)
F-ratio	1.11 n.s.	1.15 n.s.	2.18 n.s.

Table 5.12 shows the effect of a goose's social status on the three parameters of range size. The results from two of these, the total (100%) and major (90%) range areas, showed considerable similarity to those from the analysis of the inter-sighting distances. The age of the goose seems to be the most important social factor affecting range size, with yearlings (birds in their second winter: as the birds are individually marked, if they were seen as first-winters in the previous, then they can be classified as yearlings) ranging over the greatest area. There was also a significant relationship between a bird's breeding

status and its range size, with successful breeders (that is, birds with young) ranging over a smaller area. These range parameters showed an additional significant factor, the pair status of the bird; paired individuals had smaller ranges than unpaired ones.

The lack of significance between any of the comparisons of the social status categories and core (50%) home range area showed that birds ranged over similar sized core areas, regardless of status.

Table 5.12 : Effect of social status on home range area

	100% range km^2 (SE)	90% range km^2 (SE)	50% range km^2 (SE)	N
1) Age				
Adult (3rd winter +)	24.1 (0.2)	21.8 (0.2)	8.6 (0.1)	871
Yearling (2nd winter)	27.2 (0.9)	24.0 (0.6)	8.7 (0.1)	19
Juvenile (1st winter)	20.4 (0.8)	19.3 (0.6)	8.2 (0.03)	35
	***	***	n.s.	
2) Sex				
Female	23.8 (0.3)	21.6 (0.2)	8.6 (0.4)	414
Male	24.1 (0.3)	21.8 (0.3)	8.5 (0.3)	496
	n.s.	n.s.	n.s.	
3) Breeding status (adults)				
Non-breeder	24.3 (0.2)	22.0 (0.2)	8.6 (0.3)	797
Breeder	22.3 (0.5)	20.6 (0.4)	8.5 (0.6)	127
	*	*	n.s.	
4) Pair status				
Unpaired	25.1 (0.6)	22.6 (0.4)	8.7 (0.8)	81
Paired	23.9 (0.2)	21.7 (0.2)	8.6 (0.3)	843
	*	*	n.s.	

(*** = $P<0.001$, * = $P<0.05$, n.s. = $P>0.05$, Students' T-test for two-sample tests, one-way ANOVA for three- sample).

Table 5.13 shows the results of the home range area analysis of the radio-transmitter birds in relation to their social status. The trend is similar to the results obtained from the ringed birds, with juveniles (and hence families) having a smaller total and major range, but little difference in core range area.

Table 5.13 : Home range areas of radio-transmitter birds in relation to social status

		100% range km^2	90% range km^2	50% range km^2
Adult non-brdrs	(n=5)	17.5	15.4	8.0
Juvenile	(n=2)	12.0	12.0	7.8

(n = no. of individuals).

The correlation between a bird's range size in consecutive winters was not as great as for its mean inter-sighting distance, though there was a significant correlation in total and major range areas between 1985/6 and 1986/7 (see table 5.14). The lack of any correlation between years in the core range area again results primarily from the low variation in this parameter, with most birds having a very similar core range area.

Table 5.14 : Comparison of home range areas between years (all birds)

	100% range	90% range	50% range	Sample
1984/5 v. 1985/6	0.071 n.s.	0.014 n.s.	0.049 n.s.	99
1985/6 v. 1986/7	0.317 **	0.277 **	0.084 n.s.	187

(values are correlation coefficients, ** = $P<0.01$, n.s.= $P>0.05$)

Section 5.2 Movements of Greenland Barnacle Geese within the whole winter range of the population

Methods

This work on the movements of geese within the whole population range had two main approaches. The first was to investigate the seasonal pattern of use that the geese make of Islay, to see whether birds are resident through the winter, or if there is turnover of birds moving to and coming from other sites in the range. The second part looks at the origins and destinations of the birds which are changing their wintering site, to establish the role that Islay plays for the whole Greenland population.

Seasonal Pattern of the Use of Islay by the Geese

The database of the sightings of ringed individuals seen on Islay described in section 5.1 can be used to look at turnover of individuals on Islay. Using the value of the overall proportion of birds on the island which are ringed (details of the sampling method and the calculation are given in section 5.1), it is possible to calculate the total numbers of birds using Islay at a given time during each season and during the whole winter. The population for any given period is estimated from the following equation, and this can be compared with the total count of birds on the island :-

Population = No. of ringed birds recorded / % ringed

It is unlikely that a significant number of ringed individuals were present on the island unrecorded, as large number of birds were checked on a regular basis and the resighting rate was high, with a mean of over 10 sightings per individual each winter. A cumulative frequency diagram of the number of individuals recorded through the three winters is shown in fig. 5.1, providing evidence that the large majority of marked birds on the island have indeed been recorded; all three curves soon reach a plateau in mid-late November. Therefore it is reasonable to assume that if a bird was not seen in two consecutive months, it had left the island. Based on this assumption, individuals were classified according to the months in which they were present on the island :-

"Autumn only"	recorded in October or November but not subsequently.
"Spring only"	recorded in March, April or May but not previously.
"Winter only"	recorded in December, January or Feb. but not previously or subsequently.
"Autumn/Spring"	recorded in both autumn and spring periods.

