BTO Research Report No. 420

Analysis of Islay Greenland White-fronted *Anser albifrons flavirostris* and Barnacle *Branta leucopsis* Goose datasets

Authors

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EXECUTIVE SUMMARY

A Appraisal of the International Paired Count Data

A.1 A monitoring programme has been in operation on Islay since the winter of 1983/84 to investigate population changes of Greenland White-fronted and Greenland Barnacle Geese. Whole-island counts are carried out on a single day and then repeated on the following day ('paired counts'). A count is deemed unsuitable if it is affected detrimentally by bad weather or disturbance. Repeat counts on consecutive days increase the chance of at least one of the counts being 'adopted' as satisfactory. This counting design allows for some appraisal of the likely discrepancies associated with these counts based on comparisons between the two count days, although it does not allow the derivation of a measure of true counting error.

A.2 Mean count discrepancy, the percentage difference between each pair of goose counts (the difference as a percentage of the higher count), was estimated using ratio estimators as 9.2 % (95 % C.I.: 7.4 to 11.0) for Greenland White-fronted Goose and 6.0 % (95 % C.I.: 5.6 to 6.4) for Greenland Barnacle Goose. The lack of any significant seasonal trend in count discrepancy suggested that, as planned, most counts took place outwith the main periods of goose migration either to or from the island. Between the winters of 1983/84 and 2003/04, count discrepancy decreased for Greenland White-fronted Goose, while it increased for Greenland Barnacle Goose. The possible reasons for these trends are discussed.

A.3 Generalised additive models (GAMs) were used to smooth annual winter maximum counts ('paired' where available) for the two goose species, and bootstrapped 95% confidence limits used to assess the significance of changes in goose numbers over the 20-year (and shorter) periods. This analysis concludes that the Islay Greenland White-fronted Goose population increased significantly between 1983 and the mid-1990s; the suggested recent decline was not quite significant when paired count data were modelled. The Islay Greenland Barnacle Goose population increased during the whole period and the increase was significant for the period as a whole and for the most recent five-, ten- and fifteen- year periods.

A.4 For either species, the population modelling using single day counts (using either Day One or Day Two of the paired counts) or paired counts produced very similar population trends. Paired counts generally resulted in wider bootstrapped 95% confidence limits, which in one case (the most recent five-year period under consideration for White-fronted Goose) resulted in the paired counts showing a non-significant decrease that was significant when either the Day One or Day Two counts were modelled in isolation.

A.5 In summary, our results suggest the following:
Given the variation associated with the date of peak numbers of each goose species present on Islay in winter, the maintenance of a programme of counts spanning the period October to March each year is the safest option for detecting the true annual maximum and also monitoring any change in the pattern of goose movements involving Islay;
We advise that at least a proportion of the counts be maintained as 'paired', so that some measure of counting consistency is included in the modelling of population trends. Given the observed changes in count discrepancy for both species over the last twenty years, the retention of paired counts is also important to allow any future changes in count discrepancy to be detected and explicitly allowed for in the population models. Paired counts are of most value if the programme ensures that the maximum count each winter is derived from a pair of counts. As the date of maximum count has varied through time, it may be difficult to achieve this unless attempts are made to carry out paired counts throughout the core winter counting period.

B Effectiveness of Goose Scaring on Islay

B.1 Islay holds goose numbers of international conservation significance: the maximum counts of Greenland White-fronted Goose and Greenland Barnacle Goose in the winter of 2003/04 were *ca* 11,000 and 50,000 respectively. The geese come into conflict with agriculture, eating agricultural grasses resulting in reduced crop yields. A programme of goose scaring as part of field management, with the aim of limiting agricultural damage, has been in use on Islay since the winter of 2000/01. The scaring techniques used on the island involve lethal shooting (under licence; Greenland Barnacle Geese only), shooting to scare (non-lethal shooting), and the use of non-shooting scaring devices. We undertook a preliminary investigation of the extent to which the datasets collected by SNH on Islay can be used to determine the effectiveness of scaring as a whole, and of each of the different techniques.

B.2 We first assessed the extent to which field usage by each goose species in turn could be modelled, based on goose count and field-attribute data collected during an eight-year period (winters of 1992/93 to 1999/2000) when scaring was not allowed. The resultant models were then used to predict field usage during four winters of the current Goose Management Scheme (2000/01 to 2003/04), during which a programme of goose scaring was implemented. These predicted field use patterns were then compared with observed field usage during the current Goose Management Scheme, and assessment made of the extent to which differences could be related to spatial variation in the use of the various scaring techniques.

B.3 The goodness-of-fit of the field use models based on the data from the eight winters prior to the onset of the scaring programme was statistically satisfactory for both goose species. As expected, crop type was a key variable in the models of field usage produced, particularly for Greenland Barnacle Geese, for which higher numbers were associated with younger grassland. Other variables that showed a significant influence on field usage for one or both species included: field gradient; degree of undulation; distances to nearest roads, lochs and known roost sites. Fertiliser application was also found to influence patterns of field use when data from the Loch Gruinart RSPB Reserve were analysed but could not be considered in the whole-island analyses. Livestock, electricity transmission lines and topographic exposure were additional variables that it would have been preferable to include but for which suitable datasets were not available in the timescale of this preliminary study.

B.4 The analyses that aimed to compare the effectiveness of scaring and the individual scaring techniques were limited by the methods and duration of data collection to date:
information on shooting was available at the field scale only in the most recent winter (2003/04) and only at the scale of individual holdings in the previous three winters;
information on non-lethal shooting was only available from holdings where the SNH marksman had been employed, not from farms where farmers carried out their own shooting to scare;
information on the deployment of non-shooting scaring devices was only available for two winters (2002/03 and 2003/04), although such devices were used prior to those winters;
information on non-shooting scaring devices was often incomplete, so that more detailed analyses (related to e.g. the length of time devices were employed) were not feasible;
sample sizes were insufficient to look for variation in effect between different scaring devices.
These analyses were also limited by the quality of the predictive field use models (B.3 above).

B.5 In all four winters for which information on scaring was available (2000/01-2003/04), preliminary modelling showed that numbers of Greenland Barnacle Geese were lower than expected (based on predictions from the field-use models) in areas in which scaring was permitted, and this differed significantly from areas where scaring was prohibited: zones defined as ‘feeding’ and ‘buffer’ on average each held more geese than expected (means of 20-120% more than expected across the four winters) while ‘scaring’ areas held less geese than expected (means of 11-44% less across the four winters). No such differences were detected for Greenland White-fronted Geese alone but when combined numbers of the two goose species were considered, areas where scaring was permitted again showed lower than expected numbers compared with areas in which scaring was prohibited (‘scaring’ and ‘buffer’ areas means of 5-44% lower across the four winters, one mean of 6% higher than expected; ‘feeding’ area means of 8-55% higher numbers than expected across the four years). These preliminary results suggest strongly that scaring has had desirable benefits overall in terms of discouraging geese from the ‘scaring’ areas on Islay (newly re-seeded grassland) and also from the ‘buffer’ areas to a lesser extent. However, this tentative conclusion is based fundamentally on the assumption that other (unmeasured) factors that might influence goose field use have not changed between 2000/01 and 2003/04 with a systematic bias towards areas in which scaring has been undertaken. The analytical approaches available to us (pattern of prior data collection) do not allow cause and effect to be proven but, rather, suggest influences of scaring that should be investigated further with: more winters of field-specific data collection; improved data collection methods; and possibly future fieldwork based on a more rigid experimental design see (B.7 below).

B.6 The modelling detected some differences in the effects on goose field use between scaring techniques (or combinations of techniques) but these differences varied between species and between years. Rigorous comparisons were only possible for one winter (2003/04) because only in this year were data available both on the deployment of non-shooting scaring devices and on shooting at the level of specific fields. For Greenland Barnacle Goose, three categories of scaring appeared to result in lower numbers of geese than expected in 2003/04, differing significantly in effect from areas without scaring: non-shooting scaring alone; non-shooting scaring combined with non-lethal shooting; and lethal combined with non-lethal shooting. For this species, the same effects were mirrored in the previous winter also. For Greenland White-fronted Goose, significant differences were only detected in 2003/04, and in contrast to those for Barnacle Goose, only fields in which all scaring types (non-shooting scaring, lethal and non-lethal shooting) were used had significantly fewer geese than expected and differed significantly from fields where scaring was absent. A combination of factors might explain differences in response between the two goose species, including: differential behavioural responses to disturbance; competitive interaction; and differing habitat preferences rendering greater or lesser exposure to the scaring measures. When the two goose species were considered in combination, no significant effects of individual scaring types or combinations were detected in 2003/04; in 2002/03, however, areas subjected to non-shooting scaring, and this combined with non-lethal shooting, did contain significantly less geese than expected relative to areas where scaring was absent (similar to the results for Barnacle Goose alone).

B.7 Two types of simple analyses were also undertaken to investigate whether the scaring programme under the current Goose Management Scheme has led to large-scale changes in the distribution of geese of the two species on Islay:

i. measures of aggregation/dispersal on the dates of International Paired Counts were compared between an earlier period when scaring was not permitted (1992/93 to 1999/2000) and the current scaring period (2000/01 to 2003/04); and
ii. a cumulative curve of new fields used each year was produced for each goose species for the above 12-year period (using International Paired and Scheme Count data pooled), and the rate of increase compared between the pre-scaring and scaring periods.

These tests (and inferences from them) were limited by:

i. insufficient Paired Counts were available to allow control for seasonal variation in dispersal;
ii. changes over time have been confounded with changes in goose population size; and
iii. changes in cropping patterns and other unmeasured factors may also have effected changes.

Despite these limitations, any large changes in goose distribution as a result of scaring should have been apparent, and none was detected. Detection of more subtle effects would require more complex spatial modelling with more winters of rigorous data collection.

B.8 Given the data limitations revealed by this preliminary assessment (B.4 and B.7 above), we make a number of recommendations concerning collection of data on Islay that would improve any future investigation into the effects of the different scaring techniques and their relative efficiencies:

i. Continue to collect shooting data at the level of specific fields, so that extra years of data can provide extra statistical power and analyses that include the influence of shooting frequency/seasonality can be carried out;
ii. Continue to collect data on the use of non-shooting scaring devices, including installation and removal dates, so that the influence of duration of use can be assessed in future analyses;
iii. Make more regular counts of geese if at all possible, to allow more accurate measurement of field usage, to allow more detailed analyses of effects in relation to time since scaring (habituation effects) and to allow interactions with other factors (e.g. seasonal changes in field use) to be assessed more effectively;
iv. Collect further information from farmers if at all possible on: non-lethal shooting (additional to that carried out by the SNH marksman); fertiliser use; presence of livestock. Information on the latter might also be collected by goose counters.
v. For a robust investigation into scaring, an experimental protocol that allows for fields to be studied under each of three conditions (non-lethal shooting, lethal shooting and no scaring) is highly recommended, but that the practical design and implementation of such an experiment will be difficult is acknowledged.

In addition, attempt could be made to improve the predictive field-use models by: improved modelling of the error distribution; checking for and accounting for autocorrelation issues; and adding information on additional explanatory variables. Given the other limitations of the data currently available for assessing the effects of scaring, however, these relatively small changes in the predictive modelling would be unlikely to result in major improvements to determining the influences of scaring.

B.9 Even given the improvements to data collection advocated, the correlative approaches that have necessarily been adopted here can never be a substitute for an experimental approach designed specifically to investigate the effects of scaring and differences between the various scaring techniques. Any field experiment would ideally allow individual fields to be studied under a range of scaring scenarios (with treatments rotated across a number of years) and a suitable number of replicate fields (with treatment and reference fields matched with respect to other influences on goose usage. The practicalities of running such an experiment, including influencing the behaviour of farmers, might be prohibitive but a pragmatic compromise (pseudo-experimental set-up) could be considered in more detail.

1 INTRODUCTION

1.1 Background

BTO Scotland has been contracted by the Scottish Executive Environmental and Rural Affairs Department (SEERAD) to analyse and appraise the datasets, collected between the winter seasons of 1987-88 and 2003-04, on wintering Greenland White-fronted Goose (*Anser albifrons flavirostris*) and Greenland Barnacle Goose (*Branta leucopsis*) populations on Islay, Argyll. There are two main parts to the project:
To carry out analyses of existing 'paired' count data to: investigate the variation in discrepancy between counts made on consecutive days; assess the factors that might determine the magnitude of such discrepancies; and assess the most effective use of the paired count data for assessing the significance of any observed population trends through time; and

i. To investigate whether datasets collected as part of the Islay Goose Management Scheme can be used to determine the effectiveness of scaring by shooting to kill *versus* non-lethal shooting and scaring by other means, as options for reducing the extent of agricultural damage by the geese on Islay.

1.2 The Islay Situation

The island of Islay (11,864 ha) is located approximately 30 km to the south-west of the Argyll mainland, western Scotland. Islay holds internationally important wintering populations of Greenland White-fronted and Greenland Barnacle Geese. These goose species come into conflict with agriculture, resulting in reduced crop yields (Patton & Frame 1981; Percival & Houston 1992). Their high conservation status, however, necessitates information to help ensure favourable conservation while, whenever possible, ensuring that agricultural interests are protected. For example, in 2003-04, following agreement with the Scottish Executive through the National Goose Management Review Group (NGMRG), £612,810 was spent by Scottish Natural Heritage (SNH) on 112 agreements covering 6,719 ha to help integrate productive farming with the maintenance of target populations of wintering geese on Islay (ILGMG 2004). The payments go towards paying for damage to grassland by grazing geese, and covering the costs of scaring (NGMRG 2000).

The current Goose Management Scheme came into operation in the winter of 2000-01. The previous Goose Management Scheme ran between the winters of 1992-93 and 1999-2000, during which scaring was not permitted. The current scheme allows for the scaring of geese from certain fields (see Section 1.7 for further details).

1.3 Greenland White-fronted Goose

The Greenland White-fronted Goose, the *flavirostris* race of the White-fronted Goose, breeds in western Greenland. These birds migrate via Iceland to winter in western and northern Scotland, Wales and Ireland (Stroud *et al.* 2002). The numbers wintering in Britain and Ireland were estimated as comprising between 17,500 and 23,000 individuals in the 1950s, declining to between 14,300 and 16,600 by the 1970s (Ruttledge & Ogilvie 1979). There was then a slow increase in numbers, leading to a peak of 21,000 in 1998-99 (Trinder *et al.* 2005). However, there is now a suggestion of a recent decline, with the population estimated at 17,500 in 2002-03 (Trinder *et al.* 2005). The proportion of the Scottish population wintering on Islay has increased from 48 to 60 % between 1982 and 2003 (Trinder *et al.* 2005). Analysis of demographic data suggests that the proportion of birds breeding in any particular year decreased between 1995 and 2003, but that there have been no significant changes in adult survival or productivity (Trinder *et al.* 2005). The Greenland White-fronted Goose is listed in Annex 1 of the EC Directive on the Conservation of Wild Birds and in the Amber List of Birds of Conservation Concern (Gregory *et al*. 2002).

1.4 Greenland Barnacle Goose

The Greenland population of the Barnacle Goose breeds in eastern Greenland and winters exclusively along the coasts of western Scotland and Ireland (Owen 2002). Estimates suggest that the population has increased from 8,000 individuals in 1959 to over 56,000 in 2003 (Trinder *et al.* 2005). Islay currently holds approximately 65 % of the world's population (77 % of the Scottish wintering population) of this race during the winter (Trinder *et al.* 2005). Analysis of demographic data suggests that both the proportion of birds breeding in any particular year and productivity decreased between 1995 and 2003 (Trinder *et al.* 2005). The Greenland Barnacle Goose is listed in Annex 1 of the EC Directive on the Conservation of Wild Birds and in the Amber List of Birds of Conservation Concern (Gregory *et al*. 2002).

1.5 Goose Monitoring on Islay

A programme of regular monitoring of population sizes and demographic parameters of both Greenland White-fronted Goose and Greenland Barnacle Goose on Islay has been put in place in the hope of ensuring that any changes in these two biogeographic populations of high conservation status are identified rapidly. Surveys on Islay cover all the fields where the geese may potentially be located (Figure 1.5.1). The areas not covered by the surveys are predominately upland and do not contain habitat suitable for geese (M. Morris, *pers. comm.*). Two types of counts of wintering geese have been undertaken on Islay, both carried out by a team comprising SNH Bowmore Office staff and a number of part-time goose counters employed by SNH:

i. *'International Counts'*. These are the counts that have been undertaken specifically for population monitoring purposes. They have been carried out up to 13 times a winter each year since 1987-88 (Table 1.5.1). They involve the whole island being surveyed twice over consecutive days ('paired counts'), effectively giving two replicates per count. For use for monitoring purposes to date, an average of the two counts has been calculated, unless one is deemed unsuccessful by the observers (e.g. due to mass disturbance of the birds or poor visibility), in which case the single successful count has been used. Counts that have been agreed as comprehensive and reliable by the team of counters on each occasion are referred to as 'adopted counts'.

ii. *'Scheme Counts'*. These counts have been undertaken primarily to estimate goose usage of fields on a farm-by-farm basis, specifically to allow the calculation of payments to farmers for income forgone due to the presence of the geese. The counts have been carried out between 15 and 20 times a winter, between October and April, each season since 1992-93 (Figures A7 to A12). They are less coordinated temporally than the 'International Counts' in that each session does not cover the whole island within a single day. Within the current project, these counts were assessed, in conjunction with the 'International Counts', for the information that they hold on field usage by the geese.

1.6 Factors Influencing Field Preferences Shown by Geese

Both goose species feed chiefly on the leaves and stems of grasses, with their diet supplemented by stubble, grains, and root crops when available (Cramp 1977, Mayes 1991). Previous studies have looked at the attributes of fields that influence their use by feeding Greenland White-fronted Geese and Greenland Barnacle Geese on Islay (Percival 1993, Ridgill 1994). Specific research on Greenland

Barnacle Goose on Islay has identified a number of such factors (Percival 1993), which allow us to make some *a priori* predictions regarding field usage by this species, as follows:

Newly reseeded pastures (years one and two of the seeding regime) are likely to be used more than older pastures, with the preference being greater in the autumn and the spring than in mid-winter (Percival 1993). This seasonal difference is likely to be due to resource availability decreasing at a faster rate on the newer pastures due to higher goose usage. The result is believed to be higher relative resource availability on older pastures, compared to the newer pastures, during the mid-winter period. By early spring, resources on the newer pastures will have recovered, allowing these fields to be used again by more geese;

i. The application of fertiliser in early October and March may increase usage of fields by geese due to increases in crop yield. The effect is likely to vary between years, however, depending on weather conditions, and also to vary between fields, depending on their original nutrient status. This has been demonstrated for Greenland Barnacle Goose on Islay, but was not the case for all fields or all years (Percival 1993), and also for Pink-footed Goose (Patterson & Fuchs 2001) and Brent Goose (Vickery *et al.* 1994). A study on field use by Greenland White-fronted Goose, which looked at three fields in one year, found no indication that their distribution was affected by fertiliser application (Ridgill 1994); and

The reduced usage of fields close to public roads is likely due to disturbance from vehicles and pedestrians. A small effect of this nature was found by Percival (1993), plus a combined effect of proximity to roads and overhead electricity cables that tended to limit usage further, but only in the early part of the season.

Similarly, work carried out specifically on Greenland White-fronted Goose on Islay allows us to predict *a priori* that:

i. The presence of cattle is likely to result in reduced usage by the geese. Ridgill *et al.* (1994) found an inverse correlation between the number of geese and the number of cattle present in the field on the same day; and
ii. Greenland White-fronted Geese favour fields also used by Barnacle Geese. The same study found a positive association between the number of Greenland White-fronted Geese and the number of Barnacle Geese present at a site (Ridgill *et al*. 1994). No test was carried out to examine whether this result was due to common preferences or a preference for being in larger flocks (e.g. for increased protection from predation due to safety in numbers or decreased individual allocation to vigilance; Carbone *et al*. 2003)

1.7 Scaring Programme

A programme of scaring is used currently on Islay to attempt to make particular areas less attractive to the geese and therefore limit the extent of agricultural damage. The aim is to scare geese from defined 'scaring' and 'buffer' areas, and encourage them onto 'feeding' areas (ILGMG 2004). The 'scaring' areas comprise newly re-seeded fields (re-seeded in the summer), the aim being to reduce usage by geese and promote sward establishment in these fields. The 'buffer' areas can comprise up to 20 % of the total improved and permanent grassland within a holding (ILGMG 2004). The 'feeding' areas are documented as being selected as areas of improved or permanent pasture in which the highest densities of geese have been recorded previously (ILGMG 2004). Farmers receive payment for income forgone due to the geese being present on these latter areas. For the purposes of calculating payments for the 'buffer' areas, it has been assumed that the scaring will result in a 22 % reduction in goose usage (ILGMG 2004). The aim of the scaring is to make 'scaring' and 'buffer' areas less attractive to the geese over time.

The use of deliberate disturbance has previously been shown to move geese from particular areas. For example, a reduction in Barnacle Goose numbers of over 50 %, from a scaring zone in the

Ballygrant valley and Mulindry areas of Islay, was achieved (in 1987-88) by using a combination of human scarers, gas guns and plastic tape (Percival *et al.* 1997).

Similar effects have been shown for other goose species. At sites in northern Norway, grazing by Pink-footed Geese was reduced by intensive scaring ("geese systematically chased off the fields throughout their complete staging period"; Madsen 1985, Tombre *et al.* 2005). The intensity and duration of grazing by Dark-bellied Brent Geese *Branta b. bernicla* at sites on the north Norfolk coast, England, were reduced using a human scarer, including lethal shooting, and the effects were compared to the use of non-shooting scaring techniques such as scarecrows, coloured flags, gas guns and electronic whistlers (Vickery & Summers 1992). Similar effects have also been shown for other species. For example, scaring experiments in northern Italy showed a greater effect of crackers or shooting than gas guns on Great Crested Grebe *Podiceps cristatus* foraging patterns (Gagliardi *et al*. 2006).

An evaluation of the effects of lethal and non-lethal shooting on numbers of Great Cormorant *Phalacrocorax carbo* found a reduction due to shooting compared to controls, but no difference between lethal and non-lethal shooting methods (McKay *et al*. 1999, Parrott *et al*. 2003). Despite many studies into the effects of scaring on local bird numbers, the effectiveness of lethal versus non-lethal shooting requires further investigation (Bishop *et al*. 2003). In the Cormorant study, further work was recommended to investigate whether there might be site-dependant differences in the relative effectiveness of lethal versus non-lethal shooting (Parrott *et al*. 2003). For geese, investigations comparing the effects of lethal and non-lethal shooting have not been made to date.

On Islay, farmers can elect to carry out scaring themselves, following a programme agreed with SNH, or they can opt to use various scaring devices supplied by SNH. For Barnacle Geese only, scaring can also be implemented via licensed shooting, either by the farmers themselves or by a SNH marksman. Scaring by shooting can be carried out either with the aim of killing one or more individuals amongst the flock (subsequently referred to as 'lethal shooting'), or by aiming into the air so that the noise of the shot (and the presence of the marksman/farmer) scares off the flock (subsequently referred to as 'non-lethal shooting'). White-fronted Geese cannot be shot but their behaviour may nevertheless be affected by the scaring targeted at the Barnacle Geese.

The SNH Marksman during the current goose scheme (between the winters of 2000/01 and 2003/04) was Ian MacLellan. The methods used for lethal and non-lethal shooting were discussed with him. Non-lethal shooting was used first, in an attempt to deter geese away from a field, and lethal shooting was used in addition if geese continued to return to the field. Lethal shooting entailed the marksman leaving the vehicle and stalking the birds. Either a rifle or a shotgun, depending on the distance to the geese, was used to shoot to kill a goose. Greenland Barnacle Geese only were shot in this way; Greenland White-fronted Geese were not shot. When aiming to kill a bird, the marksman hit the target the majority of the time. If the birds were still too distant to shoot to kill after stalking, he would stand up and shoot over the flock (non-lethal shooting). Once a bird was killed, he would walk into the field to collect the corpse. Non-lethal shooting involved the marksman leaving the vehicle, walking towards the goose flock, and making two or three shots over the flock, using a shotgun and standard cartridges. Fields to be shot over were chosen based on the numbers of geese present: lethal shooting was more likely to be used at fields holding larger numbers of geese. There were no particular times of day when a particular shooting technique would be chosen in preference to the other.

The scaring devices that do not include shooting (subsequently referred to as 'non-shooting scaring techniques') include (ILGMG 2004):
the 'flashman' – a silent, revolving wind-powered mirror, standing about 1.2 m tall;

the 'scary man' – a battery-powered, fluorescent, inflatable man, standing about 1.2 m tall, that operates on a timer (lamp and siren options are available);
the 'vigilante helikite' – a kite containing a helium balloon that can fly at up to 61 m;
the 'Dunford kite' – a self-launching kite on a 12 m flexible aluminium pole;
the 'gas gun' – a propane-powered gas gun, operating on a battery-powered timer, producing a loud bang;
'squawkers' – battery-powered electronic devices that emit a range of distress noises and electronic noises; and
the 'peace pyramid' – a small, battery-powered, revolving pyramid-shaped device with reflective mirrors on each side, mounted on a fence post.

1.8 Project Aims

The current project had two primary aims:
To determine the most appropriated method of using the International Paired Counts to assess population trends of Greenland White-fronted Goose and Greenland Barnacle Goose on Islay, and the significance of these trends. This involved:
Investigation of the variation in count discrepancy between consecutive-day counts to assess the factors that might determine the magnitude of such discrepancies;
Assessment of the most effective use of the paired count data for assessing the significance of any observed population trends; and
Provision of advice on the program of counts likely to be required in the future; and

i. To investigate the extent to which the SNH Islay goose datasets can be used to determine the effectiveness of lethal shooting as a scaring strategy, *versus* non-lethal shooting and the non-shooting scaring techniques, and carry out analyses to test the results of scaring, if possible. Initially, this involved assessing whether models could be produced to adequately predict use of fields by the two goose species. If possible, the project aimed to test initial predictions that: the scaring strategies would result in reduced field usage by geese and greater dispersal of feeding geese, with lethal shooting being the most effective, followed by non-lethal shooting and then the non-shooting scaring techniques.

2. METHODS

2.1 Use of International Paired Count Data to Assess Count Quality and Significance of Population Trends

2.1.1 Data selection and calculation of count discrepancy

In this analysis, the International Paired Count data were used to produce a measure of count quality by calculating the discrepancy between the two consecutive-day counts of each pair. 'Adopted counts' (those deemed complete and satisfactory based on the experience of the counters themselves) were selected for use for the years in which this information was made available to us. There were 14 and 21 'adopted counts' for Greenland White-fronted Goose and Greenland Barnacle Goose, respectively. For the years in which adopted counts were not flagged in the count dataset, counts were excluded if visibility was recorded as 'poor' or 'very poor' by the counters. Following filtering, these years provided 34 and 30 additional counts for Greenland White-fronted Goose and Greenland Barnacle Goose, respectively. Note that for these latter counts, we had to assume that counts during reasonable visibility were satisfactory in all other respects (i.e. there had not been an unacceptable level of disturbance of geese during the count day, for example). In support of this assumption, there was no difference detected when comparing count discrepancies associated with 'adopted' counts and those included in the analysis but not flagged as 'adopted' (Greenland White-fronted Goose: $\chi^2 = 0.48$, d.o.f. = 1, $p = 0.49$; Greenland Barnacle Goose: $\chi^2 = 0.99$, d.o.f. = 1, $p = 0.32$; modelled in a Generalised Linear Model (GLM) with a Normal error distribution, controlling for a year effect).