"Winter arrival"	recorded in winter and spring but not in autumn.
"Winter departure"	recorded in autumn and winter but not in spring.
"Resident"	recorded in all three periods, autumn, winter and spring.

Calculations using the numbers of individuals in each of these categories enable an analysis to be made of the seasonal turnover of birds on the island. As all the birds were of known age-class, sex and pair and breeding status, these movement patterns were analysed further to see how they were affected by the social status of the birds. The fidelity of individual birds to their movement patterns of previous years was also assessed, using the ring sightings data from all three winters.

Visits to Greenland Barnacle Goose sites outside Islay

Several other sites in the range were visited during the three winters of the study, to obtain sample observations of ringed individuals, to gain more information on the pattern of movement of the whole population. The main aim was to find out where the birds which were not resident on Islay through the whole winter went to and came from. Six sites were visited; two on the west coast of Ireland in March 1986 (Lissadell and the

Mullet peninsula), two in the Western Isles in April 1987 (North Uist and the Sound of Barra), and two other Inner Hebridean islands, Coll (in April 1986 and March 1987) and Tiree (in February 1985, January 1986, April 1986, January 1987 and March 1987). The locations of all these sites are shown in the fig 1.2 in chapter 1. During each visit to all the sites as many rings as possible were read, a count of the birds was made, and the proportion of the total checked for rings recorded.

Population mixing

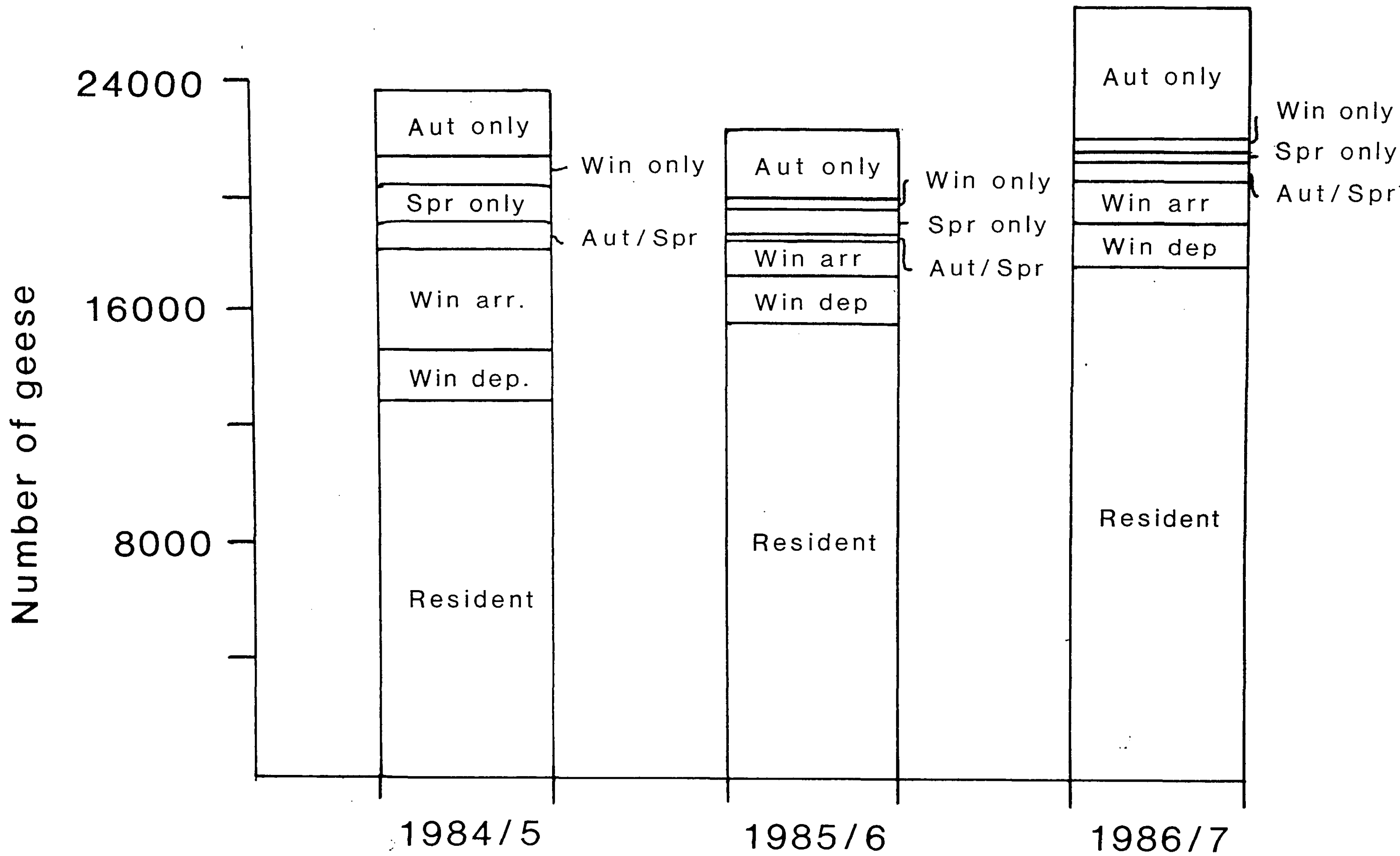
It was also possible to look at the rate of interchange of individuals between the Greenland population and that which breeds in Svalbard (and winters on the Solway Firth). A large number of the latter are also carrying Darvic rings (M. Owen, pers. comm.) and several have been recorded on Islay, despite the fact that the two populations had been described as discrete (Ogilvie 1978, Owen 1980).

Results

Seasonal use of Islay by the geese

Figure 5.8 summarises the seasonal occurrence of individual geese on Islay. It can be seen that a large

Fig. 5.8 Seasonal occurrence of Barnacle Geese on Islay



majority of the birds are resident on the island through the whole winter period, but there are substantial numbers of transients as well. In particular there are a considerable number of individuals which spend the autumn on Islay, then move on to other sites for the remainder of the winter. The turnover of individuals continues right through the whole period, as birds depart and others move in from other sites.

This turnover is further illustrated by looking at the total numbers of ringed birds recorded on Islay in each winter. Using the proportion of birds that are ringed in the population, it is possible to calculate the total number of birds using the island during the course of the winter. Table 5.15 shows the results of such calculations for the three winters of the study. It can be seen that the total numbers were well in excess of the maximum number of birds counted in all three years, so turnover must have been taking place.

Table 5.15 : Seasonal numbers of geese on Islay - comparison of direct counts and estimates from ring sightings

	No. of birds using Islay (from rings)	Mid-winter count
1984/5	24,076	17,600
1985/6	22,249	18,500
1986/7	26,494	21,800

The social status of a goose did not seem to have much effect on its length of stay on Islay (see table 5.16). The chi-squared tests are based on the null hypothesis that the same proportion of residents and transients occurred in each social status category. Only pair status showed any significant difference from what would have been expected if social status and seasonal occurrence were not related. More unpaired birds were resident on Islay through the whole winter than would have been expected.

Table 5.16 : Effect of status on seasonal pattern of occurrence on Islay

	X^2	d.f	P
Age	4.05	4	n.s.
Sex	4.50	2	n.s.
Breeding status	2.17	2	n.s.
Pair status	12.53	2	$P<0.01$

Geese generally showed the same seasonal pattern of occurrence on Islay in consecutive winters. Table 5.17 shows that in 1986/7 over 75% of the birds were classified into the same category as the previous winter. The slightly lower value of 60% in 1985/6 was almost certainly due to the poor observer coverage in autumn 1984.

Table 5.17 : Fidelity of geese to seasonal pattern between years

Winters compared	% same class	Sample
1984/5 v. 1985/6	60.3%	302
1985/6 v. 1986/7	76.0%	337

In both 1985/6 and 1986/7 about half of the ringed birds seen on Tiree had already been seen previously on Islay in the same winter (table 5.18). Other sites did not have such a high proportion of Islay birds, but some were recorded in every area visited. The large percentage of Islay birds seen on Tiree was at least partly due to the island's proximity to Islay (50 miles, compared to the distance of 100-150 miles between Islay and the other sites), but even so there are clearly a considerable number of birds wintering on these other sites that visit Islay at some stage during the winter.

Table 5.18 : Ring samples from Coll, Tiree and Ireland

	No. rings read	No. also seen on Islay in same winter	% of total also seen on Islay
Ireland 1986	38	5	13.2
Coll/Tiree 1986	23	12	52.2
Tiree 1987	18	8	44.4
Uist 1987	10	1	10.0

Interchange with Svalbard population

During the three winters of the study nine birds which were originally marked as part of the Svalbard population were recorded on Islay. Though this movement between the populations is small, it could be significant at the genetic level, reducing the isolation of the populations. Of these nine birds, three have been recorded with young, showing that they are breeding successfully despite their change of population. The birds that were recorded moving from the Svalbard to the Greenland population represent a total of about 40 individuals, as about 25% of the Svalbard population were ringed during the study period (Owen pers. comm.). None of the birds recorded on Islay during the study have yet been sighted subsequently in the Svalbard population, even though the Svalbard birds have been the subject of much intensive study.