Only counts made on consecutive days were compared to produce our measure of count quality. In the absence of replicate counts made on single days, it was necessary to assume that the probability of net immigration or emigration of geese from the island between consecutive count days was minimal but that this probability would increase with time elapsed between counts. Given this latter assumption, the use of counts more than one day apart would have been increasingly likely to confound true count discrepancy with actual biological variation in goose numbers on the island.

The above selection criteria resulted in 48 and 51 sets of paired counts (between one and six per year) rendered suitable for inclusion in the analysis, for Greenland White-fronted and Greenland Barnacle Geese respectively (Table 2.1.1.1). The reasons for the slightly lower number of counts available for Greenland White-fronted Geese are documented therein.

Proportional count discrepancy between consecutive-day paired counts was calculated using the theory of ratio estimators (Cochran 1953), by dividing the smaller of the two counts by the larger, and subtracting the difference from unity:

Count discrepancy = 1-(smaller count of pair/larger count of pair).

This measure of count quality is not a measure of true counting error. A measure of true counting error could be derived only in the event of:

i. numbers of geese being counted accurately on at least one of the count days; and
ii. there being no change in the actual numbers of geese present in the count areas during the two-day count period.

We attempted to meet the requirement in point (ii) as far as possible by using only counts made outwith the period of main migration to or from Islay. Given that neither count of any pair is likely to be accurate, however, the requirement in point (i) will not be met, such that true counting error could not be estimated from the data available.

2.1.2 Correlates of count discrepancy

Our measure of proportional count discrepancy (Section 2.1.1 above) was used as the dependent variable in analyses to investigate potential influences on the quality of counts through time. We hypothesised *a priori* that a number of factors, on which we had some information available, could have led to variation in the quality of a count, through an influence on the behaviour of the birds and/or the ability of counters to count them:

i. *Total number of geese requiring counting*: Larger numbers of geese might be harder to count precisely; or alternatively, larger numbers might lead to changes in behaviour or larger aggregations, making the birds easier to find and count. The mean of the two counts in each pair for the species in question was used. Both linear and quadratic functions of this term were tested in the models;
ii. *Spatial distribution of geese*: Higher densities of geese might be harder to count precisely but aggregated concentrations might be easier to find for counting. Both linear and quadratic functions of measures of density were tested in the models;
iii. *Weather conditions*: Freezing conditions might lead to sudden net emigration from the island (extra biological variation in numbers rather than count discrepancy) and poor weather might also render counting more difficult;
iv. *Day length*: Shorter days might alter the behaviour of the birds or make counting harder because of the shorter time available;
v. *Date of the season*: A surrogate variable, including some of the influences stated above;
vi. *Calendar year*: The team of observers that has carried out counts of geese on Islay has changed through time. Overall improvement in count quality due to observer experience would therefore not be expected, although improved counts as a function of knowledge acquired about the geese on the island as a whole could occur. Calendar year is also a surrogate for some of the other influences stated above, however, particularly changes in goose numbers and any associated changes in behaviour and distribution; and
vii. *Scaring*: In years that scaring was allowed, this may have increased the mobility of goose flocks, thus reducing count quality. The winters in which scaring was permitted (2000/01 onwards and prior to 1992-93) were compared with those previous years in which scaring was not allowed (winters of 1992/93 to 1999/2000). It should be considered, however, that other factors may have also differed between these two periods, particularly goose numbers.

The range of dates during the winter period over which the International Paired Counts have been conducted was selected originally to span the period when the wintering goose species were present on Islay, but to exclude specifically the main periods of arrival in autumn and departure in spring. As a first step, we assessed the count data to determine whether there was a period during the winter months when counting discrepancy, as defined above, was more stable, with the aim of checking that the periods most subject to large movements of geese to or from the island were eliminated prior to our further analysis. The inclusion of counts calculated using data from such periods might otherwise over-inflate the measure of count discrepancy. This potential filtering was not designed to detect (and would not have detected) smaller changes in goose numbers between days (e.g. in a scenario in which say 10 geese arrived each day through an extended period of the winter) but such smaller movements were less likely to bias our analyses and were therefore of less concern.

To this effect, count discrepancy was modelled with date (as a continuous variable from 1 October to 31 March), controlling for the factors listed above, in a GLM with a Normal error distribution. Sample sizes were 48 counts for Greenland White-fronted Goose and 51 for Greenland Barnacle Goose. Count discrepancy (proportional data) was first transformed using the arcsine transformation. If a period of the winter existed during which count discrepancy was less stable, this would have been suggested by a relationship (linear, quadratic and cubic relationships were tested for) between date and count discrepancy, suggesting that data from a reduced period should form the subset from which to assess population trends and their associated count discrepancy. In the absence of such a significant relationship, we would assume that there were no clear periods of reduced stability and recommend methods for assessing population trends and associated errors with this in mind.

Day-length data were obtained for a point at 56.0ºN, 6.5ºW (*ca* 15 km west of Islay) from the National Schools' Observatory website (www.schoolsobservatory.org.uk). This variable was available for the whole study period.

A subset of analyses was run to investigate the effects of density and dispersal of the geese on each count day on the associated count discrepancy. A measure of 'goose density' (average number of geese per field) was calculated by dividing goose count by the number of occupied fields. Two measures of the degree of 'goose dispersal' were used: the number of occupied fields; and the number of occupied 1-km squares (based on the British National Grid).

Data for 'goose density' and 'number of occupied fields' were available only for the winters of 1992-93 to 2003-04 inclusive (sample sizes: 24 for Greenland White-fronted Goose and 25 for Greenland Barnacle Goose). Data for 'number of occupied 1-km squares' were available for this latter period plus the winters of 1984-85 and 1985-86 (sample sizes: 31 for both species). The analyses were carried out separately from the main analyses above due to an incomplete dataset on the spatial distribution of the geese being available.

A further subset of analyses (also due to incomplete data availability) was carried out to assess any effects of weather on count discrepancy. Temperature data were available for 1983 from the Upper Killeyan weather station (situated on The Oa; NR281419) and for 1984 to 1998 from the Orsay weather station (situated off the Rhinns of Islay; NR165515) (sample sizes: 35 for both species). Rainfall data were available for 1983 to 2000 from the Eallabus weather station (situated near Bridgend; NR335634) (sample sizes: 31 for Greenland White-fronted Goose and 36 for Greenland Barnacle Goose). All the weather data were obtained from the British Atmospheric Data Centre. Two temperature measures were used: minimum temperature (to investigate the possible effects of freezing conditions); and the midpoint of the minimum and maximum temperatures.

Means were derived for these two measures for two periods: the two count days; and the count days plus the previous day (in an attempt to make provision for potential short-term effects of weather on goose movements).

Temperature data for a particular day were provided for the 24-h period prior to 2100h. Rainfall data for a particular day were provided for the 24-h period from 0900h.

Following modelling to assess correlates of count discrepancy, significant parameters from the GLM modelling could be bootstrapped to obtain robust 95 % confidence intervals of the intercept and coefficients. Using this latter method, an estimate of count discrepancy for any year in question could be produced.

2.1.3 Population trends and their significance

The programme of International Paired goose counts carried out on Islay has been designed to count at approximately monthly intervals through the winter in order to detect a winter peak in goose numbers. Previous analyses of population changes have used the maximum count from the programme each winter and, following this, we also based our assessment of trends on the maximum counts. Given an appropriate number and distribution of counts undertaken annually, and in the absence of individual marking data, the annual maxima are likely to provide the best estimate of the highest number of geese of each species present on the island each winter. Annual means would be less prone to the sampling limitations associated with a single (paired) maximum count and, given a comparable number and distribution of paired counts each winter, would form an alternative index of mean use of the island by each species, although they would underestimate absolute population size. We elected to base our assessments on annual maxima, with appropriate acknowledgement that the larger the number of counts that were carried out in any given winter, the more accurate would be the measurement of these maxima.

We filtered these International Paired Counts in the same way as for the analysis of count discrepancy (Section 2.1.1), retaining counts flagged by the counters as 'adopted', and removing all counts without flagging for which visibility was described as 'poor' or 'very poor'. Where both counts made on consecutive days were retained, both counts were available for use. Where only one count of a pair was retained, this single count was used. This resulted in 80 and 89 counts (between two and 13 per year) being available, for Greenland White-fronted and Greenland Barnacle Goose respectively (Table 1.5.1).

A further aim in this project was to assess whether data from the Scheme Counts (Section 1.5) could be used to supplement that from the International Paired Counts, to provide a larger sample of counts of the whole island (from which to derive the annual maxima). The major concern over use of the Scheme Counts in this context is that the whole island is not counted in a single day. The movement of goose flocks between different count areas (Figure 1.5.1), during the counting period used to produce any single all-island count, could result in large over- or under-estimation of the true goose numbers present during that count period.

As a first step, we assessed the frequency with which Scheme Counts covering the whole island were carried out over a consecutive two-day period as opposed to a longer period of days. This showed that there were a sufficient number of Scheme Counts that covered the whole island in two consecutive days (65 counts over the period 1992/93 to 2003/04; Figure 2.1.3.1) to make further appraisal of the data for population modelling purposes worthwhile.

The next step was to assess the degree to which intra-island movements might bias the totals from Scheme Counts carried out during a consecutive two-day period. We examined the dataset from the International Paired Counts (filtered as indicated in Section 2.2 below; only pairs of counts made on consecutive days included in the analysis) to assess the likelihood that major movements of geese took place between the six count areas A-F (Figure 1.5.1) during each pair of consecutive-day counts. To this end, the overall difference in goose numbers between each pair of consecutive-day all-island counts for each species was compared to the sum of count differences for the six count areas A-F on that pair of days, divided by two (to account for movements being in two directions – in and out of each area). This latter sum was regressed against overall count difference, using a GLM with a normal error distribution and the intercept set to zero. A gradient of 0.5 (since the summed differences were divided by two) was expected if there was no additional variance due to movements between the six areas, while a gradient significantly greater than 0.5 was expected if there was significant intra-island movement (i.e. movements between the counting areas A to F in Figure 1.5.1) between the two days. The absence of such movements would justify inclusion of any Scheme Counts completely covering the island in a consecutive two-day period (within the same period of the winter as the International Paired Counts) in further analyses of population change and of seasonal changes in numbers of geese present on Islay through the winter.

From this analysis, the gradient of the regression line for Greenland White-fronted Goose was 1.74 ± 0.18 (n = 21; 95 % C.I.: 1.38 to 2.09; Figure 2.1.3.2), and the gradient for Greenland Barnacle Goose was 1.03 ± 0.15 (n = 21; 95 % C.I.: 0.73 to 1.33; Figure 2.1.3.3). The gradients for both species were therefore significantly greater than 0.5 (based on the 95 % confidence intervals). This strongly suggested that intra-island movements between different counting days would be likely to increase error if whole-island Scheme Counts were used in addition to the International Paired Counts for estimating population trends. We therefore did not include Scheme Counts in further analyses of population change.

To produce population trends for the two goose species, the annual maxima from the International Paired Counts were analysed as a function of year using Generalised Additive Models (GAMs; Hastie & Tibshirani 1990) to produce smoothed trends. GAMs have been used previously to analyse Wetland Bird Survey (Austin *et al.* 2004) and Common Bird Census (Fewster *et al.* 2000) data. As with previous bird trends work, the degree of smoothing was arrived at by using the maximum number of degrees of freedom that produced a smooth line and removed sudden peaks of increase or decrease. This approach aims to provide a smoothed output that maintains all major features of population trend over time but ignores fine-scale fluctuations (Fewster *et al.* 2000). The GAMs were also bootstrapped to produce 95% confidence limits.

Percentage changes in goose numbers were calculated from the smoothed GAM trend for five-, ten-, 15- and 18-year time periods by taking the index value at the start of the period under consideration from that of the most recent year. These change values were expressed as a percentage of the index at the start of each period under consideration. In producing these between-year changes, the 1983/84 and 2003/04 points were not used owing to the unreliable nature of end points (Hastie & Tibshirani 1990). The significance of changes in goose numbers over each of these time periods was assessed with reference to the 95% confidence limits surrounding the trend line.

2.1.4 Value of paired counts

Our initial modelling of trends used data from both count days of each paired count that constituted the winter maximum when both counts were satisfactory, or a single count if only one of a pair of counts remained after filtering the data (Section 2.2.1 above). The trends derived from all these available count data were termed 'F_{all}'.

As a direct investigation into the likely effect of carrying out routinely only single counts rather than paired counts, we repeated the GAM trend analysis using only the day 1 (F_1) or day 2 (F_2) counts of each pair. The count data were filtered in the same way as above (Section 2.2.1); if one of a pair of counts was excluded from the analysis on the basis of the selection criteria, the other count was retained in the analysis. This latter approach assumed that any programme of counts based on single rather than paired counts would have gone ahead on the specified counting days, and individual counts would not have been repeated if they were not suitable for 'adoption'. There were 71 counts for F_1 and 72 counts for F_2 for Greenland White-fronted Goose available for analysis; and 78 counts for F_1 and 83 counts for F_2 for Greenland Barnacle Goose. The F_1 and F_2 counts were modelled in GAMs (in the same way as described for F_{all} above) and any differences in changes in goose numbers assessed via the bootstrapped confidence intervals.

In the absence of multiple counts of geese made on the same day, the paired counts provided the only source of information available on the potential error associated with counts (see Section 2.1.1 above for assumptions), and the discrepancy between the two counts of each pair influenced the boostrapped confidence limits in the F_{all} model (but not the F_1 and F_2 models, which were based on single counts for each year). Hence we expected that confidence limits would be underestimated in these latter models compared to the models using all the available count data (paired and single counts) for each goose species. The modelling results supported this expectation (Sections 3.1.3 and 3.1.4 below). For this reason, we also fitted GAMs and boostrapped confidence intervals for a model 'F_{pairs}', which included only those maximum counts for which paired counts were available, for comparison with the F_{all} model for each species. The F_{pairs} models for Greenland White-fronted Goose and Greenland Barnacle Goose used 16 and 13 paired counts, respectively.

2.2 Factors Influencing Field Usage by Geese on Islay

The aim of the second part of the current project was to establish whether the database of goose counts held by SNH could be used to investigate the relative effectiveness of different scaring techniques. First, this involved modelling field usage by Greenland White-fronted Goose and Greenland Barnacle Goose based on count and field-attribute data collected during the eight-year period of the previous Goose Management Scheme (between 1992-93 and 1999-2000), under which scaring (including shooting) was not allowed (ILGMG 2004). Given models that explained the observed spatial variation in goose numbers satisfactorily, these could then be used to derive a predicted pattern of field use during the current Goose Management Scheme (data from 2000-01 to 2003-04). Such predictions would then be compared with the observed patterns of field usage during the same period to assess whether any differences could be related to the occurrence of the various scaring techniques.

2.2.1 Selection of data for field use modelling: whole-island analyses

Goose count data were taken both from the International Paired Counts and the Scheme Counts for the period November to March inclusive each winter. Count data from October were excluded because: preliminary modelling showed significantly lower numbers of geese present in October than in the later months of the winter; and shooting did not begin until November according to the data set that was available.

Data were available for each of the relevant months, for each of the six counting areas (Figure 1.5.1), during the study period (between 1992-93 and 1999/2000) except for March 2000 (Figures A1 to A6).

2.2.2 Models of field use: whole-island analyses

The models of field usage by geese were built in a Generalised Linear Modelling (GLM) framework, using a negative binomial error distribution and logarithmic link function. The identity of each individual field was included as a repeated measure. The natural logarithm of the number of counts of geese per month was included as an offset, to control for the number of visits per month varying between fields. The entire data sets were known to be substantially zero-inflated and two measures were taken to reduce this problem. First, fields that were not used regularly by geese were omitted from the modelling for each species. Any field with a maximum count of less than 10 geese of the species in question was excluded from the appropriate analysis. The aim here was to exclude field where, for example, a few geese had landed and been counted during a single count, perhaps as a result of a disturbance event. Second, standard default scaling was used during modelling (the dispersion was set to the deviance divided by the degrees of freedom) so that the standard errors of the estimated coefficients were adjusted appropriately. The number of observations (counts in fields) used in the whole-Islay models was 225,997 spread over 1401 fields for Greenland White-fronted Goose and 159,373 spread over 1024 fields for Greenland Barnacle Goose.

In producing the field-use models, the influences of season, size of goose population present on Islay at the time, and a number of field characteristics were considered. The method of step-wise deletion was used to select variables to remove from the GLMs. For significant factors with more than two levels, any levels that did not have significantly different effects on field usage (as judged by log-likelihood ratio tests) were combined in the reduced models.

We hypothesised *a priori* that a number of factors, on which we had some information available, could have influenced goose usage of a particular field. These factors were included in the global models:

i. *Goose population size*: An increase in the winter population of geese present on Islay during the study period was expected to give rise to increased numbers on particular fields, assuming other factors remained constant. Mean annual goose numbers were derived from the International Paired Counts;

ii. *Season (month)*: Seasonal variation in field usage was expected due to changes in resource availability and fluctuations in goose numbers. This was defined by a level for each month (November to March);

iii. *Field size*: Goose numbers were expected to be higher in larger fields due to greater resource availability. Field size was derived for each field by calculating the area of digitised fields in ArcView GIS 3.3;

iv. *Crop type / habitat*: Vegetation type was expected to be a key factor in determining field usage. Details on habitat were collected on a field-by-field basis during the goose counts by the counters, and also by SNH staff in the autumn. The former were not used, however, since the details were not provided on all occasions (between 20 and 40 % of fields missing data each year) and SNH Bowmore staff (Margaret Morris) advised us that the codes were not strictly defined such that observer bias was likely to arise. For this reason we opted to use crop type as recorded by SNH staff. Given that habitat change, such as re-seeding, tends to take place outside the period under consideration (November to March), we believe the data to be satisfactory for these purposes. The categories used were:

    a) grassland re-seeded in the current season;
    b) grassland re-seeded in the previous year;
    c) grassland re-seeded two years previous;
    d) older improved grassland (seeded more than two years previous);
    e) permanent pasture (not improved through seeding);
    f) juncus fields; and bog fields.

    Re-seeding of fields took place in the summer. There were a number of field types that were excluded from the analysis due to being present in less than 20 fields in which goose counts were made: mud, wooded areas, heath, saltmarsh, beach, marsh, dunes, crops (barley, turnips, potatoes and beetroot) and human areas (golf-course, airfield, playing fields, landfill and cemetery);

v. *Proximity to roost sites*: Day-time usage of fields was expected to be greater for fields closest to roost sites due to the geese aiming to minimise daily travelling time. A survey of Greenland White-fronted Goose roost sites was made in 1991-92 (Ridgill *et al*. 1994). Greenland Barnacle Geese are known to roost in three main locations on Islay: Gruinart Flats, Bridgend Merse and Laggan Point (M.A. Ogilvie & M. Morris, *pers. comm.*). Seventy-eight Greenland White-fronted Goose roost sites and the three main Greenland Barnacle Goose sites were mapped in ArcView GIS 3.3 (Figure 2.2.2.1). Distances (to the nearest 10 m) were then calculated for each goose species by measuring between each field's centre point and the nearest roost site.

vi. *Proximity of the field to roads, woodland and lochs*: Field usage was expected to be:

    a) lower by roads due to disturbance from vehicles and people;

b) lower by woodland due to increased perceived predation risk arising from a reduced field of view;
c) and higher by lochs for Greenland White-fronted Goose due to the presence of damp-loving vegetation.

Each distance was calculated, in ArcView GIS 3.3, for each field (to the nearest 10 m) by measuring the distance between the field's centre and the nearest appropriate feature; and

vii. *Field gradient and variation in topography*: Field usage was expected to be lower for fields with steeper gradients, due to increased perceived predation risk arising from a reduced field of view, and also in fields with greater variation in topography (termed 'undulation'). Gradient was calculated to the nearest 1 degree, in ArcGIS 9.1, for each point on a 10 m grid. The mean gradient was then calculated within the digitised boundary of each field. Field 'undulation' was calculated as the variance of gradient of each point on the grid within the field boundary. The calculations were based on Ordnance Survey Land-Form Profile data provided by the Scottish Executive Geographic Information Service (SEGIS).

There were a number of factors on which we had information but that we decided to omit from the modelling for the following reasons (*p*-values presented are based on Pearson's correlation coefficients):

i. *Proximity of the field to the coast*. This factor was not expected to have a large influence on field-use and was excluded due to being correlated with proximity to roads (p = 0.0009), lochs ($p < 0.0001$) and woodland ($p < 0.0001$), all of which were thought *a priori* to be of greater biological relevance;
ii. *Elevation*. This factor was not expected to be important within the fields that we were investigating (M.A. Ogilvie, *pers. comm.*) and was excluded due to being correlated with gradient ($p < 0.0001$), proximity to roads ($p < 0.0001$) and lochs ($p < 0.0001$), all of which were again thought *a priori* to be of greater biological relevance; and
iii. *Site Designation*. There are sites on Islay designated as Ramsar Wetlands (Bridgend Flats, Eilean na Muice Duibhe, Gruinart Flats and Rhinns of Islay), Special Protection Areas (SPAs; Bridgend Flats, Eilean na Muice Duibhe, Gruinart Flats, Laggan and Rhinns of Islay) and Special Areas of Conservation (SACs; Eilean na Muice Duibhe, Feur Lochain; Glac na Criche, Rhinns of Islay and the south-east Islay skerries). These sites are designated due to having significant numbers of relevant biodiversity, including Greenland White-fronted Goose and Greenland Barnacle Goose. Fields within some of these sites are therefore likely to have larger numbers of geese. Designation status was not included in the models, however, as we had no *a priori* reasons for designated fields being treated differently to other fields with respect to factors other than those above already included in the models.

There were also a number of factors of biological relevance that we were unfortunately unable to include in the models due to a lack of suitable information:

i. *Use of fields by grazing livestock*: Field use was expected to be reduced for fields with grazing (Ridgill *et al.* 1994). The presence or absence of livestock was recorded on a field-by-field basis during the goose counts only from 2000-01 onwards. Hence this factor could not be included in the predictive models based on the earlier data. The presence of livestock was also recorded only for fields in which geese were present at the time of each count;
ii. *Proximity of the field to electricity power-lines*: Field-use was expected to be reduced for fields containing electricity power-lines (Percival 1993). There are no large pylons on Islay; instead the transmission lines are carried along poles, which are not shown on the

Ordnance Survey map data that were available for SEGIS to supply to us. We could have elected to map the present distribution of transmission lines ourselves but these alone would have been of doubtful value as their number and locations are thought to have changed during the study period;

iii. *Fertiliser use*: Fertilised fields may be used more by geese, although this is likely to depend on other factors too, such as the original nutrient status of the field (Percival 1993, Vickery *et al.* 1994, Patterson & Fuchs 2001). No data were available on fertiliser use across the whole island; and

iv. *Topographic exposure*: Fields with greater 'exposure' will have a greater field of view and such fields are expected to be preferred by geese, since they will enable geese to detect predators more easily. This variable could not be incorporated into models built in the current project due to technical difficulties but mean field gradient and variation in topography were included in the modelling, and provided some measure of field of view. Topographic exposure (TOPEX; Chapman 2000) could be considered in any future modelling of such datasets however.

The goodness of fit of the models of field usage was assessed with reference to model deviance divided by degrees of freedom (where values of greater than unity tend to indicate a poor fit). Additionally, predicted and observed values were compared via a scatter-plot. Given the large number of observations that required plotting, the Spearman's rank-order coefficient was also obtained, to assist in 'visualising' the quality of fit only.

2.2.3 Models of field use: Loch Gruinart analyses

Data specifically on fertiliser use do exist for a small subset of fields on Islay: the RSPB (Royal Society for the Protection of Birds) reserve (1621 ha) at Loch Gruinart, at the north of the island of Islay. We used this subset of goose field use data to investigate the possible effects of excluding information on fertiliser usage from the whole-island modelling process (due to the lack of data for the whole island). The modelling used a GLM framework, a negative binomial error distribution, logarithmic-link function), default scaling, and the repeated measure of 'field identity'. Model fit was assessed in the same manner as for the whole-island models (Section 2.2.2 above).

The count data provided by RSPB were monthly maximum counts for each field for the period 1994-95 to 1999-2000 (i.e. again prior to the onset of the current scaring programme). As for the whole-island analyses, counts between November and March were used. The number of observations (counts in fields) used in the Loch Gruinart models was 2,189 for Greenland White-fronted Goose and 2,148 for Greenland Barnacle Goose, spread over 57 fields. More detailed habitat data were also available for this subset of fields:

i. grassland re-seeded in the current season;
ii. improved grassland;
iii. permanent pasture (not improved through seeding);
iv. inundated grassland;
v. acid grassland;
vi. grazed moorland;
vii. ungrazed moorland; and
viii. spring cereals.

Of these habitats, only re-seeds, improved grassland, permanent pasture and spring cereals received a summer application of fertiliser, and re-seeds always received this application (Table 2.2.3.1). For this reason, we confined the analyses to three crop types: improved grassland, permanent pasture and spring cereals (a sub-sample of 29-31 fields per year; Table 2.2.3.1). Due to the much smaller number of fields in this subset compared to the whole island, many of the variables tested in the whole-island models were confounded with crop type. For this reason, the models were run both with and without the following variables: field area, gradient, undulation, and distances to woodland, lochs, roads and roost sites. Whether this subset of variables was included or excluded had negligible influence on the modelling results (and models without them are presented for brevity). We included year as a factor in these Gruinart models rather than a maximum or mean winter count of geese of the appropriate species, because, in contrast to the whole-island models, there was no requirement to use the models for predictive purposes, and the year effect would include variation in goose numbers as well as other unmeasured variables that might vary between winters. Due to time limitations, we examined only first-order interactions between fertiliser use and other included variables, and further analyses would be required to explore more fully the variables influencing field usage on the Gruinart Reserve.

Whilst using the Loch Gruinart data set, the differences in agricultural management practice between the reserve and the rest of the Islay need to be considered. The majority of the relevant fields on Islay are managed for farming purposes, whereas at Loch Gruinart the aim is to manage fields in a balanced manner for farming and conservation purposes. In particular, one of the aims of the reserve is to manage the fields for use during the winter by both species of geese. The management techniques used to achieve this include specific cropping regimes, grazing and control of water levels. This latter subset of fields therefore needs to be used with caution to test the validity of omitting a potentially important variable from the whole-island models, taking any potential additional differences in management into consideration.

2.3 Investigation of the Effects of Scaring on Field Use by Geese

The aim of this part of the current project was to assess whether the whole-island models of field usage prior to scaring (Section 2.2 above) could be used to predict field usage by geese during the period of the current Goose Management Scheme (between 2000-01 and 2003-04; ILGMG 2004), under which shooting was allowed at some fields (‘scaring’ and ‘buffer’ fields). If predictions could be made satisfactorily, the next objective was to compare these will observed goose numbers in areas subjected to difference types of scaring under the current Goose Management Scheme, and, in turn, with those in areas without scaring.

2.3.1 Predicted versus observed numbers of geese

For the winters of the current Goose Management Scheme (2000-01 to 2003-04), and for each goose species, the number of geese expected to be present in each field in each month of the winter (November – March inclusive) was predicted from the appropriate field use model (see Sections 3.2.1 and 3.2.2 below for Greenland White-fronted Goose and Barnacle Goose respectively). During the period of the current Scheme, as during the previous Scheme, each field was generally counted two or three times each month (Scheme and International Paired Counts combined). For each goose species, the observed numbers present during these counts were averaged for each month of the winter, for comparison with the monthly predictions.

When the observations of usage during the current Scheme were investigated, there were a considerable number in which no geese had been counted. The observations falling into this category did not show any systematic bias with respect to any particular scaring practice or environmental variables, and they were not concentrated on individual holdings. We thus concluded that many of the zero observed values were due to fewer counts per field being made during the present Scheme (based on one to four years of data, depending on the model to be fitted; see Section 2.3.2 below) than during the previous Scheme (for which there were eight years of data on which to base field use predictions). Due to this problem, we elected to average both the observed and predicted numbers of geese in each field (taking a mean of the monthly values across the months November to March inclusive for each of the observed and predicted values) to produce a whole-winter mean. This gave us more confidence in the observed counts under the current Goose Management Scheme, which were then based in general on two to three counts per month, over five months, for each of one to four years (depending on the analysis in question; see Section 2.3.2). In taking this approach, we were forced to limit our analyses of the effects of scaring to look for any effects over the winter period as a whole, despite the fact that there was considerable variation in the pattern of shooting through the winter (Table 2.3.1.1). We did not feel that the quantity of data available (i.e. the frequency of monthly counts) allowed for more subtle effects, such as variation in any influence of scaring through the winter, to be investigated, particularly as only one or two winters of data were available for some analyses (Section 2.3.2 below). We included a year effect in all models based on more than one year of data because there was considerable between-winter variation in both the number of shots fired and the pattern of shooting through the winter (Table 2.3.1.1).

In forming the dependent variable for use in the models to investigate any effects of scaring, we elected to express the difference between the mean whole-winter observed count and predicted count for each field as a proportion of the predicted value:

Proportional whole-winter count difference (PWWCD) = (whole-winter observed mean – whole winter predicted mean)/whole-winter predicted mean

We used the proportional difference (PWWCD) between observed and expected goose counts rather than the absolute difference because we felt that coefficients based on proportional change in goose numbers as a result of scaring could be interpreted more intuitively, relative to the overall goose numbers present, than those based on a change in absolute numbers. The analyses could be run just as easily using absolute differences if required.

2.3.2 Models to assess any effects of scaring

The proportional whole-winter count difference (PWWCD) between observed and predicted counts of geese in each field was calculated (Section 2.3.1 above), and formed the dependent variable in models to investigate whether the any spatial differences in PWWCD were related to the distribution of the different scaring techniques.

Each analysis was carried out separately for the two goose species, and also for the two species combined. For the combined analyses, the predicted and observed counts were derived by summing the relevant counts for both species. Only Greenland White-fronted Goose and Greenland Barnacle Goose numbers were used to calculate 'total' goose numbers. There are a number of other species of geese that are found amongst these geese flocks, but the numbers are small (less than 100 individuals).

All modelling again used a GLM framework, with normal error distribution, identity link function and 'field identity' as a repeated measure. The PWWCD data were first log transformed.

The quantity and spatial resolution of the scaring data varied over the four winters for which they were provided, so that models had to be designed to run on different subsets of data that varied in their size and/or resolution (summarised in Table 2.3.2.1). The scaring data available for analysis are summarised in Tables 2.3.2.2 and 2.3.2.3. Data were available at the highest resolution (specific fields over which shooting was known to have taken place) for one winter (2003-04) only. For the previous three winters, we knew only which holdings had carried out shooting, not the specific fields that were targeted (Table 2.3.2.2). In the winters in which shooting data were available only at the holding level (not specifically for individual fields), we had to identify a subset of fields in each holding at which the shooting could have taken place, based on the fields that were known to be designated as “scaring” or “buffer” zones, over which shooting was allowed to take place. Hence in models using the full four winters of scaring information, fields were allocated specifically to a scaring type where data were available at the field scale (2003/04 winter only) and according to whether they were in a scaring, buffer or feeding area for the remaining years (Table 2.3.2.1).

The numbers of fields contained within designated “shooting”, “buffer” and “feeding” zones in each of the three years are shown in Table 2.3.2.3. In each of the four years, shooting was allowed over a maximum of around 100 fields, compared to more than 3,000 “feeding” fields over which shooting was prohibited. Non-lethal shooting was recorded from a maximum of 29 holdings in any given year, and lethal shooting from a maximum of 15 holdings (Table 2.3.2.2). Information on the use of non-shooting scaring devices was available for two winters only (2002-03 and 2003-04; both at the level of specific fields; 29 and 48 fields in the two winters respectively).

Three types of models, of increasing resolution with respect to scaring measures, were run for each goose species and the two species combined, as follows (summarised in Table 2.3.2.1):

i. *Comparison of all fields in which scaring was allowed with those in which it was prohibited* (i.e. ‘scaring’ and ‘buffer’ fields combined compared with ‘feeding’ fields). If scaring had the intended effect on field usage, then usage should have been proportionately lower than expected on fields at which scaring takes place. In these models scaring involved a single factor with two levels (fields where scaring took place and fields where there was no scaring). A year effect was also included when more than one year of data was included (Section 2.3.1 above).
ii. *Comparison of ‘scaring’, ‘buffer’ and ‘feeding’ fields* (i.e. a single factor with three levels). This analysis was carried out in addition to that combining ‘scaring’ and ‘buffer’ fields (i. above) because initial appraisal of the data suggested that more scaring was carried out in ‘scaring’ areas than ‘buffer’ areas (and this was expected *a priori* to some extent because ‘scaring’ fields are largely reseeds that are somewhat favoured by geese). In support of this, in the winter of 2003/04 (the only winter for which data on shooting were available on a field-specific basis), of the 13 fields at which lethal shooting was carried out by the SNH marksman, eight were ‘scaring’ fields and five were ‘buffer’ fields. Of the 25 fields at which non-lethal shooting was carried out by the marksman, 14 were ‘scaring’ fields and 11 were ‘buffer’ fields. Overall, in the winter of 2003/04, 78 lethal and 488 non-lethal shots were fired by the SNH marksman over ‘scaring’ fields, and 56 and 324 shots of the two types respectively over ‘buffer’ fields. Of the 48 fields at which non-shooting scaring was carried out, 29 were ‘scaring’ fields and 19 were ‘buffer’ fields. A year effect was also included when more than one year of data was modelled (Section 2.3.1 above).
iii. *Direct comparison of the effects of lethal shooting, non-lethal shooting and the presence of non-shooting scaring devices*. These models incorporated a single scaring variable, with up to six levels (depending on the particular winters being considered in each model):
    a) all techniques (lethal + non-lethal shooting + non-shooting scaring);
    b) lethal + non-lethal shooting;
    c) non-lethal shooting + non-shooting scaring;
    d) non-lethal shooting only;
    e) non-shooting scaring only; and
    f) no scaring.

There were no fields in which lethal shooting alone was undertaken (Table 2.3.2.2). All models incorporating more than one winter of data included a year effect and scaring type-by-year interaction term. For each species, this type of model was run twice (summarised in Table 2.3.2.1):

a) for all four years combined (scaring variable with three levels only, excluding non-shooting scaring techniques because data on these were not available for the first two winters); and
b) for the two winters of 2002/03 and 2003/04 (scaring variable with all six levels; information available at the holding level only for the shooting types in 2002/03 and at the specific field level for every scaring technique in 2003/04).

2.4 Effects of Scaring on the Distribution of Geese on Islay

In addition to attempting to assess whether scaring techniques led to reduced usage of individual fields by geese on Islay, there is also a requirement to understand whether the scaring carried out under the current Goose Management Scheme (data from the winters of 200/01 to 2003/04 available) has resulted in greater dispersal of geese across the island. Such an assessment is complicated by a number of factors, however. First, the total numbers of both goose species under consideration have increased in number on Islay over at least part of the study period, leading to possible *a priori* predictions of increased field usage even in the absence of scaring, but also potential habitat saturation that could limit further increase in the distribution of geese across the island. Second, there will have been changes from year to year in the numbers and distribution of fields providing habitats suitable for goose foraging. At best, such changes will introduce additional sources of variation ('noise') into putative analyses but, at worst, could introduce systematic bias or misleading results that are not the result of the scaring regime. One such concern of this nature is the closure of the dairy farming industry on Islay (and associated changes in cropping patterns), which is thought to have taken place concurrent with the start of the current scaring programme.

To make some preliminary assessment of whether the scaring of geese on Islay has had any overall effect on their distribution at the whole-island scale, we first calculated some simple summary measures of goose dispersal across the island. These measures were based on the whole-island International Paired Count data because these coordinated counts carried out on a single day are designed to provide a comprehensive count of goose numbers (Section 1.5) and provide a snap-shot of goose distribution on any given counting day. Three measures were calculated for each of the two goose species on each counting day:

i. the mean number of geese per field ('density');
ii. the number of fields that were occupied by geese; and
iii. the number of 1-km squares that were occupied by geese.

Paired International Counts were filtered in the same manner as for previous analyses (Section 2.1.1). The three measures were calculated for each counting day in two periods:

i. the four winters of the current Goose Management Scheme (2000/01 to 2003/04) when scaring has been undertaken; and
ii. the eight winters of the previous Scheme (1992/93 to 1999/2000) when scaring was not permitted.

For these two periods, monthly means of the three measures were also calculated for comparison, as the pattern of field usage by the geese was thought *a priori* to vary through the winter. When both counts of a pair were useable, a mean of the appropriate measure from the two count days was used, and these were given double weighting when calculating the monthly or overall means for each measure.

To allow some further assessment of the potential effects of the current scaring regime on goose distribution, and make use of data collected both from the International Paired Counts and the Scheme Counts (that are not coordinated to cover the island in a single day; Section 1.5), the cumulative total numbers of fields in which geese were recorded on Islay were calculated for each species from the winter of 1992/93 to the winter of 2003/04. If the rate of change in the numbers of fields used by the geese was shown to vary markedly between the two time periods (1992/93-1999/2000 and 2000/01-2003/04), then the implementation of scaring as a management strategy would be one possible reason for the difference, and the data might be worth exploring in more detail. If no difference in the rate of change in field usage between years was shown when comparing the two periods, either scaring has had no large, overall effect on goose usage, or any such effect has been masked by concurrent changes in other influencing factors (e.g. goose population size and changes in cropping patterns across Islay).

2.5 Statistical Analyses

All statistical analyses were carried out using SAS 9.1. Generalised linear modelling was carried out using the PROC GENMOD procedure, employing step-wise deletion of non-significant terms. The test statistics and *p*-values provided for non-significant terms were determined by adding each term back into the minimum supported model. Statistical differences between each level of categorical variables were derived based on the χ^2 distributions for each level, as given routinely in the model output from PROC GENMOD. Correlations between putative explanatory variables were tested using the PROC CORR procedure (Pearson's or Spearman's Rank-order correlations as appropriate), prior to inclusion in models. Means ± s.e. (standard error of the mean) are presented in the text and tables. Further specific details of analyses are provided in relevant sections of the methods (above).

3. RESULTS

3.1 Use of International Paired Count Data to Assess Count Quality and Significance of Population Trends

3.1.1 Count discrepancy and its correlates

For Greenland White-fronted Goose, there was no systematic variation in count discrepancy with date within season (Figure 3.1.1.1; Table A13). Of the other possible correlates of count discrepancy considered (Table A13), only year was significant (Figure 3.1.1.2). Count discrepancy was found to decrease by 6.5 ± 2.9 % between the winters of 1983/84 and 2003/04. A relationship between count discrepancy and the numbers of geese that required counting was evident only when year was not controlled for in the analysis (coefficient = -0.0000068 ± 0.0000030, χ^2 = 5.30, d.o.f. = 1, p = 0.021; Figure 3.1.1.3). No significant relationships were identified between count discrepancy and the measures of aggregation/dispersion of the geese, weather variables or the number of daylight hours available for counting (Table A13). Count discrepancy did not differ significantly between the winters in which scaring was allowed and those in which it was not permitted (Table A13).

Similarly for Greenland Barnacle Goose, count discrepancy did not vary systematically with date of season (Figure 3.1.1.4; Table A14). Of the other variables considered (Table A14), the only factor to show a significant relationship with count discrepancy was year (Figure 3.1.1.5). Count discrepancy was found to increase by 5.5 ± 2.3 % between the winters of 1983/84 and 2003/04. No significant relationships were identified between count discrepancy and the numbers of geese that required counting (even when year was excluded from the model: χ^2 = 2.97, d.o.f. = 1, p = 0.08; Figure 3.1.1.6), measures of aggregation/dispersion of the birds, weather variables or the number of daylight hours available for counting (Table A14). Count discrepancy did not differ significantly between the winters in which scaring was allowed and those in which it was not permitted (Table A14).

For both goose species, plots of count discrepancy against date of season (Figures 3.1.1.1 and 3.1.1.4) suggested a higher degree of variation late in the counting season (from Day 170, i.e. the third week of March onwards). Preliminary discussion of this result concluded that this might have been due to migratory movements having begun by this date in some years, and it was agreed to run the analyses again with counts after Day 170 omitted. For Greenland White-fronted Goose, the significant negative relationship between count discrepancy and year disappeared when counts after Day 170 were excluded (all other variables remained non-significant; year: χ^2 = 1.54, d.o.f. =1, p = 0.21). For Greenland Barnacle Goose, the exclusion of these later counts had no overall effect on the modelling results, and the positive relationship between count discrepancy and year was maintained (year: χ^2 = 5.68, d.o.f. = 1, p = 0.017).

Since no systematic variation in count discrepancy through the winter was identified in our analyses for either goose species, we used counts from the whole winter period to investigate count quality and in later derivation of population trends.

3.1.2 Estimates of count discrepancy

From the dataset spanning the whole winter period, the estimated mean count discrepancy for Greenland White-fronted Goose was 8.9 ± 0.8 % (95 % C.I.: 7.2 to 10.6 %). To test whether counts from the latest part of each winter were inflating the discrepancy estimate, because of the possible problem of the onset of spring departure movements (Section 3.1.1), count discrepancy was estimated using a sub-sample that excluded the latest 14 counts (day 170 onwards). A lower discrepancy estimate would have been expected from this sub-sample if the counts from the latest period were inflating the discrepancy estimate but in fact the estimate from this sub-sample was slightly higher at 9.8 ± 1.0 %. There was therefore no reason to exclude the latest counts when calculating an overall measure of count discrepancy or deriving population trends. The use of count discrepancies pooled across all years does not take into account the significant trend for decreased count discrepancy in the more recent years, however. To take account of this trend, we calculated count discrepancy for each year based on the following equation derived from the GLM (where year 1 is the winter of 1983/84):

Greenland White-fronted Goose count discrepancy = 12.6 – (0.307 * year number) [1]

The parameters of this equation were bootstrapped to obtain robust d 95 % confidence intervals of the intercept (12.6 ± 1.7) and coefficient (0.307 ± 0.01). Using this equation, mean count discrepancy for the period between 1983/84 and 2003/04 was estimated as 9.2 % (95 % C.I.: 7.4 to 11.0 %).

The mean count discrepancy for Greenland Barnacle Goose was 6.1 ± 0.75 % (95 % C.I.: 4.6 to 7.6 %). Exclusion of the 14 latest counts of the season (day 170 onwards), because of the possible problem of the onset of spring departure movements (Section 3.1.1), produced a similar estimate of count discrepancy of 5.7 ± 0.79 %, and gave no reason to exclude these later counts when estimating overall count discrepancy or deriving population trends. As for Greenland White-fronted Goose, the use of data pooled across all years did not take into account the significant change in count discrepancy with year, which for Greenland Barnacle Geese suggests increased count discrepancy in recent years. Once again, we calculated count discrepancy for each year based on the following equation derived from the GLM (where year 1 is the winter of 1983/84):

Greenland Barnacle Goose count discrepancy = 3.11 + (0.256 * year number) [2]

The parameters of this equation were bootstrapped to obtain robust 95 % confidence intervals of the intercept (3.16 ± 0.37) and coefficient (0.256 ± 0.004). Using this equation, mean count discrepancy for the period between 1983/84 and 2003/04 was estimated as 6.0 % (95 % C.I.: 5.6 to 6.4 %).

3.1.3 Derivation and significance of population trends for Greenland White-fronted Goose

Smoothed population changes for the winters of 1983/84 to 2003/04 from the GAMs (using four degrees of freedom) showed that numbers of Greenland White-fronted Geese on Islay increased until the early1990s and have stabilised since then (Figure 3.1.3.1; Table 3.1.3.1).

Figure 3.1.3.1 shows that the inclusion of paired counts (F_{all}; providing information on the error associated with counts) rather than only single counts (F_1 and F_2) resulted in wider confidence limits associated with the smoothed trend, and hence more rigorous conclusions regarding the significance of the trends. The same modelling using only counts for which both of each pair were useable (F_{pairs}) made very little difference to the confidence intervals surrounding the GAM trend for most of the period under consideration (Figure 3.1.3.2), because the majority of counts were paired. The wider confidence limits attached to the F_{all} trend line compared to the F_{pairs} trend in the mid-1990s are driven by the consecutive single maximum counts in the winters of 1994/95 and 1995/96 and might have been narrower had both counts been satisfactory for these pairs. For this goose species, the use of the counts from either of the single count days (F_1 or F_2) rather than the paired counts where available (F_{all}), would not have influenced our conclusions about the significance of population changes over a 10-year period or longer (Table 3.1.3.2). However, for the most recent five-year period for which data were available, use of data from single count days (F_1 or F_2) resulted in a significant decrease in population size, which was not supported when the paired count data (F_{all}) were used (Table 3.1.3.2).

3.1.4 Derivation and significance of population trends for Greenland Barnacle Goose

Smoothed population changes for the winters of 1983/84 to 2003/04 from the GAMs (using four degrees of freedom) showed that numbers of Greenland barnacle Geese on Islay increased consistently during that period (Figure 3.1.4.1; Table 3.1.3.1).

The inclusion of paired counts (F_{all}; providing information on the error associated with counts) rather than only single counts (F_1 and F_2) resulted in wider confidence limits associated with the smoothed trend (Figure 3.1.4.1), and again suggested that more rigorous conclusions regarding the significance of the trends should be reached by using paired count data. As for White-fronted Goose, the same modelling using only counts for which both of each pair were useable (F_{pairs}) made very little difference to the confidence intervals surrounding the GAM trend (Figure 3.1.4.2), because the majority of counts were paired. The magnitude of the population changes exhibited by this species meant that the use of the counts from either of the single count days (F_1 or F_2) rather than the paired counts where available, would not have influenced our conclusions about the significance of population changes over any of the time periods considered (Table 3.1.3.2).

3.2 Factors Influencing Field Usage by Geese on Islay

The whole-island field usage models for each of the two species were based on count data collected during the winters of 1992/93 to 1999-2000, during which time no systematic scaring was allowed. The models were based on data collected at the individual field scale. The field usage models for the Loch Gruinart RSPB reserve for each of the two species were based on count data collected during the winters between 1994-95 and 1999-2000. There was no systematic scaring allowed during this period. The models produced were based on the maximum monthly counts of geese on individual fields.

3.2.1 Greenland White-fronted Goose (whole-island data)

Our global model for field usage by Greenland White-fronted Geese included the following variables:

i. goose population size;
ii. month (five levels: November, December, January, February, and March);
iii. field size (area);
iv. crop type (seven levels):
    a) grassland re-seeded in the current season,
    b) grassland re-seeded in the previous year,
    c) grassland re-seeded two years previous,
    d) older improved grassland,
    e) permanent pasture,
    f) *Juncus* fields, and
    g) bog fields;
v. field gradient;
vi. field undulation;
vii. proximity to roads;
viii. proximity to woodland;
ix. proximity to lochs; and
x. distance to nearest roost sites.

The following second-order interaction terms were also included: field gradient-by-month; distance to the nearest road-by-month; distance to nearest woodland-by-month; and distance to nearest roost site-by-month (Table A15). The crop type-by-month interaction could not be supported by the model (as this resulted in non-convergence of the algorithm). This global model showed a satisfactory fit (deviance divided by the degrees of freedom = 0.183).

Stepwise deletion of non-significant terms was used to produce a minimum supported model for field usage by Greenland White-fronted Geese in which the following significant terms were retained (Table 3.2.1.1): goose population size; month (five levels: November, December, January, February, and March); field size (area); crop type (simplified to two levels: bog fields and all others; see Table A16); field gradient; proximity of the fields to roads; proximity to lochs; distance to nearest roost sites; and the two second-order interaction terms field gradient-by-month and distance to the nearest road-by-month. This reduction of the global model had no effect on the goodness of fit. A plot of the observed versus expected values is shown in Figure 3.2.1.1. (to assist in visualising the data: Spearman's rank correlation coefficient = 0.11). The influence of the extreme values on model fit was reduced somewhat when annual means were derived from the model for each field, as was required in our subsequent use of the predicted values for investigating the effects of scaring (Figure 3.2.1.2; Spearman's rank correlation coefficient = 0.16).

In the minimal model, the effects of crop type on field usage were reduced to two levels ('group 1': bog areas; and 'group 2': all other field types; see Table A16 for supporting statistics). Bog areas experienced lower goose usage than the other field habitat types. Usage by White-fronted Geese was lower for fields with a steeper gradient, this effect being greater earlier in the winter than later (Table 3.2.1.1). Higher goose numbers were associated with: fields closer to roads (the effect being greater later in the winter than earlier); fields closer to lochs; fields further away from roost sites; and larger fields. As expected, the relationship between field usage and mean annual Greenland White-fronted Goose count was positive (Table 3.2.1.1). Despite the reduction to only two 'crop types', the crop type-by-month interaction could not be supported by the model (as this still resulted in a non-convergence of the algorithm).

3.2.2 Greenland Barnacle Goose (whole-island data)

The global model for field usage by Greenland Barnacle Goose included:

i. goose population size;
ii. month (five levels: November, December, January, February, and March);
iii. field size (area);
iv. crop type (six levels):
    a) grassland re-seeded in the current season,
    b) grassland re-seeded in the previous year,
    c) grassland re-seeded two years previous,
    d) older improved grassland,
    e) permanent pasture, and
    f) *Juncus*;
v. field gradient;
vi. field undulation;
vii. proximity of the fields to roads;
viii. proximity to woodland;
ix. proximity to lochs; and
x. distance to nearest roost sites.

The following second-order interaction terms were also included: crop type-by-month; field gradient-by-month; distance to the nearest road-by-month; distance to nearest woodland-by-month; and distance to nearest roost site-by-month (Table A17). This global model showed a satisfactory fit (deviance divided by the degrees of freedom = 0.154).

Stepwise deletion of non-significant terms was used to produce a minimum supported model for field usage by Greenland Barnacle Geese in which the following significant terms were retained (Table 3.2.2.1): goose population size; month (five levels: November, December, January, February, and March); field size (area); crop type (simplified to four levels; see Table A18); field gradient; field undulation; proximity of the field to roads; proximity to woodland; proximity to lochs; distance to nearest roost site; and the three second-order interaction terms field gradient-by-month, , distance to the nearest road-by-month, and distance to nearest roost site-by-month (Table 3.2.2.1). This reduction of the global model had no effect on goodness of fit. A plot of the observed versus expected values is shown in Figure 3.2.2.1 (to assist in visualising the data: Spearman's rank correlation coefficient = 0.18). The influence of extreme values was reduced markedly when annual means were derived from the model for each field, as occurred in our subsequent use of the predicted values for investigating the effects of scaring (Figure 3.2.2.2; Spearman's rank correlation coefficient = 0.32). A small number of fields (n=13) were excluded from subsequent analyses of the effects of scaring for this species because their predicted goose numbers were very much higher than those observed (and higher than are normally observed on the island; between 2,000 and 1,300,000 in a given field). All these were grassland fields (this was not unexpected given that grassland is the predominant habitat type under consideration in the models). The excluded fields did not together show any other particular similarity (they were not all concentrated on one or two holdings favoured by geese, for example). Individually, however, some showed relatively extreme values of one or more of the variables that were found to be related significantly to goose field usage (e.g. one was at a roost site; one was very isolated from roads and woods; one was a very large field); the models would be expected to be less successful in their predictions for such fields.

In the minimal model, the effects of crop type on field usage were reduced to four levels: ('group 1': improved grassland; 'group 2': *Juncus*; 'group 3': pasture; and 'group 4': grassland re-seeded either in the current year or one or two years previously) (Table A18). Re-seeded grassland experienced the greatest goose usage, followed consecutively by: *Juncus*; older grassland; and pasture. As for Greenland White-fronted Goose, Greenland Barnacle Goose field usage was greater in fields with a shallower gradient; this effect was greater earlier in the winter that later (Table 3.2.2.1). Greater field usage was also associated with: fields with a lower degree of undulation; fields closer to lochs; fields further away from woodland; larger fields; fields closer to roost sites (the effect greater earlier in the season that later); fields closer to roads (in January only). As expected, the relationship between field usage and mean annual Greenland Barnacle Goose count was positive.

3.2.3 Loch Gruinart RSPB reserve data

We analysed goose count data from the Loch Gruinart RSPB reserve specifically to assess whether fertiliser use could be shown to have significant effects on field usage by the two goose species. Preliminary results only are presented, and further modelling would be required to further investigate the interactions between fertiliser use and other variables influencing patterns of goose field usage.

The field usage by both goose species was significantly related to fertiliser use (Tables 3.2.3.1 & 3.2.3.2) but the strength and direction of relationships varied across the six years for which data were available, and with month of the winter. The final models had satisfactory goodness-of-fit for both species: Greenland White-fronted Goose deviance divided by degrees of freedom=0.510; Greenland Barnacle Goose deviance divided by degrees of freedom=0.584.

For Greenland White-fronted Goose, field usage was significantly related to fertiliser usage, month of the winter, year and crop type (Table 3.2.3.1); the interaction terms month-by-fertiliser use and year-by-fertiliser use were both significant and the crop type-by-fertiliser use interaction term was just non-significant (p=0.054). For this species, usage was generally lower in fields that were fertilised the previous summer but the effect was greater in some years than in others and in some months of the winter.

For Greenland Barnacle Goose, field usage was also significantly related to fertiliser usage, month of the winter, year and crop type (Table 3.2.3.2) and the interaction term month-by-fertiliser use was also significant; the year-by-fertiliser use interaction was not significant, and the crop-by-fertiliser use term could not be fitted because it resulted in non-convergence of the algorithm. Usage was generally higher in fields that were fertilised the previous summer, and the effect was greater in some months than others (but did not differ significantly between years; we did not test second-order interaction terms).