Once birds have changed populations, they seemed to remain faithful to their new population. Of eight Svalbard birds recorded on Islay in 1984/5, six were recorded there in 1985/6 and the same six in 1986/7. No movement back to their original population has been recorded.

Discussion

Within-Islay movements

The multivariate analyses, inter-sighting distance and home range area all showed that the geese were generally site-faithful to a restricted range. Some birds do move considerable distances between feeding sites, dependent particularly on their social status and the area of th island that they were using. Yearlings are the most mobile group. Families were found to be the most resident site-faithful group.

The radio transmitters allowed investigation of these movement patterns in more detail. The data that they provided were in broad agreement with that from the ring sightings, which were a useful validation of the latter technique. Families seemed to occupy what would intuitively appear to be the best feeding areas; they had smaller ranges, moved about less between feeding sites and fed closer to their roost-site. Black and Owen (1987) found, in a study of the social behaviour of the Svalbard population of Barnacle Geese on their wintering grounds, that families were the dominant social group in the feeding flocks, which could explain how they are able to occupy the best feeding areas.

High site-fidelity has been suggested for several species of geese. Raveling (1969a & 1978) has shown that individual Canada Geese are extremely site-faithful as adults and less so as yearlings, St. Joseph (1979) found Brent Geese to be loyal to their wintering sites between years, and Gullestad et al. (1984) found high site fidelity amongst Svalbard Barnacle Geese on their spring staging area. Apart from these studies, however, information about the factors affecting goose foraging range behaviour and site fidelity is sparse.

The strong fidelity that birds show to certain parts of Islay suggests that there are sub-groups of birds on the island. Raveling (1969b) found that Canada Geese appeared to occur in similar such groupings. He suggested that such groupings and high site-fidelity helped to maintain family integrity through the winter, and hence to enhance the survival of young birds. In most goose species, family parties are known to feed predominantly on the edge of foraging flocks (Owen 1980), and Teunissen _et al_. (1985) have suggested that this position is the best for maximizing food intake rate. Thus as a part of a family, a young bird is able to occupy the best feeding area. There might also be some benefit accrued to the geese by high site-fidelity, by allowing them to relocate their mate if they become separated. Owen et al. (1986) have shown that Barnacle Geese breeding with new mates are less successful in raising young than birds with the same mate as the previous year, so their are advantages in avoiding separation. Another possible benefit to high site-fidelity is the accumulation of detailed local knowledge through experience of a particular area, which might, for example, enable birds to have an increased feeding efficiency. The question of whether the associations are maintained at other times of year is considered in chapter 6, together with the implications that this might have to the interpretation of observations made on the wintering grounds.

The high site-fidelity helps to explain why the number of geese using the RSPB reserve was not increasing over the three winters of the study, despite an increasing area of newly reseeded pasture (see chapter 4). Local birds might move short distances to exploit improved feeding conditions, but birds were remaining faithful to sites away from the RSPB reserve, so few new birds were being attracted to the refuge. Obviously this has profound implications for the goose management strategy on Islay. Over the three winters of this study, many geese were remaining faithful to areas outside the refuges, despite improved feeding conditions in the refuges and scaring outside them. Birds were staying to feed even in the most heavily shot areas. It appears that scaring at its present level only moves the birds around within their usual range, rather than encouraging them to move to a new area. Perhaps the best strategy would be to have a wider network of refuges, for example one within each of the ranges of the main groups of geese. Then the geese could be encouraged by a combination of scaring and pasture management to use their local refuge.

Movements across the whole range

The ring sightings have shown that there is some turnover of geese on Islay through the whole winter, with most birds remaining on Islay, and others leaving for alternative wintering sites. The number of individuals using Islay over a whole winter is considerably in excess of any one maximum count, potentially increasing the conservation importance of Islay as a site for Greenland Barnacle Geese as it is used by an even greater proportion of the whole population. Particularly large numbers of birds which arrived on Islay in the autumn and moved north again to other sites through the winter and spring. Thus, even though the majority of geese have a restricted winter range, a proportion (about 20%) of the population are mobile between wintering sites.

The social status of a goose was found to have little effect on whether it remained resident on Islay or not. The only significant factor identified was a bird's pair status; more unpaired birds than expected were found on Islay. This might be explained by birds coming to Islay to look for a mate, a reasonable strategy as the island holds such a large concentration of birds.