3.3 Effects of Scaring on Field use by Geese on Islay

The models and results of our analyses to assess the effects of scaring on field usage by the two goose species on Islay are summarised in Table 2.3.2.1. The dependent term in all of these models was the Proportional Whole-Winter Count Difference (PWWCD), which is the proportional difference between the mean winter count in any given field and the expected count based on the field use model for the given species.

3.3.1 Effects of scaring on field usage by Greenland White-fronted Geese

For Greenland White-fronted Goose, no significant effects of scaring on field usage were detected when analyses compared scaring and non-scaring areas, or when the two shooting types (non-lethal versus non-lethal + lethal) were compared directly (Table 2.3.2.1). When direct comparison was made of all scaring permutations for the two most recent winters for which data were available, differences were only detected in 2003/04, when information on scaring types was available for specific fields (which was not the case in 2002/03). In the winter of 2003/04, fields subjected to all scaring types (lethal and non-lethal shooting, and non-shooting scaring) held proportionally less geese than expected compared to fields with no scaring (Figure 3.3.1.1). Fields subjected to non-lethal shooting only had proportionally more geese than expected to fields with no scaring however. Fields with other combinations of scaring types did not differ significantly in usage from those that were not subjected to scaring.

3.3.2 Effects of scaring on field usage by Greenland Barnacle Geese

For Greenland Barnacle Goose, areas in which scaring was permitted held significantly less geese than expected compared to areas in which scaring was not allowed, across all four years for which data were available (Table 2.3.2.1). When 'scaring' and 'buffer' areas were considered separately and compared to 'feeding' (non-scaring) areas over this four-year period, the pattern of differences between the three zones was similar between years (Figure 3.3.2.1); 'scaring' areas had consistently less geese than expected compared to 'buffer' and 'feeding' areas (the latter two did not differ significantly, based on non-overlapping 95% CIs).

When fields subjected to the individual scaring techniques, and combinations of these techniques, were compared for this species (Figures 3.3.2.2 and 3.3.2.3), some combinations were associated with significantly less geese than expected compared to fields in which no scaring took place. When considering just shooting techniques (Figure 3.3.2.2), the effects varied between years. In the first three winters for which data were available (2000/01 – 2002/03; data available at the holding level, not specific to each field), areas that could have been subjected to both lethal and non-lethal shooting tended to have less geese than expected compared to areas with no scaring (with the difference being significant in the winters of 2000/01 and 2002/03 but not 2001/02, when the estimate for areas with both shooting techniques had wide confidence limits). In those three years, areas subjected to non-lethal shooting only showed intermediate usage by the geese (which did not differ from either areas in which both techniques could have been used or from areas not subjected to scaring). A contrasting pattern was apparent in the winter of 2003/04, when specific information on the use of the individual shooting techniques was available at the field scale. In that winter, fields subjected to non-lethal, but not lethal, shooting had significantly less geese than expected compared to fields in which shooting did not take place and those in which both shooting types were carried out (the latter two classes did not differ significantly; Figure 3.3.2.2).

Information on the use of non-shooting scaring techniques was available for two winters only (2002/03 and 2003/04) but the model that compared directly all combinations of scaring techniques (including non-shooting scaring) was the most rigorous possible in terms of understanding the effects of the different techniques. Using this model (Figure 3.3.2.3), the pattern of differences between the techniques, and combined techniques, did not differ significantly between the two winters for which data were available. In each winter, three classes of scaring were associated with less geese than expected when compared to areas that received no scaring: areas with non-shooting scaring only (just significant); areas with non-lethal shooting and non-shooting scaring; and areas with lethal and non-lethal shooting. In both years, areas subjected only to non-lethal shooting, or to a combination of all three scaring types (non-shooting scaring, lethal shooting and non-lethal shooting), did not differ in goose usage from those where scaring was absent.

3.3.3 Effects of scaring on field usage by the two goose species combined

We considered it important to carry out analyses to look at the effects of scaring on both goose species combined because it is these overall effects on goose numbers that influence the success or otherwise of the Goose Management Scheme measures for the farmers.

When considering data for the two goose species combined, areas in which scaring was permitted held significantly less geese than expected compared to areas in which scaring was not allowed, across all four years for which data were available (Table 2.3.2.1). When 'scaring' and 'buffer' areas were considered separately and compared to 'feeding' (non-scaring) areas over this four-year period, the pattern of differences between the three zones was similar between years (Figure 3.3.3.1) and was similar to that for Greenland Barnacle Geese alone; however, for the two species combined, both 'scaring' areas and 'buffer' areas had consistently less geese than expected compared to 'feeding' areas ('scaring' and 'buffer' areas did not differ significantly in three of the winters but 'scaring' areas had significantly less geese than expected compared to 'buffer' areas in 2002/03).

When fields subjected to the individual scaring techniques, and combinations of these techniques, were compared for the two species combined (Figures 3.3.3.2 and 3.3.3.3), as for Barnacle Geese alone, some combinations were associated with significantly less geese than expected compared to fields in which no scaring took place. When considering just shooting techniques (Figure 3.3.3.2), the effects were similar across the four years for which data were available. In each of the four winters 2000/01-2003/04, areas subjected to either non-lethal shooting alone, or lethal and non-lethal shooting combined, held less geese than expected compared to areas that were free from shooting; the effect of lethal shooting in combination with non-lethal shooting did not differ significantly from that of non-lethal shooting alone in any year.

When information on the use of non-shooting scaring techniques was also considered (Figure 3.3.3.3; information available for two winters only), the pattern of differences between the techniques, and combined techniques, differed between winters. In 2003/04, no significant effects were detected. In 2002/03, areas with non-shooting scaring, or non-shooting scaring combined with non-lethal shooting, were associated with significantly less geese than expected compared with areas where no scaring took place; other classes of single, or combinations of, scaring techniques were intermediate in their effects.

3.4 Effects of Scaring on the Distribution of Geese on Islay

The three measures of goose dispersal (number of geese per field; total number of fields occupied; total number of 1-km squares occupied) did not show any marked or consistent differences for either goose species when comparison was made between winters prior to shooting taking place, and the winters of the current Goose Management Scheme under which shooting has been permitted (Tables 3.4.1 and 3.4.2). Means of the three measures for all years and all months combined did not differ significantly between the two periods, and although there was some suggestion that the measures varied between months through the winter, there were insufficient numbers of counts in each month to allow statistical testing of differences between the pre-shooting and shooting periods.

A further analysis considered whether the total number of fields used by the two species of geese on Islay in any given winter (summed from the Paired International and Scheme Counts) had changed by comparing the period of the previous Goose Management Scheme (winters of 1992/93-1999/2000) and the current Scheme, under which shooting has been permitted (winters of 2000/01 and 2003/04). For Greenland White-fronted Goose, there was suggestion that the rate of increase over time in the cumulative number of fields used was lower in the most recent four-year period than in the previous eight years of the old Goose Management Scheme (Figure 3.4.1), the later years coinciding with the period when the goose population on Islay did not increase further (Section 3.1.3 above). For Greenland Barnacle Goose, no such difference in the cumulative rate of increase in field usage was apparent (Figure 3.4.2), and the population of this species continued to increase on Islay during the most recent four-year period (Section 3.1.4 above).

Some changes in cropping patterns occurred concurrent with the start of the current Goose Management Scheme (winter of 2000/01 onwards; Figure 3.4.3). These changes principally involved a higher proportion of re-seeding taking place.

4. DISCUSSION

4.1 Use of International Paired Counts to Assess Count Quality and Significance of Population Trends

4.1.1 Limitations of count discrepancy as a measure of count 'quality'

The 'paired count' nature of the International Count data for geese on Islay has allowed an appraisal of the likely quality of counts that is rarely possible within most monitoring schemes that only carry out a single count per counting period. The measure of count quality that was derived was based on comparisons of 'paired' whole-island counts each carried out on one of two consecutive days, rather than both on the same day. For this reason, movements to or from the island between each pair of days could confound count discrepancy with true biological variation in the numbers of geese present on Islay. As our analyses showed no significant variation in count discrepancy with date of season, however, it can be assumed that, as planned, most paired 'International Counts' have taken place outwith the periods when most goose movements into and away from Islay occur. The effects of such movements on the derived measure of count discrepancy are therefore likely to be minimal. Equally, there were no relationships between count discrepancy and any of the weather variables that could have been related to the likelihood of movements away from the island (i.e. minimum temperatures). This provides further tentative support for a minimal influence of movements away from Islay contributing to the measure of count discrepancy derived from these count data.

It is important to understand that our measure of count quality (count discrepancy) is not a measure of true counting error. The latter would be achieved only in the event that at least one of the two counts of each pair was absolutely accurate, which is unlikely to have been the case. Our measure does provide an indication of at least part of the error associated with the goose counts however, and is valid for use in the investigation of any correlates of counting discrepancy.

4.1.2 Magnitude of count discrepancy and its influences

Given the large numbers of geese that needed to be counted on each whole-island count day, differences between pairs of counts were reassuringly small. The mean count discrepancy was only 9.2 % (95 % C.I.: 7.4 to 11.0) for Greenland White-fronted Goose and 6.0 % (95 % C.I.: 5.6 to 6.4) for Greenland Barnacle Goose. The estimate of count discrepancy for Greenland White-fronted Goose was greater than that for Greenland Barnacle Goose. The former species may be more difficult to count accurately due to:

i. its less contrasting colouration;
ii. its favoured fields being more difficult to survey (due to taller vegetation such as *Juncus*);
iii. more frequent between-field movements resulting in over- or under estimates;
iv. over-looking of birds that are within Barnacle Goose flocks; and
v. its being present in more-scattered, smaller flocks that are easier to miss than the larger flocks of Barnacle Geese.

The lack of any significant relationship between count discrepancy and date of season for either goose species confirmed that most Paired International Counts are being carried out after most large influxes of geese have taken place on Islay in the autumn and before large departures begin in the spring.

Linear relationships were found between count discrepancy and year for both species, but the direction of the relationship differed: for Greenland White-fronted Goose count discrepancy decreased between 1983-84 and 2003-04, while it increased for Greenland Barnacle Goose during the same period. The difference between the two species suggested that the accumulated experience of the counters was not responsible for the changes, although this could have played a part for White-fronted Goose (see below). None of the potential correlates of count discrepancy available to us helped to explain the observed changes in this variable over the years. Count discrepancy might have increased as the number of Barnacle Geese increased due to the sheer numbers requiring counting, or due to changes in their distribution or behaviour (as there was a near-significant relationship between count discrepancy and the number of geese counted when year was excluded from the model). There were no significant relationships between count discrepancy and any of our three derived measures of goose aggregation/dispersal for this species, however, although the data from which the latter variables were calculated were available only for a sub-set of counts (which spanned a much more restricted time period), thus reducing the power of the analysis considerably. For Greenland White-fronted Goose, count discrepancy was related to the absolute number of geese counted when the year term was excluded from the model. This suggests that count discrepancy may have decreased in the more recent years because the comparative rarity of the species earlier in the count period, and its tendency to occupy different habitat to the Greenland Barnacle Goose, made small groups potentially difficult to locate previously. Accumulated knowledge of their distribution and habits on Islay over the years may have also contributed to improved counting of Greenland White-fronted Goose.

4.1.3 Population trends and their significance

Between 1983 and the mid-1990s, the Islay Greenland White-fronted Goose population increased, with the population almost tripling during that period. Since then, the population has stabilised (Table 3.1.3.2). Based on the smoothed population trend and 95% confidence limits from the GAM using the paired count data where available, the apparent decline in numbers over the most recent 5-year period is not quite significant (in contrast to significant trends if only single counts were used; Section 3.1.3). A recent study of the demographic parameters (annual survival rate, productivity rate, and the proportion breeding) of Greenland White-fronted Geese in Scotland (Trinder *et al*. 2005) concluded that a reduction in the proportion of birds breeding successfully was the most likely driver of recent population change, rather than any changes in productivity or adult survival.

The Islay Greenland Barnacle Goose population more than doubled between the winters of 1983/84 and 2003/04, showing significant increase over the period as a whole, and in the most recent five, ten and fifteen-year periods (Table 3.1.3.2). Trinder *et al*. (2005) found no evidence to suggest that the population wintering on Islay has reached carrying capacity; productivity has declined as the population has increased however, suggesting that density-dependent processes are present.

There is no established ‘alerting system’ for wintering geese in the UK. Such systems generally categorize population changes according to their magnitude and direction and trigger ‘alerts’ if population changes reach some threshold level(s). The Wetland Bird Survey (WeBS) uses such an approach (Maclean *et al.* 2005). In the WeBS alerts system, declines in the smoothed (GAM) trend over a given period of years of between 25 and 50 % inclusive are classified as ‘medium alerts’, and declines greater than 50 % as ‘high alerts’. Population increases of between 33 and 100 % inclusive are classified as ‘medium increases’ and increases greater than 100 % as ‘high increases’. Using the WeBS alerts system, the Greenland White-fronted Goose population increase during the 18-year period prior to 2003-04 was large enough to trigger a ‘high increase’, but the recent decrease has not been large enough (<25 %) to trigger a ‘medium alert’ (Table 3.1.3.2). The Greenland Barnacle Goose population increase was large enough to trigger a ‘high increase’ during the 18-year period prior to 2003-04, and ‘medium increases’ for the 10- and 15-year periods (Table 3.1.3.2). In the WeBS system, the alerts are based on arbitrary thresholds, however, and need to be interpreted carefully in relation to the biology of individual species. A series of biological filters is being introduced for the range of wetland birds that are included in the monitoring scheme, to modify the basic alert by considering such biological information as: usual variability in long-term trends; longevity of the individual species; fidelity of the species to sites within and between winters (see Maclean *et al*. 2005 for details). For the two goose species under consideration here, a system of modelling and alerting that incorporates demographic data from the population in question would be more satisfactory, and is possible because such long-term demographic data are available (this is not the case for many of the waterbird species covered by the WeBS programme). Such a method might involve comparison of predicted population changes, based on the monitoring and analysis of demographic parameters (Pettifor *et al*. 1999a 1999b, Trinder *et al*. 2005), with observed population changes modelled (as here) using pairs of counts. Discrepancies from the expected trend could then be flagged and subjected to further detailed investigation. Such a system will require the continued assessment of changes in both population size and the other demographic parameters.

4.1.4 Value of paired counts

The smoothed population trends modelled with single and paired count data for comparison (Figures 3.1.3.1 and 3.1.4.1) demonstrated the level of 'risk' associated with reducing the count programme to single counts only. The use of paired counts allowed a measure of counting error to influence the confidence limits surrounding the trend line, reducing the chances of concluding that any given trend were due to population change when in fact it were within the limits of counting (and smoothing) error. Given the magnitude of the population changes that have been taking place in wintering numbers of the two species on Islay, whether single or paired counts were used in the modelling made little difference to the conclusions reached as to the significance of population trends over the 18-year monitoring period under consideration (Table 3.1.3.2). The only exception was for White-fronted Goose over the most recent 5-year period, where, contrary to the results using single counts, the paired counts showed that the apparent decrease is still within the 95% confidence limits of the trend.

The paired count data also allowed the influences of count discrepancy to be investigated, and revealed that this measure has changed over the 20-year period under consideration: count discrepancy has increased for Barnacle Geese on Islay but decreased for Greenland White-fronted Geese. These changes in themselves demonstrate value in retaining the paired counts, so that this component of monitoring error can be tracked through time and included explicitly within the population models.

4.1.5 Future monitoring recommendations

The current surveying protocols that are used to monitor the Islay geese require six people for each count day during the winter period. An assessment of whether or not 'paired counts', rather than single day counts, are required was requested. To inform this assessment, we have attempted to: (i) compare the modelling results from single and paired counts and whether they affect the significance of observed population changes; and (ii) identify the causes of count discrepancy and assess the extent to which future changes are predictable (Section 4.1.4 above).

The advantage of changing from 'paired counts' to 'single counts' would be a reduction in the costs (both financial and time) involved with carrying out the counts. Any savings could either be used to reduce monitoring expenditure or diverted into increasing the number of 'single counts'. The latter option would increase the frequency of counts that could be made during a winter season or during the most appropriate period of the winter. This would increase the chances of counts coinciding with the annual peak in goose numbers for both species. Seasonal patterns could also be investigated more thoroughly, such as changes in the timing of goose movements involving Islay. By changing from 'paired counts' to 'single counts', the chances of a count not being carried out (due to bad weather) or of having it excluded from the analyses (due to a large amount of disturbance) would be increased. This could be offset by having a team of counters on standby, if feasible, to carry out a second count if any given count was not deemed by the observers to be suitable for adoption. The total abandonment of paired counts would mean that it will no longer be possible to include an element of count error explicitly in the population models or to track any future changes in count discrepancy, as could be done if the 'paired counts' were maintained. This may be particularly important given that systematic temporal variations in count discrepancy were found for both species. An option that might still allow any changes in counting discrepancy to be identified would be to maintain a reduced number of 'paired counts' but if the maximum count in any give winter was not 'paired', then this source of information on counting error would not be available for including in the trend modelling.

In producing trends for the two species of geese we have used the maximum adopted count during the season. As discussed in Section 2.1, the annual maxima will provide the best estimate of the highest number of geese present on Islay each season. Annual means, which would provide an index of mean use but would further underestimate absolute population size, were not used as they would be affected more by an incomplete set of counts throughout the winter. Given that the seasonal distribution of the counts has varied between years during the period 1983/84 to 2003/04 (Table 1.5.1), this variability may affect mean counts more than maxima as long as the period is covered during which the maximum count occurs. Maximum counts, on the other hand, are more prone to the sampling limitations associated with a single count (hence the value of having a 'paired' count for the maximum each year). An alternative measure for consideration would be the mean count of the month or two months that most frequently have the maximum count. This latter measure would reduce the problems involved with a single count that applies to the annual maximum. However, between the winters of 1983/84 and 2003/04, the day on which the maximum count fell was highly variable between years for both species (Figures 4.1.5.1 and 4.1.5.2). This in itself suggests that a series of counts spanning the winter (as is undertaken currently) is the safest option for future monitoring. As already stated, between 1983/84 and 2003/04 a complete set of counts (at least one per month during the winter period) was achieved in some years but not others (Table 1.5.1). A change from paired counts to single counts may not necessarily change the chances of a full set of counts being achieved if the same absolute number of count days is maintained. If the number of count days was halved, however, when changing to 'single counts', the chance of achieving a full set of counts, and a count day falling during peak numbers, is likely to be reduced.

In summary, our results suggest the following recommendations:

i. Given the variation associated with the date of peak numbers of each goose species present on Islay in winter, the maintenance of a programme of counts spanning the period October to March each year is the safest option for detecting the true annual maximum and also monitoring any change in the pattern of goose movements involving Islay; and

ii. We advise that at least a proportion of the counts be maintained as 'paired', so that some measure of counting error is included in the modelling of population trends. Given the observed changes in count discrepancy for both species over the last twenty years, the retention of paired counts is also important to allow any future changes in count discrepancy to be detected and explicitly allowed for in the population models. Paired counts are of most value if the programme ensures that the maximum count each winter is based on a pair. As the date of maximum count has varied through time, it may be difficult to achieve this unless attempts are made to carry out paired counts throughout the core winter counting period.

4.2 Predicting Patterns of Field Usage by Geese on Islay

4.2.1 Data quality and model fit

The goodness-of-fit of the field use models was satisfactory for both goose species but, as expected, a substantial proportion of variation in field usage remained unexplained by the suite of environmental variables available for the analysis. Although the standard scaling functions available to correct for over-dispersion were utilised, these can only deal with relatively minor departures from the assumed error distribution (in this case the negative binomial distribution). For this group of field use models, further modelling to account for the substantial zero-inflation in the dataset (e.g. Lambert 1992, Vandenbroek 1995) could improve the predictive power of the results. The use of ordinal regression for modelling field use could also be tested (e.g. Paradis *et al.* 2000); this would reduce statistical power but would remove the need to specify a particular error distribution. Due to time limitations, we did not attempt to correct for the potentially complex spatial autocorrelation (e.g. Augustin *et* al. 1996) within the datasets (due to the potential lack of independence of counts from adjacent fields). Whilst we do not believe this to be a major omission when using the count data in the predictive capacity required in this preliminary study, the potential effects of such spatial autocorrelation should be assessed further in formal analyses of the data.

The frequency of goose counts available for the analyses was regularly less than one per week (Figures A1 to A6), so that the counts provided only a 'snap-shot' of the spatial distribution of the geese in most cases. More frequent counts would undoubtedly have improved the predictive power of the modelling by providing more accurate data on goose distribution through the winter months.

A number of potentially important explanatory variables could not be included in the field-use models (at least in the timescale of this preliminary analysis). A number of these variables, with the reasons for their exclusion, are listed earlier (Section 2.2.2). In particular, the following could be valuable to include in future analyses if suitable data could be obtained:

i. *Use of fields by grazing livestock*. These data should be available from IACS submissions but we could not find a means to access that data set. In future, it would be valuable to ask goose counters to record the presence or absence of livestock while they are carrying out counts, including those fields not occupied by geese at the time;
ii. *Fertiliser application*. Shown to influence field usage in the analyses of the RSPB Gruinart data set. Collection of information on fertiliser application from farmers, if possible, would allow this variable to also be considered in future models (although its effects are likely to be confounded with crop type);
iii. *Location of electricity transmission lines*. These data could be obtained from energy companies, and considered in future models; and
iv. *TOPEX scores*. The calculation of topographic exposure scores might produce an improved measure of how field topography influences usage of fields by the geese (rather than using the summary elevation and undulation measures in this report; Section 2.2.2)

4.2.2 Variables influencing field usage

As expected, crop type was an important influence on field use by Greenland Barnacle Geese. Numbers were highest on grassland re-seeded up to two years previously, followed consecutively by: *Juncus*; older improved grassland; and permanent pasture. Effects of crop type were less pronounced for Greenland White-fronted Geese: numbers were lowest on bog areas but there were no detectable differences between the other crop types. Younger grassland has been shown previously in studies at Loch Gruinart, Islay to attract the largest numbers of Greenland Barnacle Geese (Percival 1993), and an increase in the use of reseeded grassland in autumn and spring was found (Percival 1993). This seasonal change was not detected in our whole-Islay analysis (but note that our analysis was limited to the period between November and March). The preference for new grassland has also been shown for other goose species (e.g. Canada Goose, *Branta canadensis*, in Quebec, Canada; Reed *et al.* 1977). No such difference in usage between re-seeded grassland and older grassland was found for Greenland White-fronted Goose, perhaps because this species is less adapted for foraging on smaller shoots (due to bill morphology). Greenland White-fronted Geese use *Juncus* fields as much as improved grassland, a preference that may be due to the concealment properties of this habitat and the ability of the geese to remain camouflaged within it.

Numbers of both goose species were higher in fields with shallow gradients, probably due to these fields giving better visibility for detecting predators. Steeper fields were shown to be used more in the later part of the season, probably as resource availability in the fields with shallower gradients is reduced in the latter part of the winter. Greenland Barnacle Goose numbers were also lower in fields with a higher degree of undulation and higher in fields further away from woodland, both effects perhaps also due to anti-predatory behaviours. These latter relationships were not found for Greenland White-fronted Goose; competition from Greenland Barnacle Goose might result in non-preferred fields being used more by the Greenland White-fronted Geese.

Goose numbers were higher in fields closer to roads, although the relationship varied through the season. The opposite trend (a positive relationship between goose numbers and distance to the nearest road) was expected, however, due to fields closer to roads being subjected to disturbance from vehicles and pedestrians (Madsen 1985). Our result was not likely to be due to the bias of fields by roads being easier to count, as fields away from roads and tracks are well covered by a series of vantage points (M. A. Ogilvie, pers. comm.). The negative relationship was significant only in January for Greenland Barnacle Goose, suggesting that the birds may have been using areas closer to roads more when resource availability was lowest. It should also be noted that distance to the nearest road is confounded to some extent with crop type, however, in that the favoured crop types of both goose species tend to be found closer to roads than some less favoured habitat types.

Both goose species were found in higher numbers in fields closer to lochs. The effect was greater for Greenland White-fronted Goose than Greenland Barnacle Goose, which may be expected due to the former species' known preference for wetter areas.

Greenland Barnacle Geese made greater use of fields closer to roost sites. This was expected in the sense that geese, whenever possible, would be likely to reduce travel times to feeding areas. The effect was also greater earlier in the season than later, suggesting that the geese tended to travel further later in the season as resource availability in the closer fields was reduced. No such effect was found for Greenland White-fronted Goose, perhaps because this species is less restricted to a small number of roost sites (78 sites known, rather than just three for Barnacle Goose).

The results of the analysis of field usage by geese at the Loch Gruinart RSPB Reserve were broadly similar to those from the whole-island analysis. The key additional variable (fertiliser use) available in the analysis of this subset of fields was found to significantly affect field use. Fields with fertiliser applied in the previous summer received higher use by Greenland Barnacle Geese. This has been observed previously for this species on Islay (Percival 1993), and other goose species at other sites (e.g. Vickery *et al.* 1994, Patterson & Fuchs 2001). The opposite effect was apparent for Greenland

White-fronted Goose, with non-fertilised fields used more than fertilised fields between December and March, probably because this species makes greater use of non-fertilised crop types.

The effects of fertiliser application on goose field usage in the Loch Gruinart models suggest that the whole-island models (particularly those for Barnacle Goose) may have been improved by including information on fertiliser use, if it had been available. It should be noted, however, that the Loch Gruinart RSPB reserve is managed with different objectives (a balance between sustainable farming and conservation) compared to most of the rest of Islay. Also, the fields to which fertiliser was applied were mainly permanent pasture, posing the potential problem of fertiliser application being confounded with crop type. Further research (consultations with farmers) is required to assess the degree of variation in fertiliser application practices across Islay before conclusions can be drawn about the value of collecting information on this practice to assist in future modelling of goose field usage.

4.3 Effects of Scaring on Field Usage by Geese on Islay

4.3.1 Comparisons of scaring and non-scaring areas

In all four winters for which information on scaring was available (2000/01-2003/04), our modelling showed that numbers of Greenland Barnacle Geese were lower than expected (based on predictions from the field-use models) in areas in which scaring was permitted, and this differed significantly from areas where scaring was prohibited; whilst the zones defined as 'feeding' and 'buffer' on average each held more geese than expected (means of 20-120% more than expected across the four winters), 'scaring' areas differed significantly and held less geese than expected (means of 11-44% less across the four winters). No such differences were detected when Greenland White-fronted Geese were considered in isolation. However, when combined numbers of the two goose species were considered, areas where scaring was permitted again showed lower than expected numbers compared with areas in which scaring was prohibited. In the case of the two species combined, both 'scaring' and 'buffer' areas generally showed lower than expected numbers of geese (means of 5-44% lower across the four winters, one mean of 6% higher than expected); both of these areas differed significantly from the 'feeding' areas (means of 8-55% higher numbers than expected across the four years).