Any improvement in feeding conditions, either through reduced disturbance or increased food availability, might have the potential to encourage birds to stay longer on Islay and hence increase the numbers on the island. This potential problem could be exacerbated, as feeding conditions in some other parts of the range are becoming less attractive to the geese. On many of the more remote machair islands sheep grazing is declining and hence the sward becomes less suitable for grazing geese (Ogilvie 1983).

There is much scope for further, more detailed work on the movement patterns between these other sites and Islay, particularly to look at the numbers and ringed birds at sites away from Islay in the autumn. The results presented here give only preliminary ideas about the direction and timing of movements between Islay and other sites in the winter range.

Interchange of individuals with the Svalbard population

It has been stated previously that the Svalbard and Greenland populations are completely discrete (Ogilvie 1978, Owen 1980). Small numbers of Svalbard birds had been recorded on Islay in the past (Owen, pers. comm.), but these were though to be of no significance to the population biology of the Greenland population. During my work on Islay nine birds originally marked as part of the Svalbard population have been recorded in the Greenland population and three of these had bred successfully. In total, the numbers are not of any great significance (about 40 birds, when the proportion ringed in the Svalbard population is taken into account), but the transfer of individuals is sufficient to remove any possibility of genetic isolation between the two populations.

When birds do change populations, they tend to remain with their new associates. The same Svalbard-marked birds have been seen in the Greenland population in subsequent winters, and no movement back to the Svalbard population has been recorded. Both the sample of birds and time-scale of observations are small, however, which might explain why these results do not concord with findings about movements between other Barnacle Goose populations. Seven out of twelve Svalbard-ringed geese which had been observed in the Netherlands (as part of the Russian population) have returned to the Svalbard population in subsequent years (M. Owen, pers. comm.).

Chapter 6 : THE ROLE OF WINTER FEEDING ON BREEDING SUCCESS

Introduction

Work by Cabot and West (1973, 1983) and Ogilvie (1983) has shown that there is a significant difference in breeding performance between the birds that winter on Islay and those in Ireland. It has been suggested that this difference in productivity is due to better feeding conditions on Islay during the winter and early spring. Cabot and West (loc. cit.) provided further evidence to support this hypothesis by correlating winter temperature, and hence, by inference, food supply, with the proportion of juveniles in flocks on the wintering grounds in the next autumn.

The main aim of this chapter is to look at this correlation in more detail, to see if there are differences in the breeding success of birds using different sites on Islay, and the rest of the winter range, and to investigate some possible explanations for any such differences. If winter feeding conditions do have a significant effect on subsequent breeding performance, then changes in the population dynamics might be expected following changes in goose management on Islay.

After establishing whether such differences in breeding performance of birds using different parts of the winter population range occurred during the three winters of the current study, further investigation was made to see whether these differences might result from differences in feeding conditions on the wintering grounds. Two alternative explanations might account for the observed difference in the proportion of young birds in different parts of the population range :-

1. Birds may associate with the same group of individuals throughout the year. Thus birds which occur together in the winter would also be together, or example, in the breeding grounds. Hence differences in the breeding success of birds using different parts of the winter range could result from those same groups of birds experiencing difference conditions in the summer. This hypothesis was tested using data collected during an expedition to the spring staging area in northern Iceland in May 1987, to see if birds that associated in the winter were also associating in spring.

2. The behaviour of family parties may differ to that of non-breeding birds. The higher than average numbers of young on Islay might be a result of families selecting Islay as a wintering area in preference to the other sites. This idea can be tested by examining the range behaviour of the marked individuals in the population, comparing movements of successful breeders with those of birds without young.

Methods

Breeding success in the previous summer was assessed in the winter flocks by measuring the proportion of young, as young geese remain with their parents throughout most of the winter (Owen 1980). Samples of the proportion of young in the flocks at each of the sites on Islay were taken throughout each winter. Additional data were obtained during visits to several other sites in the winter range (see chapter 5.2). Young (first-winter) Barnacle Geese can be distinguished from the adults in the field until the spring, by their browner mantle feathers and generally scraggy appearance (Cramp & Simmons 1977). Sampling must take into account bias within the flock; young geese are generally more abundant on the edges of the flock (Owen 1980). To ensure that a representative sample was taken, only those in which more than half the flock were sampled were included in the analysis. Another problem with sampling was the variation in the estimate of the proportion of young with flock size. For example, two theoretical samples have been taken; in one 200 geese sampled from a flock of 200 with 20% young (actual number of young = 40) and in the other 200 are sampled from a flock of 400 with 5% young (actual number of young = 20). These would together give a result of (40 + 20)/400 = 15% young, if unweighted for flock size, though the true proportion of young is only (40 + 20)/600 = 10%. To avoid this bias, samples were weighted for flock size. The cluster analyses have shown that there are groups of birds using certain sites on Islay (see chapter 4.1), so these provided convenient units for the analysis of breeding success of birds using different parts of the island.