These preliminary results suggest strongly that the effects of scaring have had desirable benefits overall in terms of discouraging geese from the 'scaring' areas on Islay (newly re-seeded grassland) and also from the 'buffer' areas to a lesser extent. It had been shown previously that numbers of Greenland Barnacle Goose were reduced from part of Islay through scaring (Percival *et al.* 1997). As in the current analysis, no effects on Greenland White-fronted Goose alone were reported in that previous study. The scaring in the Percival *et al.* (1997) study was much more intensive, involving a team of seven to eight people per day, and also less extensive, only operating on part of Islay rather than the whole island. Behavioural differences may explain a differential response to scaring between the two species, as, in general, Greenland Barnacle Geese are more affected by human disturbance than Greenland White-fronted Geese (M .A. Ogilvie, pers. comm.). In addition, the majority of the fields over which scaring is carried out are first-year reseeds, a crop type associated with higher numbers of Greenland Barnacle Geese than older (>2 years) improved fields; Greenland White-fronted Geese also utilise new re-seeds but we did not detect an effect of these being used significantly more than most other crop types for this species. Thirdly, the numbers of Greenland Barnacle Goose on Islay (which are three to four times higher than those of Greenland White-fronted Goose) are also likely to increase the probability of detecting an effect of scaring, due to comparatively higher statistical power.

4.3.2 Comparisons of scaring techniques

The most rigorous comparison of all the individual scaring types (lethal shooting, non-lethal shooting and non-shooting scaring) was possible for one winter only (2003/04), as this was the only winter in which shooting was recorded at the field scale, and information was also available on the deployment of non-shooting scaring devices. For Greenland Barnacle Goose, the significant differences detected between scaring types in the winter of 2003/04 were mirrored in the previous winter also. Three categories of scaring resulted in lower numbers of geese than expected and differed significantly in effect from areas not subjected to scaring: non-shooting scaring alone; non-shooting scaring combined with non-lethal shooting; and lethal combined with non-lethal shooting. None of these latter three combinations differed in effect from the others in the analyses that we have been able to undertake to date. Areas in which all scaring types were utilised together did not differ from areas in which scaring was absent, nor did areas in which only non-lethal shooting was employed; these latter types of scaring also showed the least precise estimates from the model (non-lethal shooting in particular), indicating large variation in their potential effects.

For Greenland White-fronted Goose, significant effects of scaring were only detected in the winter of 2003/04 (when field-specific scaring information was available). The results differed from those for Barnacle Geese in that only fields in which all scaring techniques were employed together had significantly fewer geese than expected relative to fields with no scaring; in addition, fields in which non-lethal shooting only was employed had significantly more geese than expected relative to fields with no scaring. This species was not subjected to the direct effects of lethal shooting (because the species cannot be shot under licence). Appraisal of the data for the one winter for which field-scale information on shooting was available (2003/04) did show that the species was recorded in a small sample of the fields in which lethal shooting of Barnacle Geese was undertaken (see Table 2.3.2.2). The recording methods used to date did not allow us to ascertain whether White-fronted Geese were actually present when lethal shooting of Barnacle Geese was undertaken however.

A combination of factors may be responsible for these apparent differences in response between the two goose species on Islay: the species are thought to differ in their behavioural response to disturbance (Section 4.3.1 above); the species may interact competitively, such that disturbance has a beneficial effect on one species; and the species differ in habitat preference, which might subject their populations on Islay to differences in the intensity of scaring that they experience. The SNH marksman who carried out licensed shooting during the winters of 2000/01 to 2003/04 believes that Barnacle Geese were scared much more effectively than White-fronted Geese because the Barnacle Geese graze together in larger numbers and share predator avoidance (“guarding”) behaviour more within the flock (Neil MacLennan, pers. comm.). With further winters of scaring data collected at the field-scale available for analysis (Section 4.5 below), it would be feasible to investigate influences of the various scaring techniques in more detail. For example, our analyses (due to sample size limitations) could not take into account differences in the frequency of shooting events, or in the length of time for which scaring devices were employed, between fields. Nor did our preliminary analyses take into account potential interactions between scaring and the other important factors influencing field usage by the two species (demonstrated in the models of field usage for the years prior to the onset of scaring).

From an applied viewpoint, the analyses that considered the effects of the different scaring techniques on field usage by the two species of geese in combination may be the most relevant. The results of comparing the two shooting types across all four winters were encouraging, in that both non-lethal shooting alone, and in combination with lethal shooting, resulted in significantly less geese than expected relative to areas in which no shooting occurred. However, when non-shooting scaring techniques were also considered over the two winters for which data on these were available, no significant effects of scaring were detected in the winter of 2003/04 (when shooting data were available at the field scale), this being in contrast to the significant effects that were detected when Barnacle Geese were considered alone. In the winter of 2002/03, areas with non-shooting scaring, and this combined with non-lethal shooting, did show significantly less combined goose use than expected relatively to areas where scaring was absent however (similar to the results for Barnacle Geese alone).

4.3.3 Limitations in the assessment of scaring effects

The analyses that aimed to compare the effectiveness of the variety of individual scaring techniques used on Islay were limited by the methods and duration of data collection. In particular:

i. Information on shooting was available only at the level of the individual holding (farm) for the first three winters, and at the scale of individual fields only in the winter of 2003/04;
ii. Information on non-lethal shooting was only available for holdings where the SNH marksman was utilised. It was likely to have been carried out elsewhere in addition, potentially adding extra variation that could not be accounted for in our analyses;
iii. Information on non-shooting scaring was available only for the two most recent winters for which data were available (2002/03 and 2003/04). It would also have been carried out in the previous two winters, adding additional variation that could not be accounted for in our analyses;
iv. Information on non-shooting scaring was not always complete, so that we were able to look only at the effects of the presence or absence of scaring devices, not at other factors that would be likely to influence their effectiveness (e.g. the length of time over which they were employed).
v. Many of the non-shooting scaring devices were used in small numbers only, so that sample sizes were insufficient to consider whether their effectiveness differs between types (as is likely). These techniques were necessarily pooled in our analyses.

It is probable that a combination of these limitations was responsible for at least some of the variation in the results of our comparisons of the different shooting techniques in particular, across all four years, compared with the most recent years, when higher resolution data were available. They may also have accounted in part for some of the variation between years in the effects of the different scaring techniques. Also, because shooting data were only available for specific fields in the winter of 2003/04, in these preliminary analyses we did not attempt to look for differential influences of the frequency of shooting events on goose field usage. With more winters of field-scale information, the issue of scaring/shooting intensity should be investigated, as variation in the frequency of shooting and duration of use of other scaring methods would be expected to influence the magnitude of effects on goose field use. The lack of a clear reduction in field usage by geese in our analyses when lethal shooting was used in combination with other techniques should not, at this stage, be taken to mean that lethal shooting is ineffective. Rather there is a need to explore in more detail patterns and frequency of shooting over further winters with data collected at the field scale before drawing conclusions.

In concluding that the preliminary results presented here suggest that scaring during the first four years of the current Goose Management Scheme on Islay has had beneficial effects by reducing goose usage of 'scaring' and 'buffer' areas, we must make the assumption that others factors that might influence goose field use have not changed with a systematic bias towards the scaring areas. If this has occurred, then the possible effects of scaring would be confounded. Some of these factors can be explored further (e.g. gross changes in cropping patterns; Figure 3.4.3) but for others the data are not available (e.g. fertiliser use). The approaches used in our analyses (due to the nature of the data available to us) do not prove cause and effect but rather suggest an influence of scaring that should be investigated further by: further analyses with more winters of field-scale data; improved data collection (Section 4.5 below); and careful design of future fieldwork (ideally with a pseudo-experimental approach; Section 4.5 below).

Our analyses of scaring techniques rely fundamentally on the quality of the models (based on the winters of the previous Goose Management Scheme when scaring was not allowed) from which field use under the current Scheme and scaring regime in the absence of scaring was predicted. Whilst the fits of the predictive models were adequate statistically, a great deal of variation in goose field use remained unexplained by the predictive variables available to us, and some key variables that might be explored further were identified (Section 4.2.1 above). Whilst some such information might not be obtainable retrospectively to allow the field use models to be improved, it might be possible to obtain data on some of the key omissions (fertiliser application; livestock presence and stocking rates) for more recent/future winters and use these to increase the power of inference of tests between scaring techniques by explaining additional sources of deviation from the predictive models.

4.4 Effects of Scaring on the Distribution of Geese on Islay

Two types of analyses were carried out in an attempt to investigate whether scaring under the most recent Goose Management Scheme (GMS) on Islay has led to large-scale changes in the pattern of usage of the fields on the island by the two goose species. First, simple measures of dispersal/aggregation (number of geese per field; number of fields occupied; number of 1-km squares occupied) were compared between the early period when scaring was not permitted and the four winters of the current GMS, using the Paired International Count data. Second, a cumulative curve showing new fields used by geese of each species each year was produced (using Paired Count and Scheme Count data combined), and the rate of change compared between the previous and current GMS. These analyses were limited in three major ways:

i. There were insufficient International Paired Counts to allow us to compare the measures of dispersal/aggregation statistically on a monthly basis, but both the analyses of the Paired Count data and the modelling of field usage suggest that field usage (and thus the level of dispersal of geese) vary through the winter;
ii. Changes over time in patterns of goose distribution (potentially as a result of scaring) have been confounded with changes in goose population size, and a linear relationship between population size and the measures of dispersal/aggregation cannot be assumed; and
iii. Changes in cropping patterns (Figure 3.4.3) and other unmeasured factors may have changed, which may also have influenced the distribution of geese across the island as a whole.

Despite these limitations, the simple analyses carried out here could have been expected to detect large changes in goose distribution and they did not, suggesting that scaring measures adopted under the current GMS have not caused a major increase in the areas of Islay used by the geese. More subtle changes, but nonetheless potentially important (e.g. redistribution of the geese amongst particular holdings), would not have been detected and would require more complex spatial modelling and crucially more winters of field-scale information on scaring and crop management.

4.5 Recommendations for Future Work on Scaring

There are a number of ways in which the data collection could be improved in future to increase the chances of being able to investigate rigorously the effects of the different scaring techniques and their relative efficiencies. Our recommendations on future data collection are as follows:

i. *Continue to collect data on shooting (and the other scaring techniques) at a field level (as in 2003-04) rather than per holding (as between 2000-01 and 2002-03)*. Since the available data were collected at the field level for only one year, we were unable to determine the exact fields over which shooting events took place for the remaining three. Analyses of the data at the scale of whole-farm holdings lessened the power of our tests to identify the effects of any particular scaring technique or combination of techniques. With more winters of high-quality data collected at this scale, it will be possible to look in detail at changes in goose field use both across the island as a whole and at the holding-scale, and to investigate the influence of shooting frequency.

ii. *Continue to collect data on the use of the non-shooting scaring devices, such as the type of device use, installation and removal dates, and dates of checks that the device is still present in working order*. The data available for 2002-03 and 2003-04 were not complete for all fields, making operation periods difficult to identify. With more winters of high-quality data collected at this scale, it will be possible to look in more detail at how duration of use influences goose field usage, as well as potentially to compare the efficacy of the different non-shooting scaring devices.

iii. *More regular counts of geese would increase the likelihood of detecting any differences between the different scaring techniques, and also allow investigation of the immediate effects of scaring, and the length of time taken for geese to return.* Assessment of variation in return rates with the length of time since initiation of the scaring regime would allow habituation rates to be studied. In additional, cropping patterns, seasonal changes in field use, and their potential interaction with scaring measures could be considered more rigorously.

iv. *Further information on the 'behaviour' of farmers would be useful.* In particular, farmers carry out their own non-lethal shooting, which constitutes variation that cannot be accounted for in analyses currently. Even knowledge of this per holding would allow some consideration of its effects. In addition, fertiliser application appears to have a significant but complex influence on field use by geese on Islay (Section 4.2.2 above), and information on the rate and spatial pattern of application from farmers might also prove valuable. The same is true of the influence of livestock on goose field use (Section 4.3 above).

Whilst the above improvements to data collection are likely to increase the chances of observing effects of individual scaring techniques, they can never be a substitute for an experimental approach designed specifically to provide robust data on the effects of scaring, and the relative efficiencies of different techniques. The ideal study design would allow individual fields to be studied under each of a range of scaring scenarios (e.g. non-lethal shooting only; lethal and non-lethal shooting; non-shooting scaring; no scaring). Each scenario would probably need to run for a whole season due to problems that would arise from seasonal changes due to other factors if the same field was subjected to more than one technique in the same winter. This would therefore necessitate an experiment running for three or more years (depending on the number of scaring scenarios to be tested). A suitable number of replica fields would also be required and these would need to be as similar as possible with respect to other environmental influences on goose field use (e.g. same crop (re-seed age); similar gradient and distance to features such as woods, lochs and roads). The use of grassland reseeded within three years previously might be adequate, as our models showed little difference for either goose species in the use of current-year re-seeds, grass re-seeded one year previously and grass re-seeded two years previously. Such an experimental setup would require measures to influence the behaviour of farmers, to encourage them not to carry out scaring in the 'control' fields, where experimental protocol demands no scaring, or to carry out other management practices that would negate the experimental design. The practicalities of running such an experiment are far from trivial, however, and some compromise pseudo-experimental set-up without the rotation of scenarios in the same field or without full control of some of the influencing variables might be the only feasible option.

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Table 1.5.1 Annual summaries of the number and dates of counts used in our analyses of population trends. Each count may be single or paired (i.e. paired counts are listed once only). There are discrepancies between the numbers of counts available for the two species for the following reasons:

(a) Extra White-fronted Goose count provided for March;
(b) White-fronted Goose counts not provided;
(c) Extra White-fronted Goose count provided for January;
(d) Extra Barnacle Goose counts provided for October, January and March, and an extra White-fronted Goose count provided for November;
(e) Extra Barnacle Goose count provided for December, and an extra White-fronted Goose count provided for January;
(f) Extra Barnacle Goose counts provided for November and April;
(g) Extra Barnacle Goose count provided for February;
(h) Extra Barnacle Goose count provided for January; and
(i) Extra Barnacle Goose count provided for November.

	Greenland Barnacle Goose	**Greenland White-fronted Goose**
1983-84 [a]	7 – Nov (2), Dec, Jan, Feb, Mar, Apr	8 – Nov (2), Dec, Jan, Feb, Mar (2), Apr
1984-85	6 – Oct, Nov, Dec, Jan, Feb, Mar	6 – Oct, Nov, Dec, Jan, Feb, Mar
1985-86	7 – Oct, Nov, Dec, Jan, Feb, Mar, Apr	7 – Oct, Nov, Dec, Jan, Feb, Mar, Apr
1986-87 [b]	6 – Nov, Dec, Jan, Feb, Mar, Apr	0
1987-88	3 – Nov, Feb, Mar	3 – Nov, Feb, Mar
1988-89	2 – Dec, Mar	2 – Dec, Mar
1989-90	3 – Dec, Feb, Apr	3 – Dec, Feb, Apr
1990-91	2 – Dec, Mar	2 – Dec, Mar
1991-92 [c]	3 – Nov, Feb, Mar	4 – Nov, Jan, Feb, Mar
1992-93 [d]	13 – Oct, Nov, Dec (3), Jan (2), Feb, Mar (4), Apr	11 –Nov (2), Dec (3), Jan, Feb, Mar (3), Apr
1993-94 [e]	4 – Nov, Dec, Jan, Mar	4 – Nov, Jan (2), Mar
1994-95	3 – Nov, Jan, Mar	3 – Nov, Jan, Mar
1995-96 [f]	4 – Nov (2), Jan, Apr	2 –Nov, Jan
1996-97 [g]	5 – Oct, Nov, Feb, Mar, Apr	4 – Oct, Nov, Mar, Apr
1997-98	3 – Nov, Jan, Mar	3 – Nov, Jan, Mar
1998-99	2 – Nov, Mar	2 – Nov, Mar
1999-00	3 – Nov, Jan, Mar	3 – Nov, Jan, Mar
2000-01 [h]	3 – Nov, Jan (2)	2 – Nov, Jan
2001-02 [i]	3 – Nov, Dec, Apr	4 – Nov (2), Dec, Apr
2002-03	3 – Nov, Dec, Mar	3 – Nov, Dec, Mar
2003-04	4 – Nov, Dec, Feb, Mar	4 – Nov, Dec, Feb, Mar

Table 2.1.1.1. Annual summaries of the number and dates of paired counts used in our analyses of count discrepancy (only counts where both of a pair were satisfactory are included). There are differences between the numbers of counts available for the two species for the following reasons:

a. White-fronted Goose counts not available;
b. White-fronted Goose count for March not available;
c. White-fronted Goose count for November not complete; and
d. Poor visibility in November thought to have affected the Barnacle Goose count more than the White-fronted Goose count.

	Greenland Barnacle Goose	Greenland White-fronted Goose
1983-84	4 – Nov, Dec, Feb, Mar	4 – Nov, Dec, Feb, Mar
1984-85	3 – Nov, Dec, Feb	3 – Nov, Dec, Feb
1985-86	4 – Dec, Jan, Mar, Apr	4 – Dec, Jan, Mar, Apr
1986-87 [a]	2 – Dec, Apr	0
1987-88	3 – Nov, Feb, Mar	3 – Nov, Feb, Mar
1988-89	2 – Dec, Mar	2 – Dec, Mar
1989-90	3 – Dec, Feb, Mar	3 – Dec, Feb, Mar
1990-91	2 – Dec, Mar	2 – Dec, Mar
1991-92	3 – Nov, Feb, Mar	3 – Nov, Feb, Mar
1992-93	3 – Nov, Dec, Jan	3 – Nov, Dec, Jan
1993-94	1 – Nov	1 – Nov
1994-95	1 – Mar	1 – Mar
1995-96	1 – Jan	1 – Jan
1996-97 [b]	4 – Oct, Nov, Mar, Apr	3 – Oct, Nov, Apr
1997-98 [c]	3 – Nov, Jan, Mar	2 – Jan, Mar
1998-99 [d]	1 – Mar	2 – Nov, Mar
1999-00	3 – Nov, Jan, Mar	3 – Nov, Jan, Mar
2000-01	1 – Nov	1 – Nov
2001-02	3 – Nov, Dec, Apr	3 – Nov, Dec, Apr
2002-03	2 – Dec, Mar	2 – Dec, Mar
2003-04	2 – Feb, Mar	2 – Feb, Mar

Table 2.2.3.1. Crop types and numbers of fields that received fertiliser application at the RSPB Loch Gruinart reserve during the summers of 1994 to 1999. Re-seeded grassland always received fertiliser and was not included in further analyses.

	Crop type	**Permanent pasture**		**Older grassland**		**Spring cereals**		**Re-seeds**		**Number of fields for analysis**
	Fertiliser	*Yes*	*No*	*Yes*	*No*	*Yes*	*No*	*Yes*	*No*	
Year										
1994/95		9	5	0	14	0	1	3	0	29
1995/96		10	5	1	12	0	2	2	0	30
1996/97		10	5	1	11	0	2	1	0	29
1997/98		10	5	1	11	0	2	2	0	29
1998/99		10	5	1	13	0	2	0	0	31
1999/2000		10	5	0	12	1	2	1	0	30

Table 2.3.1.1. Numbers of lethal and non-lethal shots fired on Islay each winter between 2000/01 and 2003/04, and distribution of shooting activity by month.

		% Annual total by month							
Type of shot	**Winter**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Total shots**	**Annual mean per holding**	**Annual mean per field**
Lethal	2000/01	0	<1	99	0	0	162	16.2	1.8
	2001/02	3	23	26	44	4	204	17	2.7
	2002/03	7	22	36	22	13	184	16.7	2.3
	2003/04	51	49	0	0	0	41	8.2	3.1
Non-lethal	2000/01	9	24	67	0	0	404	16.8	4.4
	2001/02	11	18	15	29	27	683	35.9	9.0
	2002/03	11	18	26	26	19	860	53.7	10.6
	2003/04	2	47	51	0	0	232	32.3	9.3

Table 2.3.2.1 Summary of the results of modelling to assess the effects of scaring on field use by Greenland White-fronted Geese (WG) and Greenland Barnacle Geese (BY) on Islay. Table numbers refer to individual tables in the appendix.

Table no.	Species	Model (and type; see methods section 2.3.2)	Winters (number of years)	Resolution	Result
A1	WG	Scaring v non-scaring (1)	2000/01-2003/04 (4)	3 years holding; 1 year field	No significant difference between zones.
A2	WG	'Scaring' v 'buffer' v 'feeding' (2)	2000/01-2003/04 (4)	3 years holding; 1 year field	No significant difference between zones.
A3	WG	Direct comparison of scaring type; shooting types only (3)	2000/01-2003/04 (4)	3 years holding; 1 year field	No significant effect of scaring type.
A4 & Fig. 3.3.1.1	WG	Direct comparison of scaring type; all types including non-shooting scaring (3)	2002/03-2003/04 (2)	1 year holding; 1 year field	Significant effect of scaring type and significant scaring type-by-year interaction (differences between types only evident in 2003/04; fields with all scaring types significantly less geese than expected relative to fields with no scaring but fields with non-lethal shooting only had more geese than expected relative to fields with no scaring).
A5	BY	Scaring v non-scaring (1)	2000/01-2003/04 (4)	3 years holding; 1 year field	Significantly less geese than expected in scaring areas compared to non-scaring areas; no significant interaction with year.
A6 & Fig. 3.3.2.1	BY	'Scaring' v 'buffer' v 'feeding' (2)	2000/01-2003/04 (4)	3 years holding; 1 year field	Significantly less geese than expected in 'scaring' areas compared to 'feeding' and 'buffer' areas (the latter two areas not differing significantly); no significant interaction with year.
A7 & Fig. 3.3.2.2	BY	Direct comparison of scaring type; shooting types only	2000/01-2003/04 (4)	3 years holding; 1 year field	Significant effect of scaring type and significant scaring type-by-year interaction; no significant effects of shooting type in 2001/02; lethal and non-lethal combined (but not non-lethal alone) resulted in

		(3)			significantly less geese than expected relative to non-scaring areas in 2000/01 and 2002/03; non-lethal alone (but not when in combination with lethal shooting) resulted in less geese than expected relative to non-scaring areas in 2003/04.
A8 & Fig. 3.3.2.3	BY	Direct comparison of scaring type; all types including non-shooting scaring (3)	2002/03-2003/04 (2)	1 year holding; 1 year field	Significant effect of scaring type; no significant interaction with year; non-shooting scaring alone, non-shooting scaring + non-lethal shooting, and lethal + non-lethal shooting all resulted in less geese than expected relative to non-scaring areas; non-lethal shooting alone and all scaring types combined did not differ in effect from either non-scaring areas or the other scaring groups.
A9	WG + BY	Scaring v non-scaring (1)	2000/01-2003/04 (4)	3 years holding; 1 year field	Significantly less geese than expected in scaring areas compared to non-scaring areas; no significant interaction with year.
A10 & Fig. 3.3.3.1	WG + BY	'Scaring' v 'buffer' v 'feeding' (2)	2000/01-2003/04 (4)	3 years holding; 1 year field	Significantly less geese than expected in 'scaring' areas and 'buffer' areas (which do not differ significantly) compared to 'feeding' areas. No significant interaction with year.
A11 & Fig. 3.3.3.2	WG + BY	Direct comparison of scaring type; shooting types only (3)	2000/01-2003/04 (4)	3 years holding; 1 year field	Significant effect of scaring type; no significant interaction with year; non-lethal and lethal + non-lethal shooting fields both have significantly less geese than expected compared to non-scaring fields (but shooting types do not differ significantly in their effects).
A12 & Fig. 3.3.3.3	WG + BY	Direct comparison of scaring type; all types including non-shooting scaring (3)	2002/03-2003/04 (2)	1 year holding; 1 year field	Significant effect of scaring type and significant scaring type-by-year interaction. No significant differences in effects of scaring types in 2003/04. In 2002/03, significantly less geese than expected in areas with non-shooting scaring alone, and non-shooting scaring + non-lethal shooting, compared to areas with no scaring; other scaring combinations do not differ from either non-scaring areas or the other scaring types.

Table 2.3.2.2. The number of fields / holdings in which the database shows that lethal shooting, non-lethal shooting, and non-shooting scaring were used during the four winters of the current Goose Management Scheme on Islay. For the winter of 2003/04, the numbers of fields in each category in which Barnacle Geese (BY) and White-fronted Geese (WG) were recorded over that winter (not at the time of the specific shooting events) are also shown.

Winter	**Non-lethal shooting only**	**Lethal and non-lethal shooting**	**Non-shooting scaring only**	**Non-shooting scaring and non-lethal shooting**	**Non-shooting scaring, lethal and non-lethal shooting**
2000/01	19 holdings	10 holdings			
2001/02	13 holdings	15 holdings			
2002/03	13 holdings	9 holdings	5 holdings	2 holdings	3 holdings
2003/04 (all)	5 fields	7 fields	35 fields	7 fields	6 fields
2003/04 (BY)	5 fields	7 fields	20 fields	6 fields	4 fields
2003/04 (WG)	5 fields	6 fields	19 fields	6 fields	4 fields

Table 2.3.2.3. The number of fields within the 'feeding', 'scaring' and 'buffer' zones on Islay for each winter between 2000/01 and 2003/04.

	Winter			
	2000/01	**2001/02**	**2002/03**	**2003/04**
'Feeding' fields	3075	3078	3067	3075
'Scaring' fields	55	54	56	55
'Buffer' fields	40	38	47	40
'Scaring' and 'buffer' fields combined	95	92	103	95

Table 3.1.3.1. Percentage changes in numbers of Greenland Barnacle and Greenland White-fronted Goose on Islay, calculated by subtracting the estimated population size from the GAM (F_{all} trend) at the start of the period from that of 2002/03; orange values signify a 'medium increase' and red values signify a 'high increase', as per the WeBS alerts system (McLean *et al.* 2005). Asterisks indicate a significant change between any given winter and the winter of 2002/03 based on the bootstrapped 95% confidence intervals from the GAMs.

Year	Barnacle Goose	White-fronted Goose
1984/85	100.2*	127.2*
1985/86	93.0*	103.4*
1986/87	85.5*	86.0*
1987/88	77.6*	66.7*
1988/89	69.0*	52.8*
1989/90	60.0*	40.8*
1990/91	51.9*	30.3*
1991/92	45.7*	21.0*
1992/93	40.9*	12.7*
1993/94	36.8*	5.3
1994/95	33.0*	-1.0
1995/96	29.3*	-6.1
1996/97	25.6*	-9.3
1997/98	21.9*	-11.1
1998/99	18.3*	-11.7
1999/2000	14.7*	-10.9
2000/01	10.8	-8.5
2001/02	6.0	-4.7
2002/03	0.0	0.0

Table 3.1.3.2. Percentage changes in numbers of geese on Islay calculated by subtracting the GAM trend value at the start of the period from that of 2002-03; orange values signify a 'medium increase' and red values signify a 'high increase', as per the WeBS alerts system (McLean *et al.* 2005). Trends are shown for 5 (1997/98 to 2002/03), 10 (1992/93 to 2002/03), 15 (1987/88 to 2002/03) and 18 (1984/85 to 2002/03) years, using all paired counts (F_{all}) or counts from just day one (F_1) or day two (F_2). Asterisks indicate significant changes based on the bootstrapped 95% confidence limits from the GAMs.

		5 year	10 years	15 years	18 years
White-fronted Goose	F_{all}	-13	+11*	+65*	+123*
	F_1	-10*	+13*	+61*	+117*
	F_2	-15*	+10*	+65*	+120*
Barnacle Goose	F_{all}	+26*	+46*	+81*	+106*
	F_1	+25*	+47*	+83*	+111*
	F_2	+24*	+43*	+79*	+110*

Table 3.2.1.1. Minimal supported GLM for field use by Greenland White-fronted Goose (whole-island analysis). The model used a Negative Binomial error distribution (and logarithmic link function), controlled for the repeated measure of field number and included an offset (the natural log of the number of counts per month). Crop types were regrouped to two levels only: group 1 = bog areas; and group 2 = improved grassland (including re-seeded fields), permanent pasture, and *Juncus* fields combined (see Table A16 for rationale). Means and s.e. are presented for the coefficients.

Term		**Coefficient**	**d.o.f.**	χ^2	***p*-value**
Intercept		1.07 ± 0.15			
Crop type	group 1	-2.52 ± 0.51	1	23.96	<0.0001
	group 2	0			
Distance to nearest loch		-0.000204 ± 0.000055	1	13.87	0.0002
Distance to nearest road		-0.000769 ± 0.000090	1	72.46	<0.0001
Distance to nearest roost site		0.000114 ± 0.000040	1	8.18	0.0042
Month	November	0.389 ± 0.119	4	41.56	<0.0001
	December	0.143 ± 0.099			
	January	-0.230 ± 0.081			
	February	-0.222 ± 0.073			
	March	0			
Gradient		-0.0480 ± 0.0202	1	29.73	<0.0001
Mean goose count		0.000103 ± 0.000009	1	136.68	<0.0001
Field area		0.000000500 ± 0.000000210	1	5.67	0.0172
Gradient-by-month	November	-0.1612 ± 0.0303	4	50.77	<0.0001
	December	-0.1015 ± 0.0239			
	January	-0.0068 ± 0.0182			
	February	0.0230 ± 0.0154			
	March	0			
Distance to nearest road-by-month	November	0.000373 ± 0.000130	4	10.74	0.0297
	December	0.000324 ± 0.000126			
	January	0.000182 ± 0.000096			
	February	0.000128 ± 0.000094			
	March	0			
Excluded terms					
Degree of undulation			1	0.32	0.57
Distance to nearest wood			1	0.53	0.47
Month-by-distance to roost sites			4	2.95	0.57
Month-by-distance to woodland			4	5.07	0.28

Table 3.2.2.1. Minimal supported GLM for field use by Greenland Barnacle Goose (whole-island analysis). The model used a Negative Binomial error distribution (and logarithmic link function), controlled for the repeated measure of field number and included an offset (the natural log of the number of counts per month). Crop types were regrouped to four levels (see Table A18 for rationale). Means and s.e. are presented for the coefficients.

Term		Coefficient	d.o.f.	χ^2	*p*-value
Intercept		2.32 ± 0.35			
Crop type	Older grassland	-1.15 ± 0.21	3	82.07	<0.0001
	Juncus	-0.643 ± 0.345			
	Pasture	-3.27 ± 0.36			
	Re-seeds	0			
Distance to nearest loch		-0.000138 ± 0.000064	1	4.55	0.0329
Distance to nearest wood		0.000167 ± 0.000067	1	6.28	0.0122
Distance to nearest road		0.0000284 ± 0.0001630	1	0.03	0.8617
Distance to nearest roost site		-0.000167 ± 0.000030	1	31.20	<0.0001
Month	November	0.591 ± 0.196	4	17.96	0.0013
	December	0.326 ± 0.173			
	January	-0.0018 ± 0.1481			
	February	-0.147 ± 0.136			
	March	0			
Gradient		-0.0938 ± 0.0469	1	15.08	<0.0001
Degree of undulation		-0.0250 ± 0.0094	1	7.03	0.0080
Mean goose count		0.0000786 ± 0.0000084	1	87.94	<0.0001
Field area		0.00000735 ± 0.00000046	1	250.76	<0.0001
Gradient-by-month	November	-0.179 ± 0.053	4	13.82	0.0079
	December	-0.0303 ± 0.0452			
	January	-0.0093 ± 0.357			
	February	-0.0082 ± 0.0332			
	March	0			
Distance to nearest road-by-month	November	-0.0000986 ± 0.0001457	4	16.44	0.0025
	December	-0.000237 ± 0.000172			
	January	-0.000432 ± 0.000132			
	February	-0.00000157 ± 0.00012447			
	March	0			
Distance to roost sites-by-month	November	-0.0000253 ± 0.0000347	4	10.26	0.0362
	December	-0.0000449 ± 0.0000356			
	January	0.0000464 ± 0.0000322			
	February	0.0000261 ± 0.0000262			
	March	0			
Excluded terms					
Crop type-by-month			12	13.26	0.35
Distance to woodland-by-month			4	6.50	0.16

Table 3.2.3.1. Global GLM for field use by Greenland White-fronted Goose on the Loch Gruinart RSPB reserve. The model used a Negative Binomial error distribution (and logarithmic link function), controlled for the repeated measure of field number. Means and s.e. are presented for the coefficients.

Term		**Coefficient**	**d.o.f.**	χ^2	***p*-value**
Intercept		-2.17 ± 0.45			
Crop type	Grassland	0.52 ± 0.52	2	20.11	<0.0001
	Permanent pasture	1.79 ± 0.36			
	Spring cereals	0			
Month	Nov	3.68 ± 0.45	4	52.61	<0.0001
	Dec	1.98 ± 0.68			
	Jan	1.22 ± 0.92			
	Feb	1.58 ±0.60			
	Mar	0			
Year	1994/95	-0.54 ±0.90	5	15.47	0.0085
	1995/96	1.15 ± 0.49			
	1996/97	0.59 ± 0.85			
	1997/98	-0.23 ± 0.62			
	1998/99	-0.58 ± 0.79			
	1999/2000	0			
Fertiliser use	No	4.14 ± 0.62	1	27.36	<0.0001
	Yes	0			
Fertiliser use-by-month	Nov – no fertiliser	-4.07 ± 0.64	4	65.48	<0.0001
	Dec – no fertiliser	-1.64 ± 0.71			
	Jan – no fertiliser	-1.74 ± 1.08			
	Feb – no fertiliser	-2.09 ± 0.66			
	Mar – no fertiliser	0			
Fertiliser use-by-year	1994/95 – no fertiliser	-1.25 ± 1.04	5	16.19	0.0063
	1995/96 – no fertiliser	-2.07 ± 0.69			
	1996/97 – no fertiliser	-0.64 ± 0.99			
	1997/98 – no fertiliser	-0.64 ± 0.72			
	1998/99 – no fertiliser	0.84 ± 0.81			
	1999/2000 – no fertiliser	0			
Non-significant terms					
Fertiliser use-by-crop type	Grassland – no fertiliser	0.99 ± 0.77	2	5.84	0.0540
	Pasture – no fertiliser	-0.39 ± 0.72			
	Cereals – no fertiliser	0			

Table 3.2.3.2. Global GLM for field use by Greenland Barnacle Goose on the Loch Gruinart RSPB reserve. The model used a Negative Binomial error distribution (and logarithmic link function), controlled for the repeated measure of field number. Means and s.e. are presented for the coefficients. Note that the fertiliser use-by-crop type interaction could not be included in the model as it resulted in non-convergence of the algorithm.

Term		Coefficient	d.o.f.	χ^2	*p*-value
Intercept		5.92 ± 0.86			
	Grassland	1.34 ± 0.68			
Crop type	Permanent pasture	-0.82 ± 0.71	2	12.52	0.0019
	Spring cereals	0			
	Nov	-0.87 ± 0.66			
	Dec	-1.18 ± 0.35			
Month	Jan	0.10 ± 0.42	4	9.56	0.0485
	Feb	-0.18 ± 0.48			
	Mar	0			
	1994/95	-0.88 ± 0.76			
	1995/96	0.67 ± 0.50			
	1996/97	1.37 ± 0.51			
Year	1997/98	-0.17 ± 0.46	5	23.38	0.0003
	1998/99	0.45 ± 0.57			
	1999/2000	0			
Fertiliser use	No	-2.86	1	7.01	0.0081
	Yes	0			
	Nov – no fertiliser	1.55 ± 0.80			
	Dec – no fertiliser	1.74 ± 0.50			
Fertiliser use-by-month	Jan – no fertiliser	-0.03 ± 0.57	4	20.88	0.0003
	Feb – no fertiliser	0.91 ± 0.78			
	Mar – no fertiliser	0			
Non-significant terms					
	1994/95 – no fertiliser	1.99 ± 1.15			
	1995/96 – no fertiliser	0.24 ± 0.69			
Fertiliser use-by-year	1996/97 – no fertiliser	-1.17 ± 0.79	5	10.22	0.0693
	1997/98 – no fertiliser	-0.12 ± 0.74			
	1998/99 – no fertiliser	-0.05 ± 0.62			
	1999/2000 – no fertiliser	0			

Table 3.4.1. Summary statistics used to investigate whether there was a difference in the distribution of Greenland White-fronted Geese on Islay between winters in which scaring was not permitted (1992/93 – 1999/2000; n=8) and winters in which scaring took place (2000/01 – 2003/04; n=4).
(a) Goose ‘density’ (mean number of geese per field), the number of fields occupied by geese, and the number of 1-km squares occupied by geese for each International Paired Count date; and (b) data summarized across years (all winter months pooled) and by month across years for the two periods.

(a)

Non-scaring years (1992/93 to 1999/2000)				**Scaring years (2000/01 to 2001/02)**			
Count date	**‘Density’**	**N occupied fields**	**N occupied 1-km squares**	**Count date**	**‘Density’**	**N occupied fields**	**N occupied 1-km squares**
08/11/1992	99	104	65	13/11/2000	147	96	83
09/11/1992	104	86	60	14/11/2000	169	74	84
08/12/1992	103	83	62	16/01/2001	183	61	102
12/12/1992	124	77	70	08/11/2001	129	69	80
13/12/1992	136	59	76	09/11/2001	101	90	63
22/12/1992	116	77	77	10/11/2001	20	116	14
24/01/1993	167	41	97	10/12/2001	162	71	86
25/01/1993	188	40	106	11/12/2001	142	86	87
15/02/1993	160	47	82	02/04/2002	224	41	121
04/03/1993	128	78	88	03/04/2002	193	48	110
07/03/1993	164	62	93	19/11/2002	115	86	67
30/03/1993	185	46	101	09/12/2002	176	68	100
14/04/1993	139	65	84	10/12/2002	174	64	95
27/11/1993	124	93	69	31/03/2003	177	61	88
28/11/1993	143	76	85	01/04/2003	210	49	117
11/01/1994	157	57	98	10/11/2003	110	88	66
14/01/1994	144	48	81	10/12/2003	137	77	76
29/03/1994	219	43	120	10/02/2004	172	50	108
29/11/1994	101	100	59	11/02/2004	148	45	92
11/01/1995	176	58	107	30/03/2004	142	55	73
28/03/1995	276	34	144	31/03/2004	155	51	84
29/03/1995	228	43	111				
14/11/1995	141	111	84				
10/01/1996	182	66	96				
11/01/1996	208	67	105				
29/10/1996	97	102	61				
30/10/1996	106	105	79				
18/11/1996	134	91	82				
19/11/1996	153	87	90				
03/03/1997	193	48	96				
01/04/1997	202	41	100				
02/04/1997	183	47	94				
17/11/1997	160	79	95				
13/01/1998	174	68	104				
14/01/1998	207	63	120				
31/03/1998	168	71	98				
01/04/1998	195	52	93				
17/11/1998	162	79	108				

18/11/1998	136	95	94
29/03/1999	273	47	135
30/03/1999	288	48	127
13/11/1999	137	102	82
14/11/1999	119	111	67
11/01/2000	235	41	133
12/01/2000	243	44	126
28/03/2000	210	50	111
29/03/2000	233	50	116

(b)

		Means (range; number of counts)		
		'Density'	**N occupied fields**	**N occupied 1-km squares**
No scaring (1992/93 – 1999/2000)	**All months**	165 (149 – 181; 31)	67 (61 – 74; 31)	93 (86 – 100; 31)
	Oct	102 (1)	104 (1)	70 (1)
	Nov	129 (8)	93 (8)	78 (8)
	Dec	123 (3)	73 (3)	75 (3)
	Jan	183 (7)	54 (7)	104 (7)
	Feb	160 (1)	47 (1)	82 (1)
	Mar	205 (8)	52 (8)	109 (8)
	Apr	174 (3)	53 (3)	92 (3)
With scaring (2000/01 – 2003/04)	**All months**	149 (121 – 178; 12)	70 (58 – 82; 12)	85 (69 – 100; 12)
	Oct	(0)	(0)	(0)
	Nov	102 (4)	92 (4)	59 (4)
	Dec	161 (3)	72 (3)	90 (3)
	Jan	183 (1)	61 (1)	102 (1)
	Feb	160 (1)	48 (1)	100 (1)
	Mar	149 (1)	53 (1)	79 (1)
	Apr	205 (2)	46 (2)	115 (2)

Table 3.4.2. Summary statistics used to investigate whether there was a difference in the distribution of Greenland Barnacle Geese on Islay between winters in which scaring was not permitted (1992/93 – 1999/2000; n=8) and winters in which scaring took place (2000/01 – 2003/04; n=4).
(a) Goose 'density' (mean number of geese per field), the number of fields occupied by geese, and the number of 1-km squares occupied by geese for each International Paired Count date; and (b) data summarized across years (all winter months pooled) and by month across years for the two periods.

(a)

Non-scaring years (1992/93 to 1999/2000)				Scaring years (2000/01 to 2001/02)			
Count date	'Density'	N occupied fields	N occupied 1-km squares	Count date	'Density'	N occupied fields	N occupied 1-km squares
08/11/1992	447	45	24	13/11/2000	464	82	44
09/11/1992	419	54	30	14/11/2000	371	88	52
08/12/1992	362	58	30	15/01/2001	2217	16	11
12/12/1992	441	55	33	16/01/2001	405	90	53
13/12/1992	311	82	42	08/11/2001	369	87	55
22/12/1992	349	59	37	09/11/2001	620	55	37
24/01/1993	122	139	82	11/12/2001	366	94	47
25/01/1993	148	147	74	02/04/2002	233	136	52
15/02/1993	232	109	52	03/04/2002	224	145	70
04/03/1993	326	62	36	19/11/2002	363	70	82
07/03/1993	338	85	44	09/12/2002	283	118	66
30/03/1993	143	137	70	10/12/2002	304	110	63
14/04/1993	225	93	46	31/03/2003	329	111	64
27/11/1993	453	56	31	10/11/2003	790	63	36
28/11/1993	396	61	37	10/12/2003	541	71	38
14/01/1994	334	85	49	10/02/2004	278	132	74
29/03/1994	200	128	66	11/02/2004	403	95	53
29/11/1994	450	50	24	30/03/2004	302	108	63
11/01/1995	330	85	49	31/03/2004	266	106	57
28/03/1995	176	164	77				
29/03/1995	216	124	60				
14/11/1995	400	61	40				
10/01/1996	378	82	41				
11/01/1996	328	95	52				
29/10/1996	627	51	32				
30/10/1996	471	63	41				
18/11/1996	378	78	54				
19/11/1996	345	93	53				
03/03/1997	318	99	58				
01/04/1997	222	130	66				
02/04/1997	330	104	53				
17/11/1997	380	82	53				
18/11/1997	446	71	38				
13/01/1998	464	73	47				
14/01/1998	386	80	49				
31/03/1998	307	103	55				
01/04/1998	245	105	59				

18/11/1998	427	84	54
29/03/1999	241	145	69
30/03/1999	256	138	64
13/11/1999	531	69	40
14/11/1999	481	69	42
11/01/2000	242	134	75
12/01/2000	207	150	74
28/03/2000	248	120	57

(b)

		Means (range; number of counts)		
		'Density'	**N occupied fields**	**N occupied 1-km squares**
No scaring (1992/93 – 1999/2000)	**All months**	331 (296 – 367; 32)	90 (80 – 101; 31)	49 (44-54; 32)
	Oct	549 (1)	57 (1)	37 (1)
	Nov	427 (8)	67 (8)	40 (8)
	Dec	382 (4)	60 (4)	34 (4)
	Jan	301 (6)	103 (6)	58 (6)
	Feb	232 (1)	109 (1)	52 (1)
	Mar	259 (9)	113 (9)	58 (9)
	Apr	249 (3)	105 (3)	55 (3)
With scaring (2000/01 – 2003/04)	**All months**	362 (317 – 407; 11)	98 (86 – 111; 11)	58 (52 – 64; 11)
	Oct	(0)	(0)	(0)
	Nov	425 (3)	75 (3)	59 (3)
	Dec	374 (3)	98 (3)	54 (3)
	Jan	405 (1)	90 (1)	53 (1)
	Feb	341 (1)	114 (1)	64 (1)
	Mar	306 (2)	109 (2)	62 (2)
	Apr	228 (1)	141 (1)	61 (1)

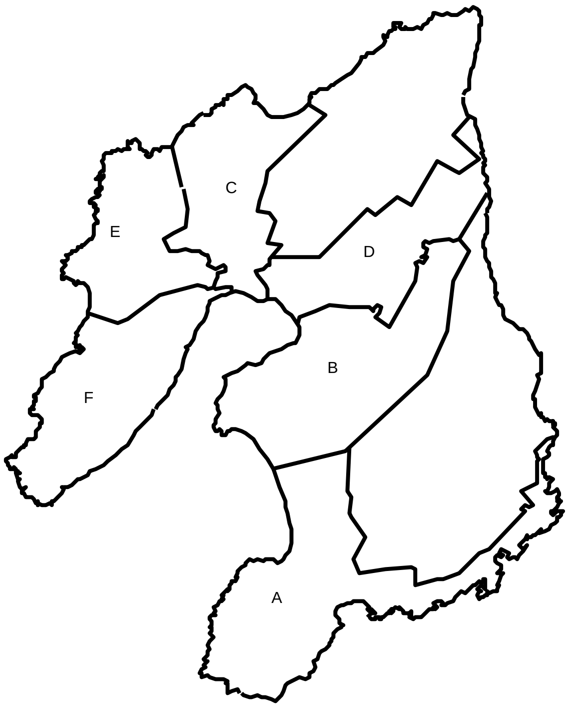

Figure 1.5.1. Map of Islay showing the 6 survey areas used for counting by the Islay Local Goose Management Group.

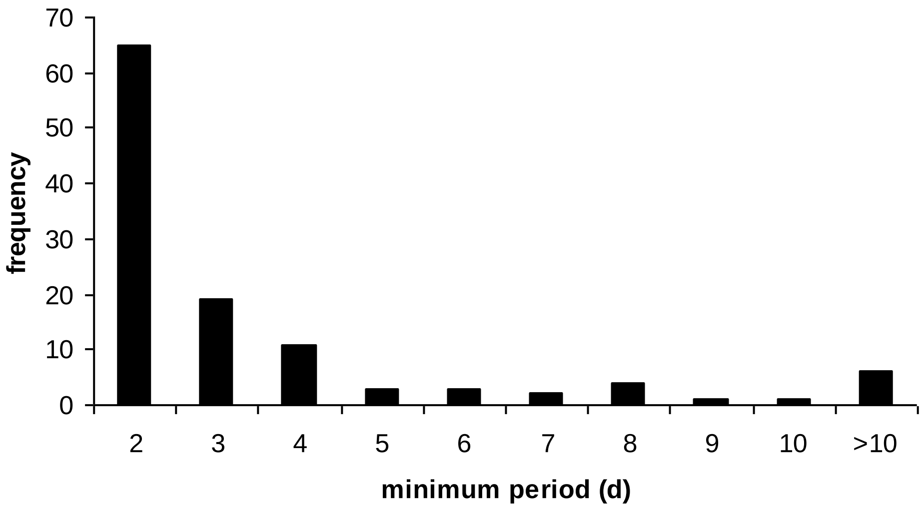

Figure 2.1.3.1. Frequency distribution of the minimum periods during which the whole island was surveyed during Goose Management 'Scheme Counts'.

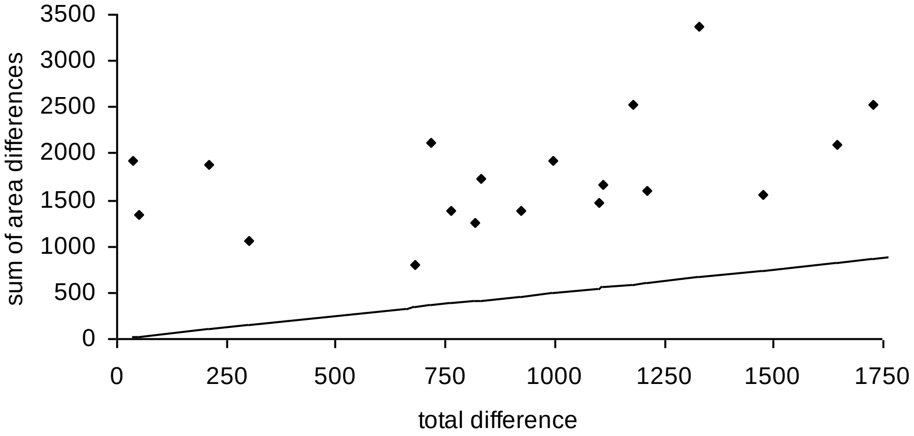

Figure 2.1.3.2. Sum of differences between consecutive-day counts (divided by two) for each of the six count areas against the total difference between the counts on these two days, for Greenland White-fronted Goose. The line shows the (y = 0.5 x) line.

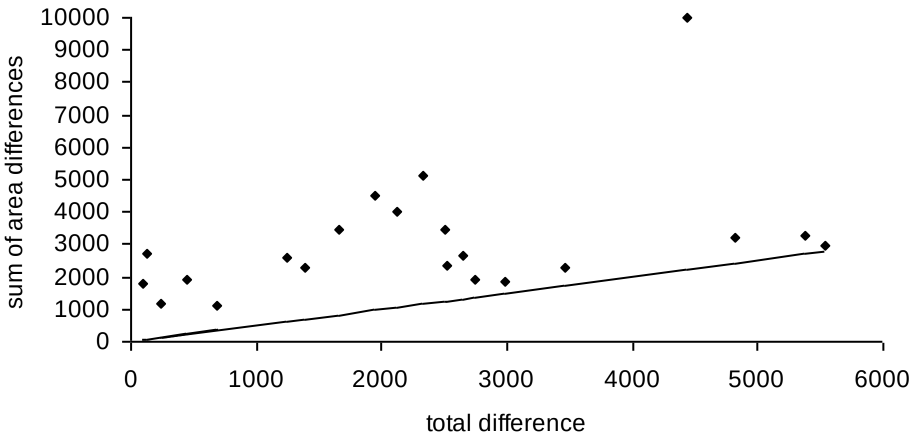

Figure 2.1.3.3. Sum of differences between consecutive-day counts (divided by two) for each of the six count areas against the total difference between the counts on these two days, for Greenland Barnacle Goose. The line shows the (y = 0.5 x) line.

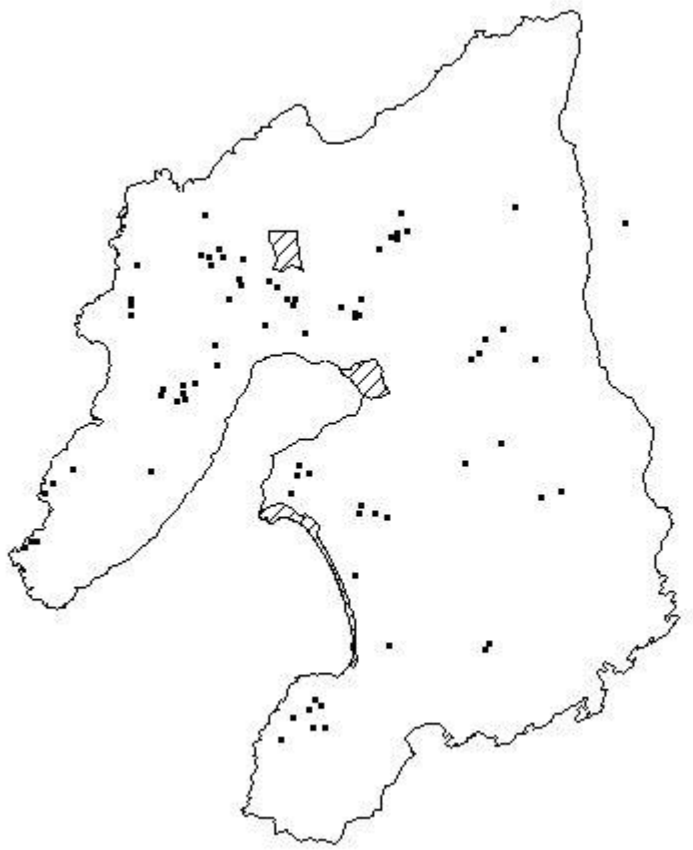

Figure 2.2.2.1. Map of Islay showing the locations used as roost sites for Greenland White-fronted Goose (dots; after Ridgill *et al.* 1994) and Greenland Barnacle Goose (shaded areas; information from M.A. Ogilvie & M. Morris). Note that the point east of Islay is a Greenland White-fronted Goose roost on Jura.

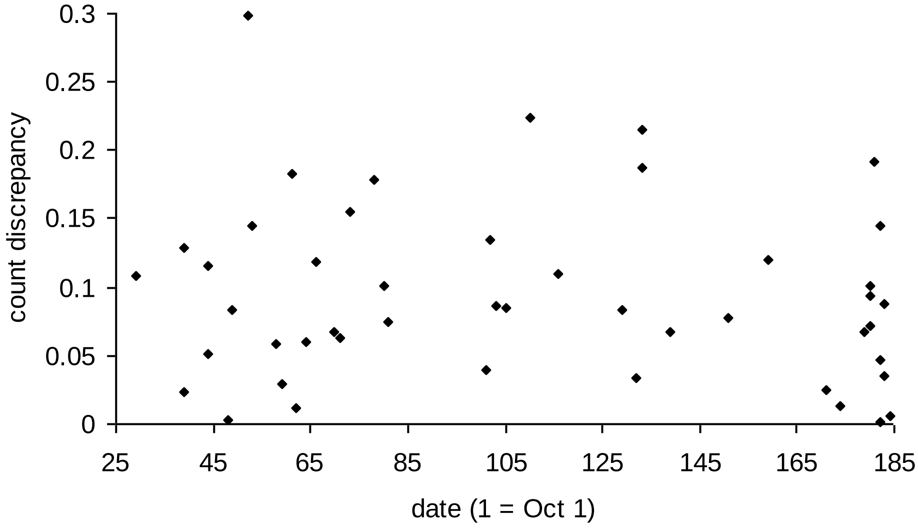

Figure 3.1.1.1. Variation in proportional 'count discrepancy' with date within the winter for Greenland White-fronted Goose (data for 1987/88 to 2003/04 pooled).