The age samples were used to test the prediction that breeding success is uneven across the range, but they could not provide any information about whether any difference is due to winter feeding behaviour, or other factors such as differences in the behaviour of families. Further data were obtained from observations of the marked birds in the population (see chapter 5.1). In May 1987 observations were made of the geese on their spring staging grounds in northern Iceland, to see whether birds which associated during the winter were also found together in the spring. If such associations were found to be consistent, the the observed differences in breeding performance between groups of birds using different wintering areas could be due to factors acting at other times of year. The marked birds also provided information about the range behaviour of birds of different breeding status, to see if the home range and seasonal use of Islay is affected by a bird's breeding status (see chapter 5).

Results

The proportion of young at different sites on Islay for the three years is given in table 6.1. There is a clear difference between areas, which is consistent between years (see table for X^2 tests of significance).

Table 6.1 : Variation in the proportion of young in flocks in different areas of Islay

Site	1984/5	1985/6	1986/7
Gruinart E.	6.69 (3321)	9.85 (17675)	13.39 (15566)
Gruinart W.	9.22 (10099)	9.29 (21448)	12.60 (25584)
Ardnave	10.72 (3201)	10.16 (3901)	14.28 (5427)
Home Farm		10.42 (9855)	13.25 (9355)
Ballygrant	10.44 (15507)	8.09 (8417)	14.07 (8432)
Mulindry	11.96 (1946)	9.88 (10214)	17.84 (8567)
Laggan/Oa	14.78 (6818)	9.23 (11585)	17.51 (14991)
Rhinns	-	15.45 (1289)	24.84 (2331)
Total Islay	10.55 (40892)	9.56 (84384)	14.66 (90253)
Chi-squared	184.0	80.64	386.9
Degrees of of freedom	5	7	7
	***	***	***

(*** = P<0.001, X^2 test)

Age samples were also obtained from several other sites in the winter range, and the results are given in table 6.2, together with overall totals from Islay (using samples taken at the same time of year) for comparison. In

1984/5 and 1985/6 the proportion of young at all sites was consistently lower than that on Islay. In 1986/7, however, Tiree and Uist both had a significantly higher percentage of juveniles in their flocks than in the Islay flocks. Details of the X^2 tests are given in the table.

Table 6.2 : Comparison of the proportion of young on Islay with the rest of the winter range

Site	Date of visit	% juvs (sample)	% juvs on Islay at same time
Tiree	Feb '85	7.47 (443)	9.71 (14,446)
Tiree	Jan '86	7.02 (470)	7.46 (15,626)
Lissadell	March '86	5.66 (865)	8.56 (10,594)
Mullet	"	9.24 (476)	8.56 (10,594)
Tiree	Jan '87	18.81 (730)	14.9 (12,893)
"	March '87	18.42 (624)	11.1 (26,277)
Uist	April '87	17.33 (1164)	11.1 (26,277)

(1984,5 & 6 : chi-squared = 20.35, 3 d.f., $P<0.01$,
1986/7 : " = 82.5, 2 d.f, $P<0.001$)
for null hypothesis that no difference in % juvs to Islay at same time as visit)

The results of observations of ringed birds made in Iceland on the spring staging ground in 1987 are shown in table 6.3. The data were tested for independence by a G-test, based on the null hypothesis that there is a random scatter of Islay birds through the whole of the spring the proportion of Islay birds to be the same at each site, equal to the proportion that they make up of the whole ringed population (about 73%). The analysis was made on bird 'units' rather than individuals, so that pairs counted as one unit. It can be seen from table 6.3 that there were some sites at which there were significant aggregations of Islay birds and others at which birds which had not visited Islay predominated.

Table 6.3 : Proportions of bird units at different sites on the staging grounds that have been on Islay during the previous winter

Area	No. of Islay bird units	No. of non-Islay bird units	% Islay birds
V.-Hunavatn	10	2	83 %
A.-Hunavatn	7	12	37 %
Skagi peninsular	17	8	68 %
Skaga valley (N)	4	4	50 %
Skaga valley (E)	26	8	76 %
" " (W)	31	3	91 %

(G-test results : G=20.03, d.f.=5, $P<0.01$)

Discussion

There were significant differences in the previous summer's breeding performance of birds using different sites on Islay, and between those using Islay and the rest of the winter range. The higher productivity of birds wintering on Islay in 1984/5 and 1985/6 was consistent with observations made by Cabot and West (1983) and Ogilvie (1983), but results in 1986/7 showed the opposite to be true.