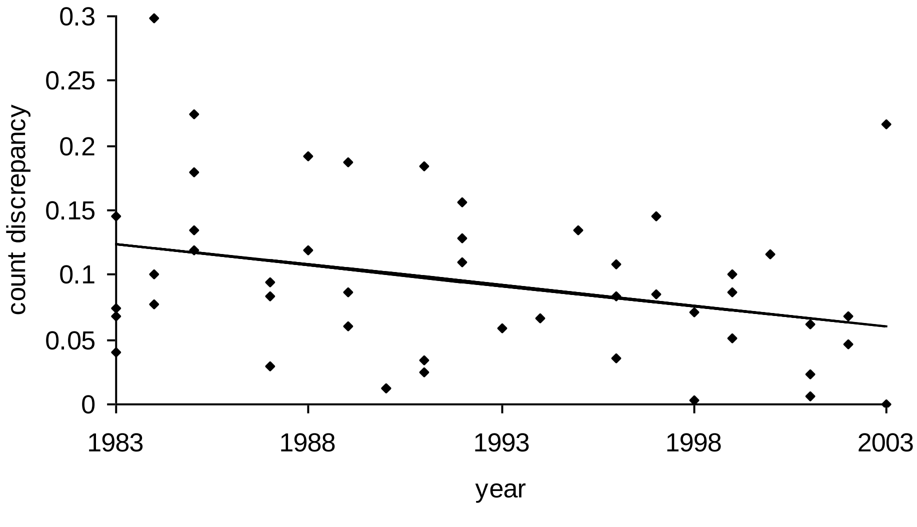

Figure 3.1.1.2. Variation in proportional 'count discrepancy' with year for Greenland White-fronted Goose (data for the winters of 1987/88 to 2003/04 pooled).

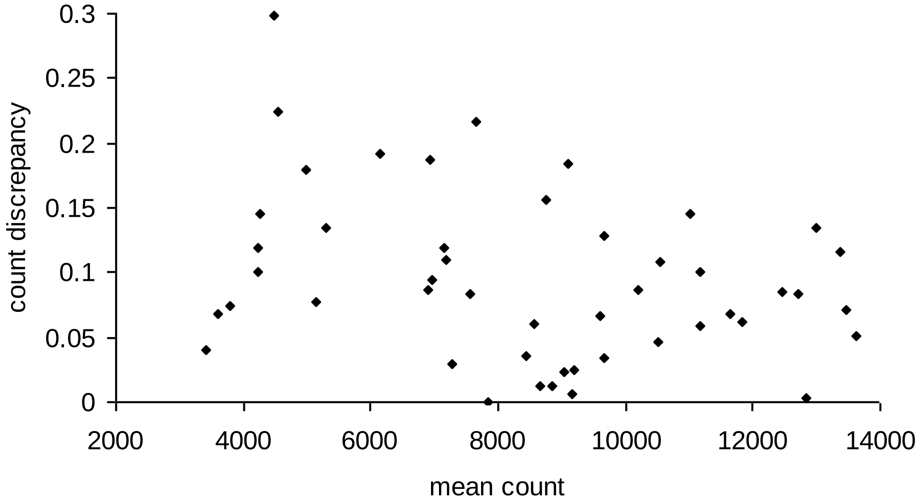

Figure 3.1.1.3. Variation in proportional 'count discrepancy' with mean count for Greenland White-fronted Goose (data for the winters of 1987/88 to 2003/04 pooled).

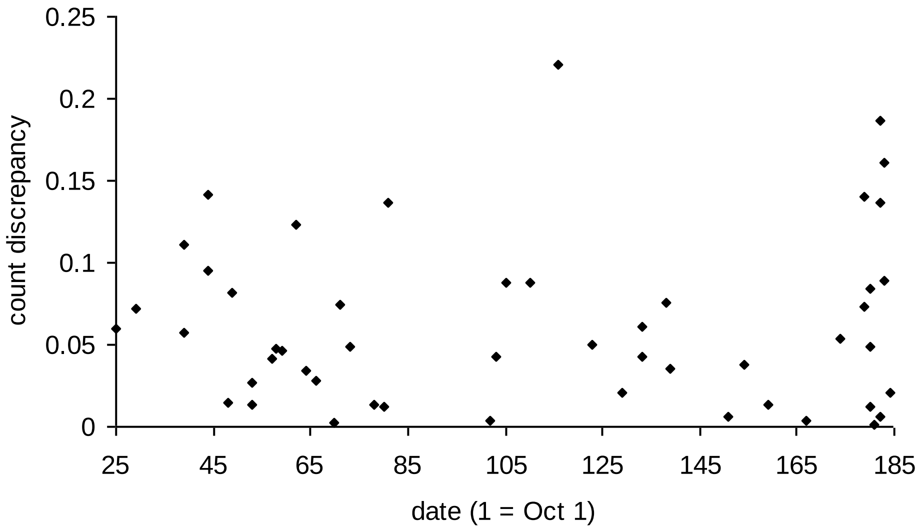

Figure 3.1.1.4. Variation in proportional 'count discrepancy' with date within winter for Greenland Barnacle Goose (data for 1987/88 to 2003/04 pooled).

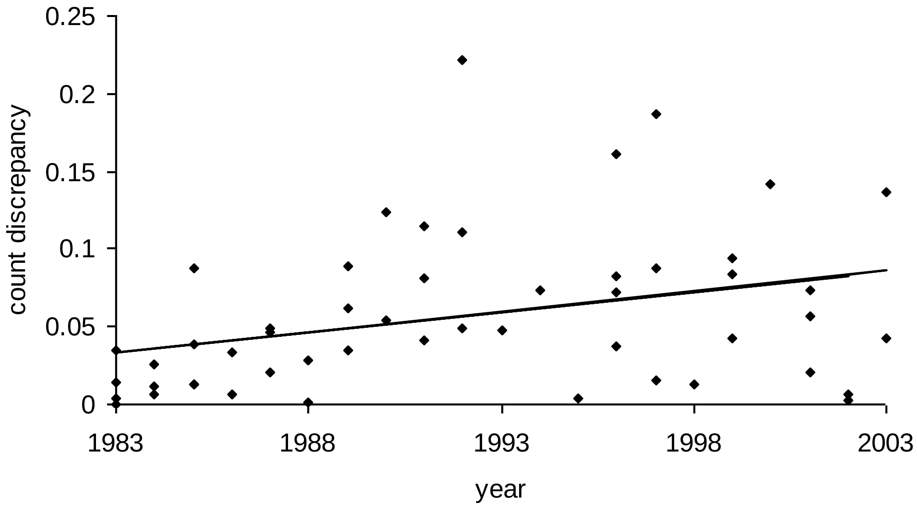

Figure 3.1.1.5. Variation in proportional 'count discrepancy' with year for Greenland Barnacle Goose (data for the winters of 1987/88 to 2003/04 pooled).

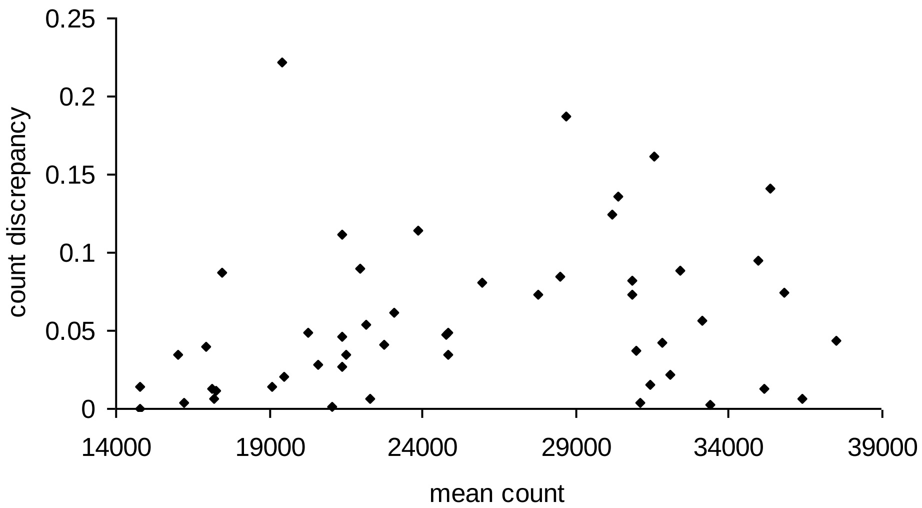

Figure 3.1.1.6. Variation in proportional 'count discrepancy' with mean count for Greenland Barnacle Goose (data for the winters of 1987/88 to 2003/04 pooled).

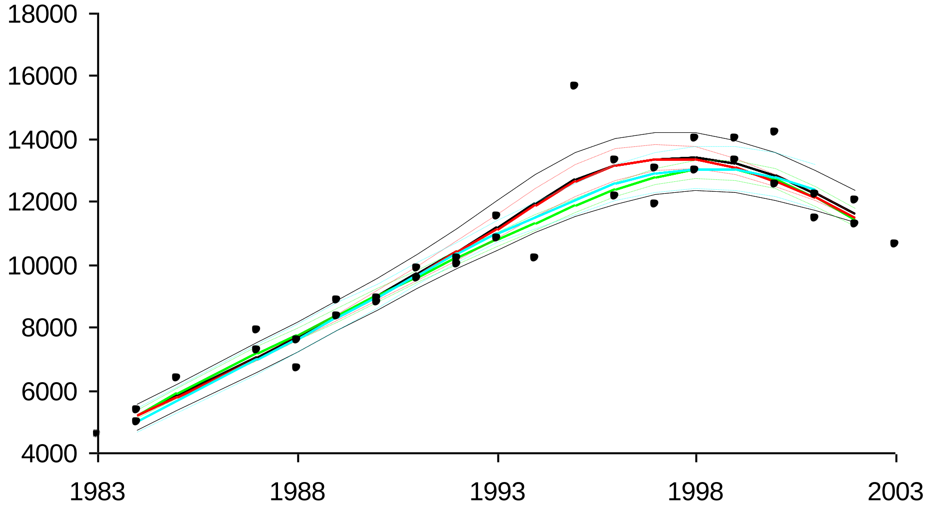

Figure 3.1.3.1. Smoothed population trends for Greenland White-fronted Goose (GAMs of maximum annual counts). Black line: F_{all}. Blue line: F_{pairs}. Green line: F_1. Red line: F_2. Dashed lines: 95% confidence intervals. See text for further explanation.

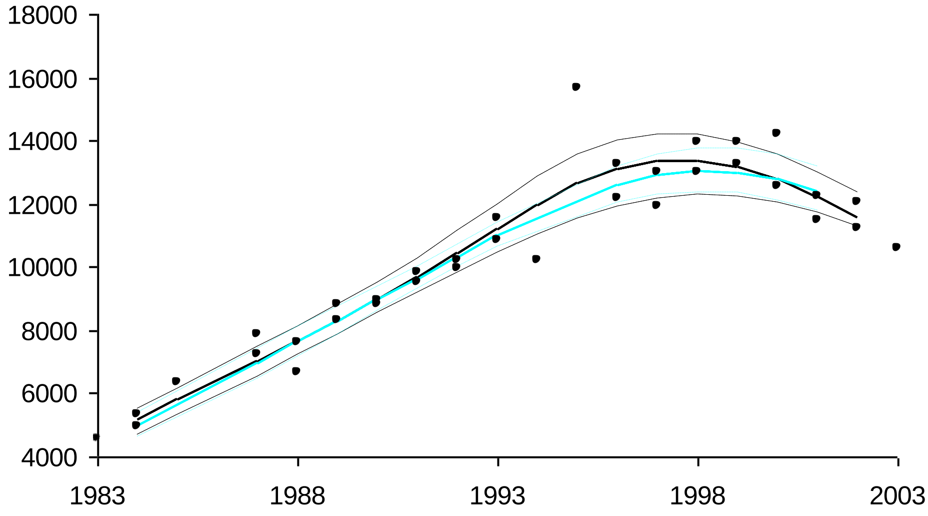

Figure 3.1.3.2. Smoothed population trends for Greenland White-fronted Goose (GAMs of maximum annual counts). Black line: F_{all}. Blue line: F_{pairs}. Dashed lines: 95% confidence intervals. See text for further explanation.

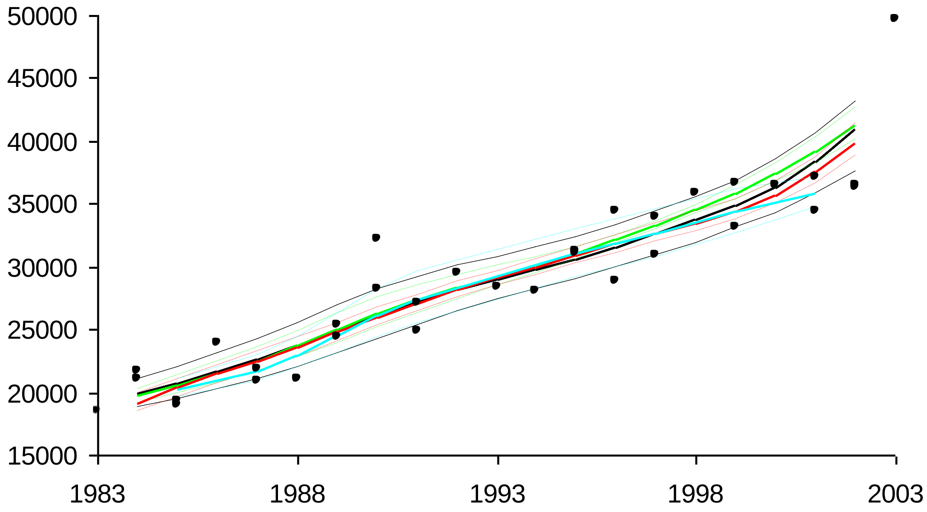

Figure 3.1.4.1. Smoothed population trends for Greenland Barnacle Goose (GAMs of maximum annual counts). Black line: F_{all}. Blue line: F_{pairs}. Green line: F_1. Red line: F_2. Dashed lines: 95% confidence intervals. See text for further explanation.

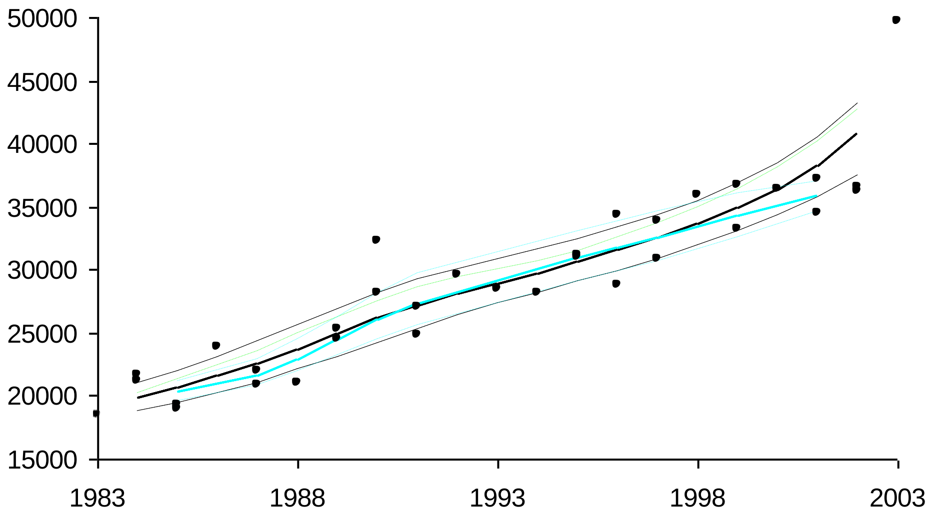

Figure 3.1.4.2. Smoothed population trends for Greenland Barnacle Goose (GAMs of maximum annual counts). Black line: F_{all}. Blue line: F_{pairs}. Dashed lines: 95% confidence intervals. See text for further explanation.

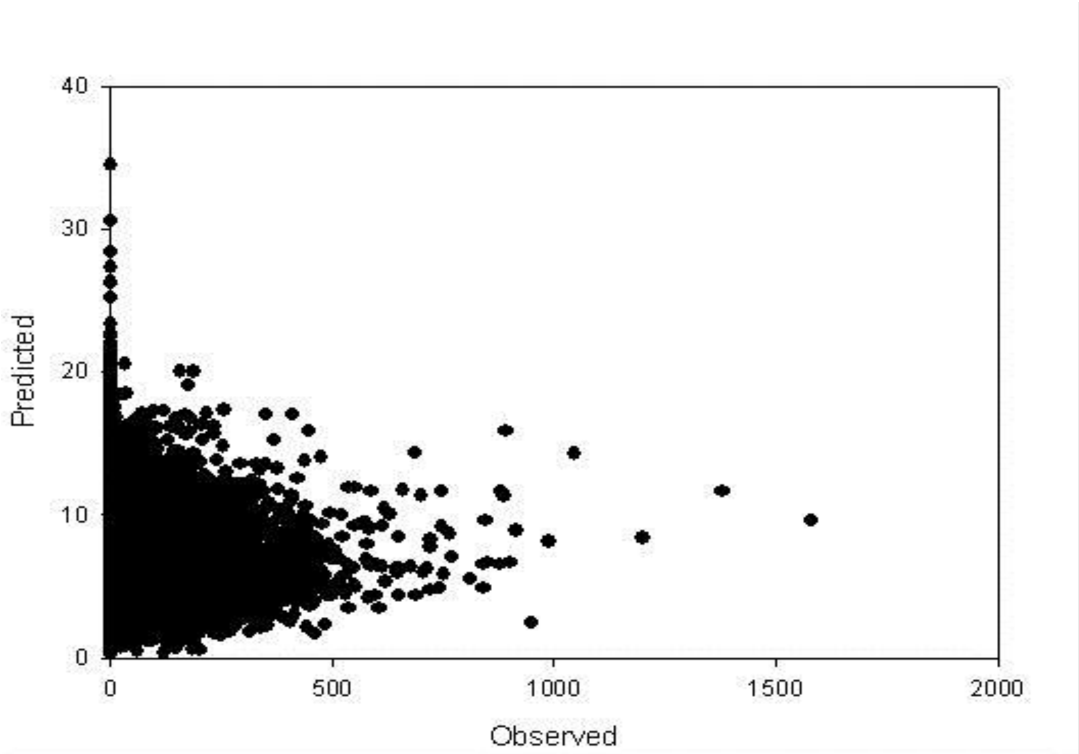

Figure 3.2.1.1. Predicted against observed values from the minimum supported field-use model for Greenland White-fronted Goose.

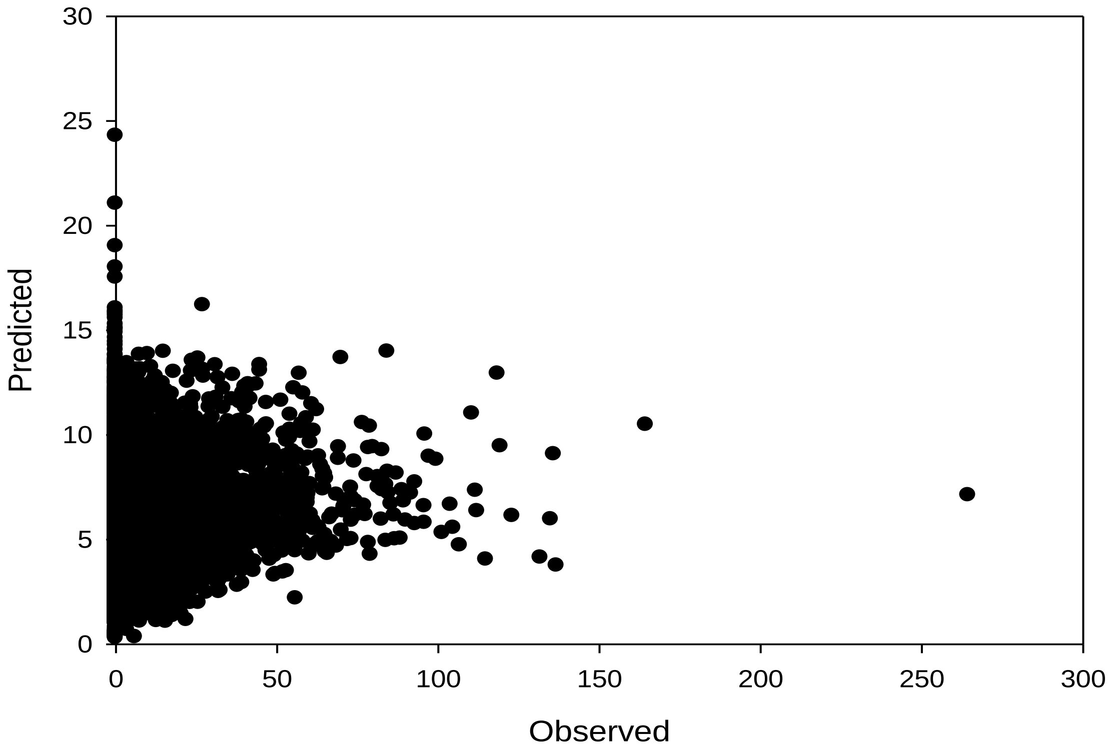

Figure 3.2.1.2. Predicted against observed values from the minimum supported field-use model for Greenland White-fronted Goose (after conversion to annual means; see text for further explanation).

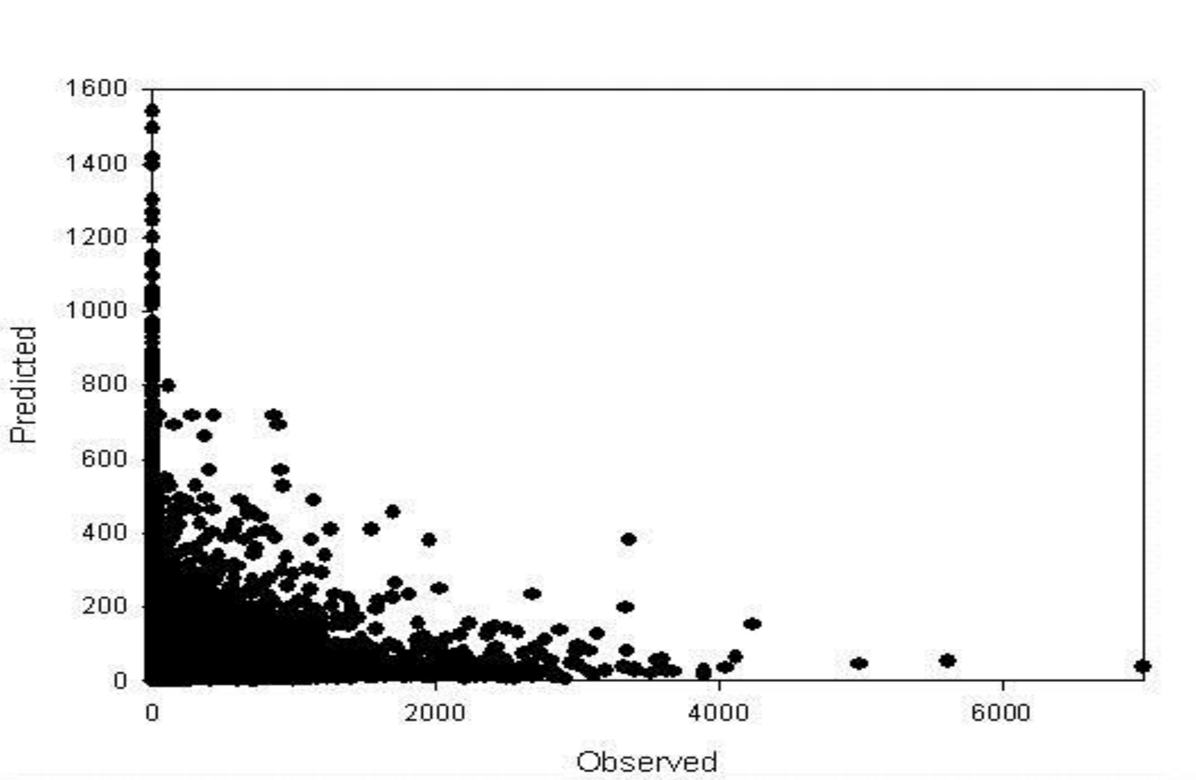

Figure 3.2.2.1. Predicted against observed values from the minimum supported field-use model for Greenland Barnacle Goose.

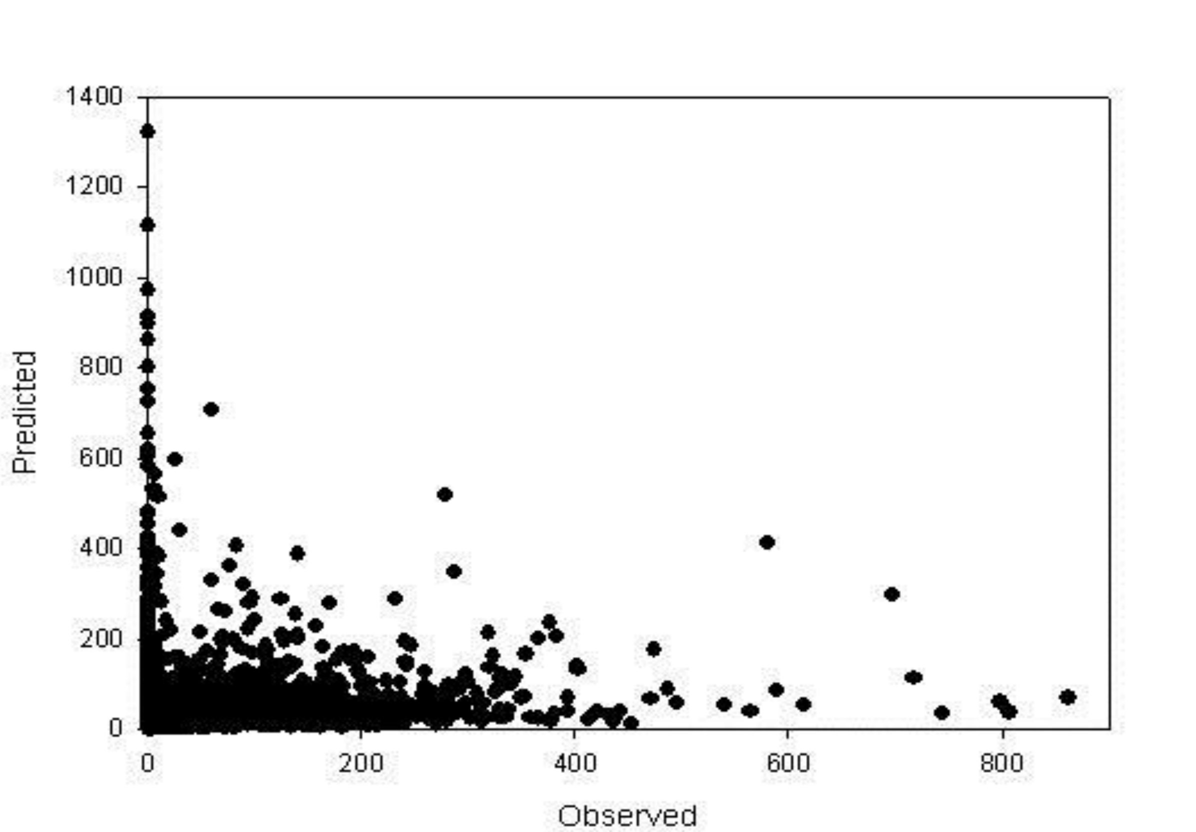

Figure 3.2.2.2. Predicted against observed values from the minimum supported field-use model for Greenland Barnacle Goose (after conversion to annual means; see text for further explanation).