There is no immediate explanation why feeding conditions should be better on Islay. Pastures have been improved at many of the other wintering sites, where there is probably less competition from other geese, and, on the west coast of Ireland the climate is warmer so grass growth should be prolonged, and hence food availability increased. The differences in breeding performance between birds wintering in different parts of Islay are even more difficult to explain in terms of winter feeding opportunities, as all have substantial coverage of newly reseeded pasture. The low breeding performance of the Gruinart birds is not readily explained, as this area appeared to be a particularly attractive to feeding geese, with individuals showing a high degree of fidelity to the site. It had a high concentration of reseeded grassland, and also, being within the refuge network, had low levels of disturbance.

Two alternative hypotheses were suggested that might account for the differences in the proportion of juveniles in flocks across the winter range. Firstly, if groups of individuals remain together through the year, as suggested by the clumping of birds from certain ringing sites in the Islay cluster groups (see chapter 5.1), then the differences in breeding performance could be due to factors operating on the spring staging areas in Iceland or on the breeding grounds in Greenland. Observations of ringed birds on the spring staging grounds in Iceland in 1987 provided evidence to support this idea, suggesting that there was some aggregation on the spring staging areas of birds from the same wintering site.

If birds were staying together through the year, one might expect some advantage, such as increased breeding performance or survival, to be accrued from this strategy. Many studies have suggested that birds associate at a particular time of year (Raveling 1978, Metcalfe 1986), but little work has been done to see whether these aggregations are maintained at other times of year. Gullestad et al. (1984) suggested that there may be some segregation in the Svalbard Barnacle Goose population on the spring staging grounds with respect to breeding area, but failed to show any statistical significance in their overall results. Associations at just one time of year could simply result from birds using the same feeding or roosting sites, but if they are staying together at other times, then these associations could have a more important biological function. The benefits of traditional site use have been discussed in chapter 5, and it is possible that these might occur at other times of year. This still does not answer the question of why birds should stay with the same group of birds throughout the year. The possibility of a complex kin-based strategy should not be ruled out, if these associations represent local breeding groups. Owen et al. (1987), in a study of pair formation in Svalbard Barnacle Geese, suggested that birds may pair with birds of the same natal area, to concentrate genetic traits advantageous to the exploitation of resources in that area. Such a strategy might explain the benefits of association with the same group of individuals throughout the year. More data need to be collected if such ideas are to become anything more than speculation, firstly to establish that these aggregations exist throughout the year,and secondly to look in detail at the possible functions of such social organisation.

The second hypothesis was that the difference in the proportion of young in flocks in different parts of the winter range might be due to different behaviour of birds when they have families. The home ranges and movement patterns of birds in relation to their social status was discussed fully in chapter 5.1. It was shown that families were even more site-faithful than non-breeders, which is the opposite to the behaviour that would be necessary to explain the observed differences in breeding performance. This hypothesis is thus unlikely to explain the variation in the proportion of young between sites. Of the hypotheses considered, the most likely seems to be the idea that birds are staying together at other times of year, and the observed differences are just a correlation with factors acting on those same birds on the staging or breeding grounds.

Chapter 7 GENERAL DISCUSSION AND CONCLUSIONS

In the introduction to this thesis the aim was set out to investigate the impact of Barnacle Geese on the agriculture of Islay, and to look at some ways in which this impact might be reduced. In this last summary chapter the findings of the work have been brought together and are discussed in the context of a conservation management plan for the geese on Islay.

The agricultural impact work (chapter 3) showed clearly that the geese can have a very significant damaging effect on the island's agriculture. This damage was most severe on areas that were grazed particularly heavily by the geese, where there was substantial loss of silage yield and a reduction in the availability of grass to farm stock in the spring. Even in less heavily goose-grazed areas, large losses in spring yield were attributable to the grazing activity of the geese, though the silage yield reduction was not so great. The effect of the geese was further exacerbated by causing a delay in the spring application of fertilizer. Without the presence of the geese this would have been carried out around mid-March, but experimental work showed that the geese consume most of the extra yield that such application promotes. Thus the farmers have to wait another month before applying the fertilizer, further reducing the spring availability of grass to farm stock from its potential yield, and also causing a slight decrease in the silage crop. Goose damage to the grasslands was found to cumulative through the whole winter and spring. It has been suggested by several workers that goose grazing can increase the quality of a sward (for example, Ydenberg & Prins 1981, Cargill & Jeffries 1984), removing old material and stimulating nutritious new growth. Experiments showed that the geese did indeed increase the crude protein and reduce the fibre content of the spring sward, but this nutritional benefit was tiny in relation to the overall yield losses, and had disappeared by the time of the silage cut in mid-June.

Overall, then, there is little doubt that the geese have a very significant economic impact on Islay's agriculture. This study has shown that the magnitude of the damage can be great, but that it is also highly variable between years. If precise assessment of the economic damage is required, then several years specific study would be required, to construct a model similar to that built by Bruinderink (1987) for goose damage to grassland in the Netherlands.

How can this impact of the geese on the island's agriculture be reduced, whilst maintaining a management plan sensitive to the conservation of this potentially vulnerable species, for which this country has a special obligation to protect under the EEC Birds Directive?

The present conservation plan is to maintain a network of refuges, including the RSPB reserve, over the island, with the aim of attracting most of the geese into these areas. It is important to know how to manage the grassland within these refuges to maximize the number of geese that they can support. Experimental work on the RSPB reserve showed that two management techniques could substantially increase the number of geese using a field; (1) reseeding, where a field is cultivated (usually ploughed) and resown with a nutritious, high-yielding grass mix (usually based primarily on rye grass, Lolium perenne, and (2) fertilizing, applying extra nitrogen to the soil in October and February. The reseeding was effective in all experiments, giving about 100% increase in goose grazing pressure. The fertilizing was effective on most fields, but not those where the soil nitrogen levels were already very high.

Work on the behaviour of the geese on different grassland types did not identify any particular explanations for the selection that the geese exhibited for newly reseeded pasture. Detailed experimental work using captive individuals would be necessary to investigate the mechanisms of this selection.

Reseeding and fertilizer application could theoretically be used to increase the carrying capacity of the refuges. However, the solution to the conservation problem is not quite so straightforward. Over the three years of the study the area of recently reseeded grassland on the RSPB reserve increased from 25 to 75 hectares, but no significant increase in goose numbers was recorded. The geese just appeared to be concentrating in the reseeded fields. This suggests that factors other than food availability are affecting a goose's choice of feeding site.

Human disturbance was found to have little effect on goose grazing, except on very narrow strips of grassland alongside roads and adjacent to farm buildings. Barnacle Geese on Islay seemed to be much less sensitive to disturbance than most other goose species, but this may be a result of the relatively low levels of human disturbance to which they were subjected.

To gain more insight into the lack of success of improved grassland management in attracting more geese to the refuges, an investigation was made of the movements and feeding site selection of individually-marked birds. An extensive study was carried out using leg-ringed birds over the whole island for all three winters, together with an intensive four-month radio- telemetry project. These showed the geese to be very site-faithful, generally staying in the same part of the island throughout the winter, and returning to that area in subsequent winters. This explains what occurred on the RSPB reserve. Improved grassland management attracted the local birds to those specific improved fields, but birds in other areas remained faithful to them.

Could the birds from areas outside the refuges ever be moved to them? At the levels of disturbance during the three winters of this study, this would appear to be unlikely. Birds were remaining faithful, even to areas of highest disturbance and shooting pressure. It also has to be borne in mind that increased mortality brought about through an increase in shooting might not be acceptable under the terms of the EEC Birds' Directive. An increased scaring effort, particularly non-lethal scaring, is planned for the winter of 1987/88, so it remains to be seen whether this will be effective in moving birds to the refuges. If it is not successful, the conservation plan will have to be modified, perhaps by increasing the area of the refuge network.

It is important for any conservation plan for the Islay geese to consider the remainder of the Greenland Barnacle Goose population. Sightings of ringed birds have shown that a large proportion of the population visited Islay at some stage through the winter. There is a flux of birds on the island, with turnover of some individuals moving through to/from Ireland and other Scottish wintering sites. Habitat changes at these other sites could affect numbers of geese on Islay, so it is of benefit to both conservation and agricultural interests to manage these other sites to accommodate as large a proportion of the population as possible away from Islay.

The winter goose management plan could also affect the subsequent breeding performance and hence numbers of birds returning in the following autumn. Aggregations of groups of birds through different stages of the annual cycle makes it difficult to interpret differences in breeding performance of birds using different parts of the winter range, but winter feeding could be of importance in attaining body condition for spring migration and breeding. There is much need for more work to be done to look in detail at the factors affecting the population dynamics of these birds throughout the annual cycle.

In summary, the present conservation plan is providing large numbers of Barnacle Geese with safe feeding grounds through the winter, and offsetting the economic impact that they have on some of Islay's farms. However, there are still some farms where the birds are causing considerable damage but the farmers are receiving no payment at all, and where the geese are still being shot in large numbers. A solution might be to designate refuges within each of the main goose areas rather in than just some of them, so that all the geese have a refuge within their main home range, and all the farms which are suffering heavy goose damage are being compensated.

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