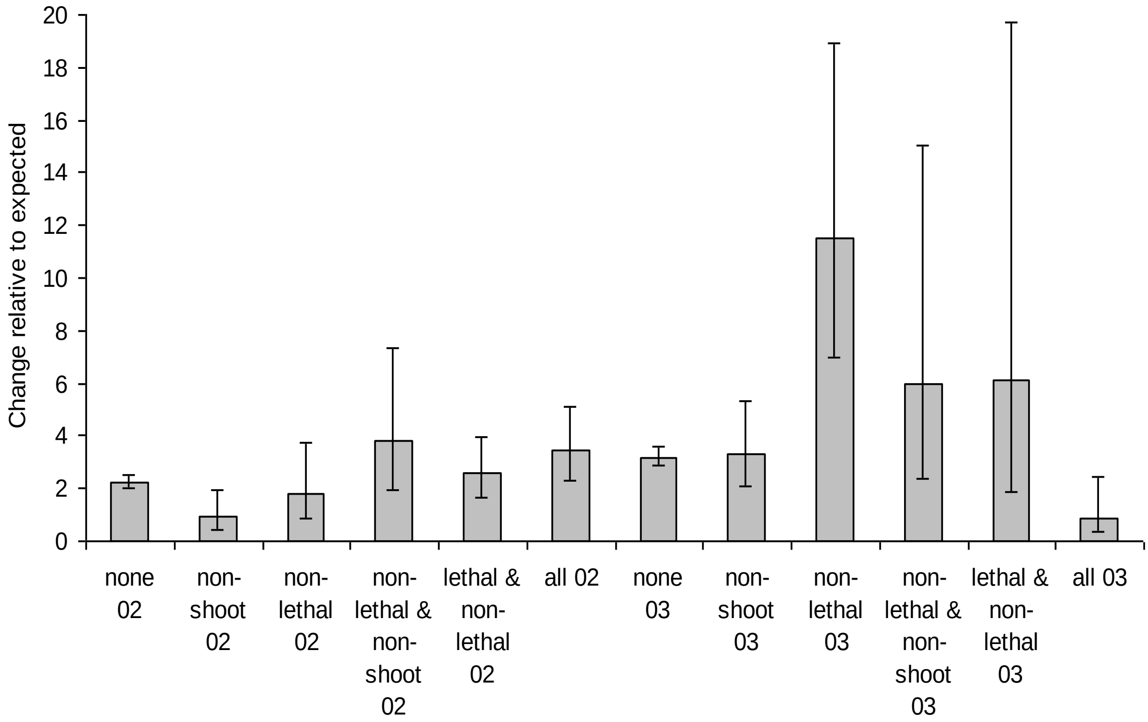

Figure 3.3.1.1. The change relative to expected (where no change = 1) for each scaring type-by-year interaction from the GLM for difference between predicted and observed counts (per year, as a proportion of the predicted count) for the winters of 2002/03 and 2003/04 for Greenland White-fronted Goose. (Key: 02 = 2002/03; 03 = 2003/04; none = no scaring; non-shoot = non-shooting scaring devices only; non-lethal = non-lethal shooting; lethal = lethal shooting; all = lethal and non-lethal shooting and non-shooting scaring devices used in combination.)

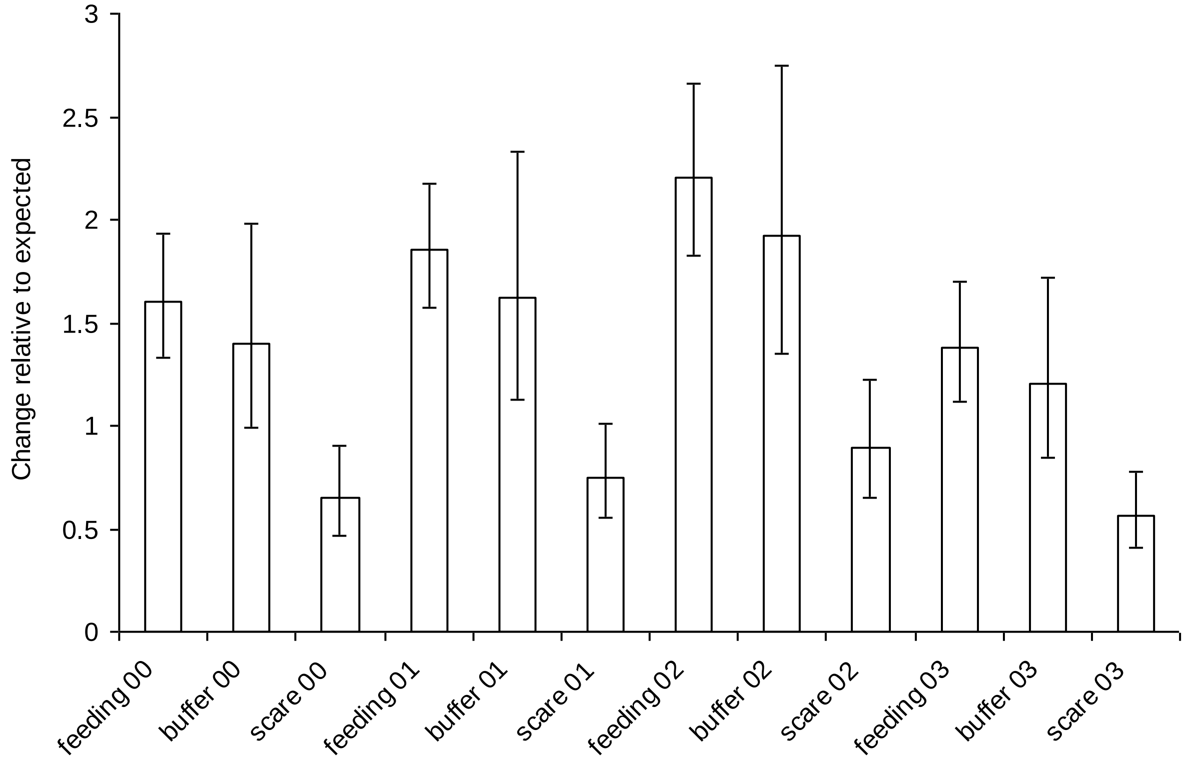

Figure 3.3.2.1. The change relative to expected (where no change = 1) for each zone (‘feeding’, ‘buffer’ or ‘scaring’)-by-year interaction from the GLM of difference between predicted and observed counts (per year, as a proportion of the predicted count) for the winters between 2000/01 and 2003/04 for Greenland Barnacle Goose. (Key: 00 = 2000/01; 01 = 2001/02; 02 = 2002/03; and 03 = 2003/04.)

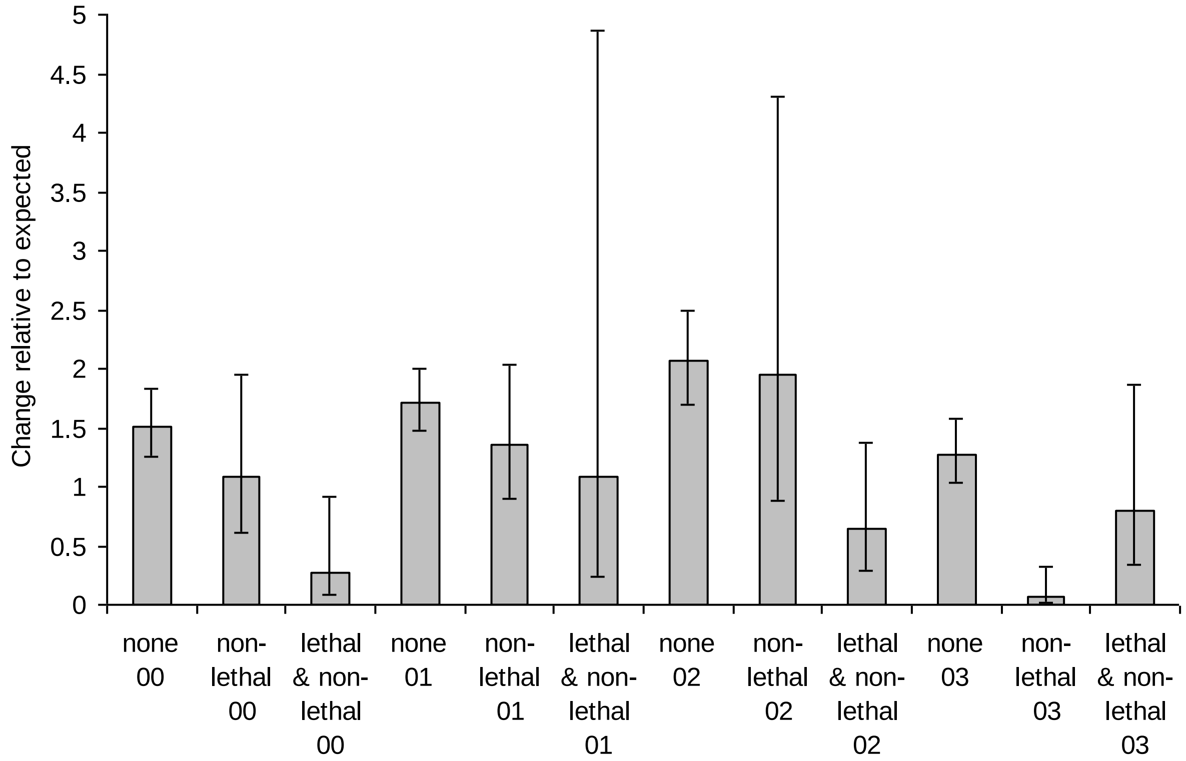

Figure 3.3.2.2. The change relative to expected (where no change = 1) for each scaring type-by-year interaction from the GLM of difference between predicted and observed counts (per year, as a proportion of the predicted count) for the winters between 2000/01 and 2003/04 for Greenland Barnacle Goose. (Key: 00 = 2000/01; 01 = 2001/02; 02 = 2002/03; 03 = 2003/04; none = no scaring; non-lethal = non-lethal shooting; lethal = lethal shooting.)

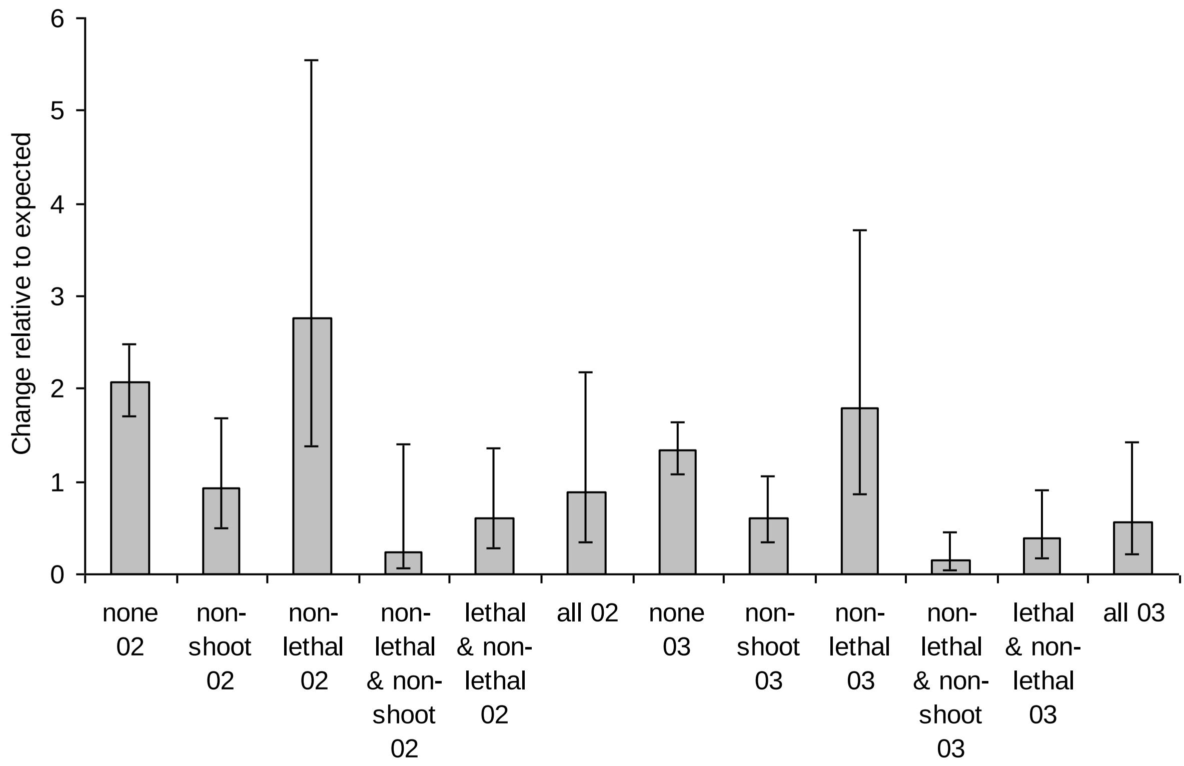

Figure 3.3.2.3. The change relative to expected (where no change = 1) for each scaring type-by-year interaction from the GLM of difference between predicted and observed counts (per year, as a proportion of the predicted count) for the winters of 2002/03 and 2003/04 for Greenland Barnacle Goose. (Key: 02 = 2002/03; 03 = 2003/04; none = no scaring; non-shoot = non-shooting scaring devices only; non-lethal = non-lethal shooting; lethal = lethal shooting; all = lethal and non-lethal shooting and non-shooting scaring devices used in combination.)

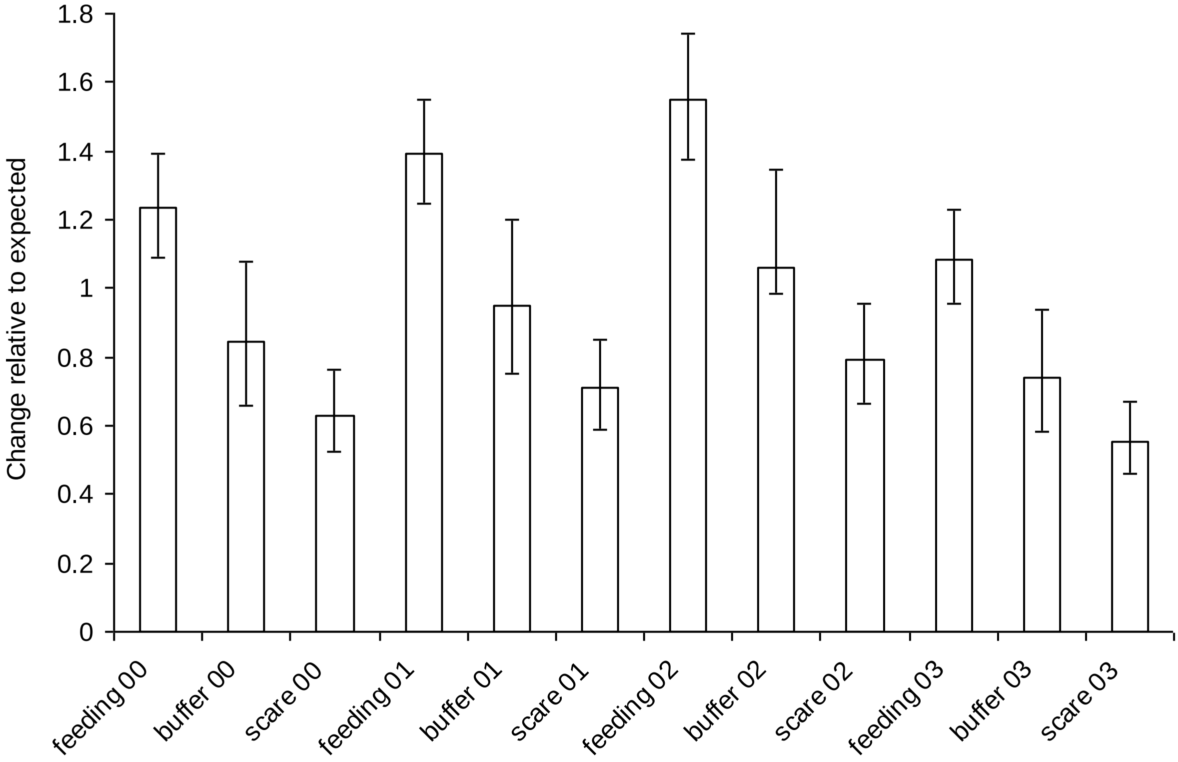

Figure 3.3.3.1. The change relative to expected (where no change = 1) for each zone ('feeding', 'buffer' or 'scaring')-by-year interaction from the GLM of difference between predicted and observed counts (per year, as a proportion of the predicted count) for the winters between 2000/01 and 2003/04 for Greenland Barnacle Goose and Greenland White-fronted Goose combined. (Key: 00 = 2000/01; 01 = 2001/02; 02 = 2002/03; and 03 = 2003/04.)

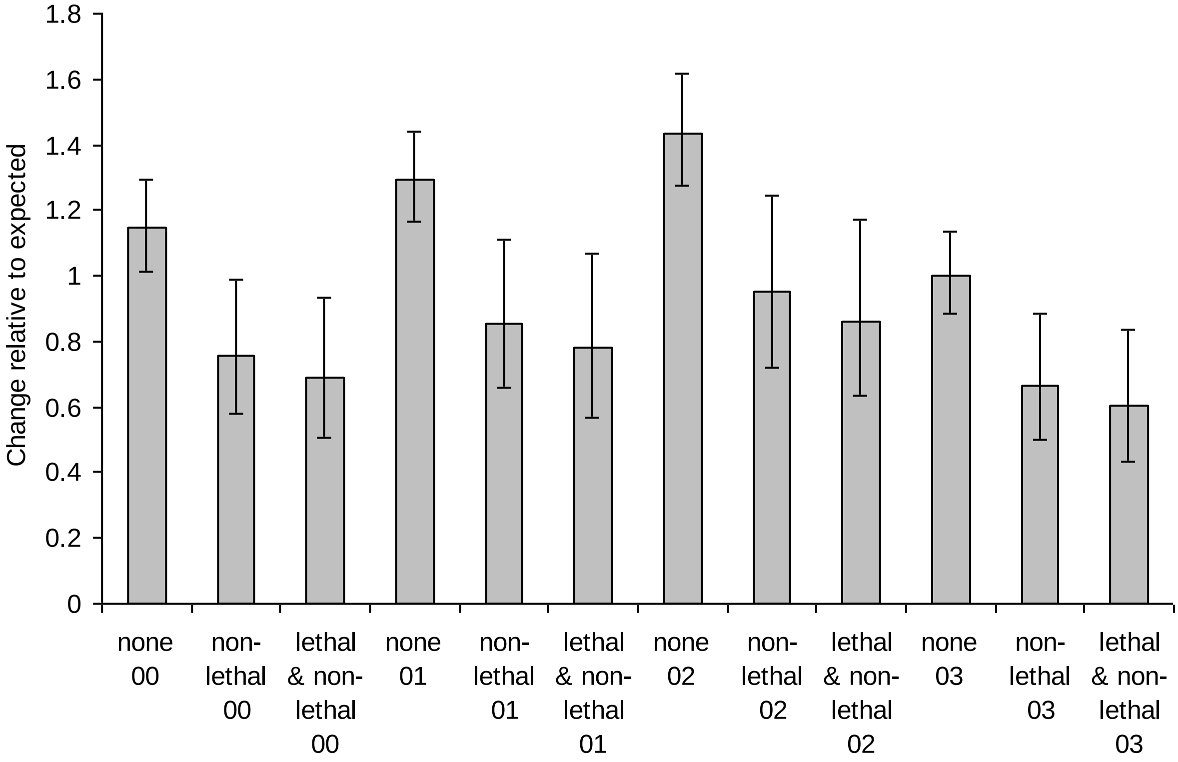

Figure 3.3.3.2. The change relative to expected (where no change = 1) for each scaring type-by-year interaction from the GLM of difference between predicted and observed counts (per year, as a proportion of the predicted count) for the winters between 2000/01 and 2003/04 for Greenland White-fronted Goose and Greenland Barnacle Goose combined. (Key: 00 = 2000/01; 01 = 2001/02; 02 = 2002/03; 03 = 2003/04; none = no scaring; non-lethal = non-lethal shooting; lethal = lethal shooting.)

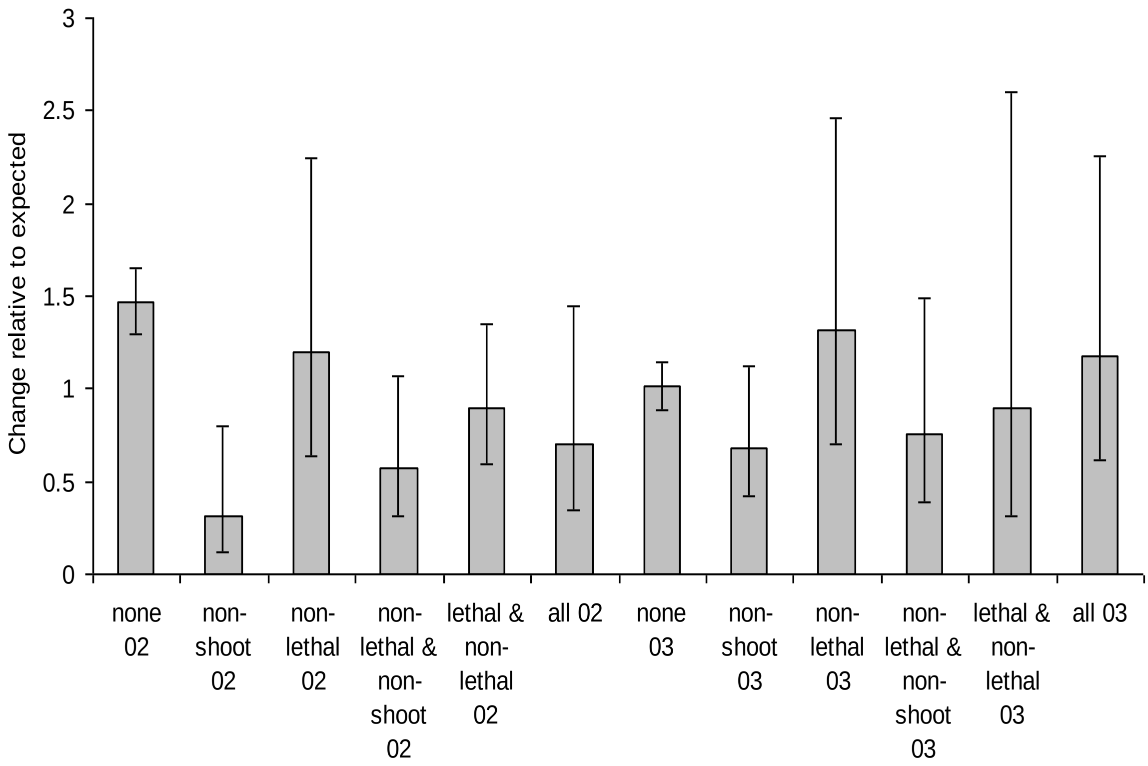

Figure 3.3.3.3. The change relative to expected (where no change = 1) for each scaring type-by-year interaction from the GLM of difference between predicted and observed counts (per year, as a proportion of the predicted count) for the winters of 2002/03 and 2003/04 for Greenland White-fronted Goose and Greenland Barnacle Goose combined. (Key: 02 = 2002/03; 03 = 2003/04; none = no scaring; non-shoot = non-shooting scaring devices only; non-lethal = non-lethal shooting; lethal = lethal shooting; all = lethal and non-lethal shooting and non-shooting scaring devices used in combination.)

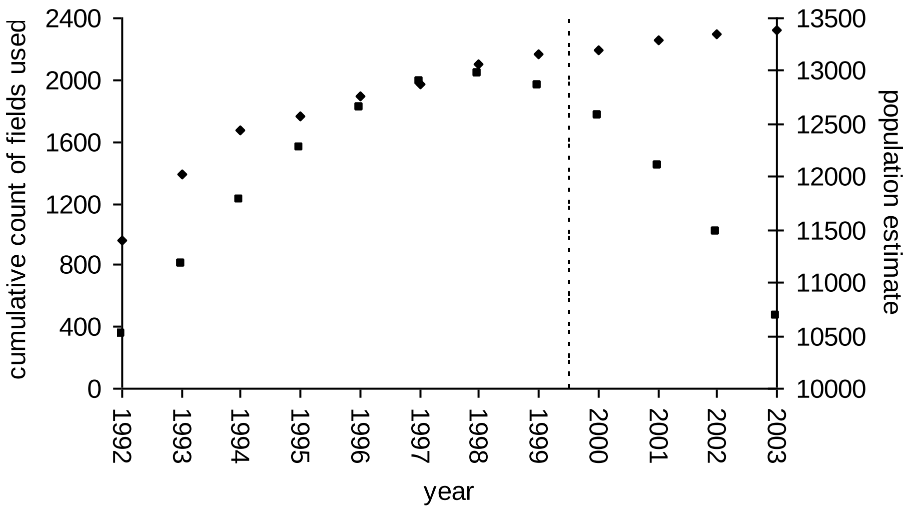

Figure 3.4.1. Diamond symbols: cumulative number of fields used each winter by Greenland White-fronted Goose, from the season of 1992/93. Square symbols: population estimate (from model F_{all}; see text for explanation). Dashed line: divider between non-shooting (1992/93-1999/2000) and shooting (2000/01-2003/04) periods.

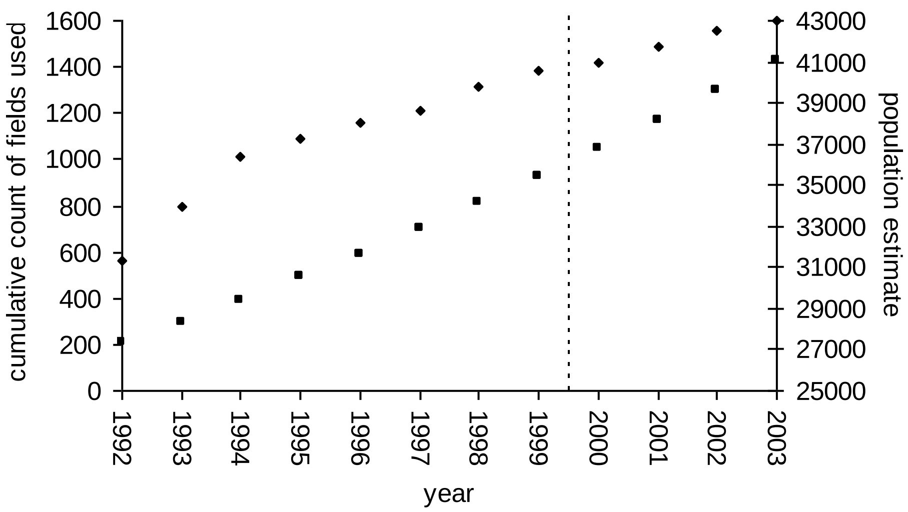

Figure 3.4.2. Diamond symbols: cumulative number of fields used each winter by Greenland Barnacle Goose, from the season of 1992/93. Square symbols: population estimate (from model F_{all}; see text for explanation). Dashed line: divider between non-shooting (1992/93-1999/2000) and shooting (2000/01-2003/04) periods.

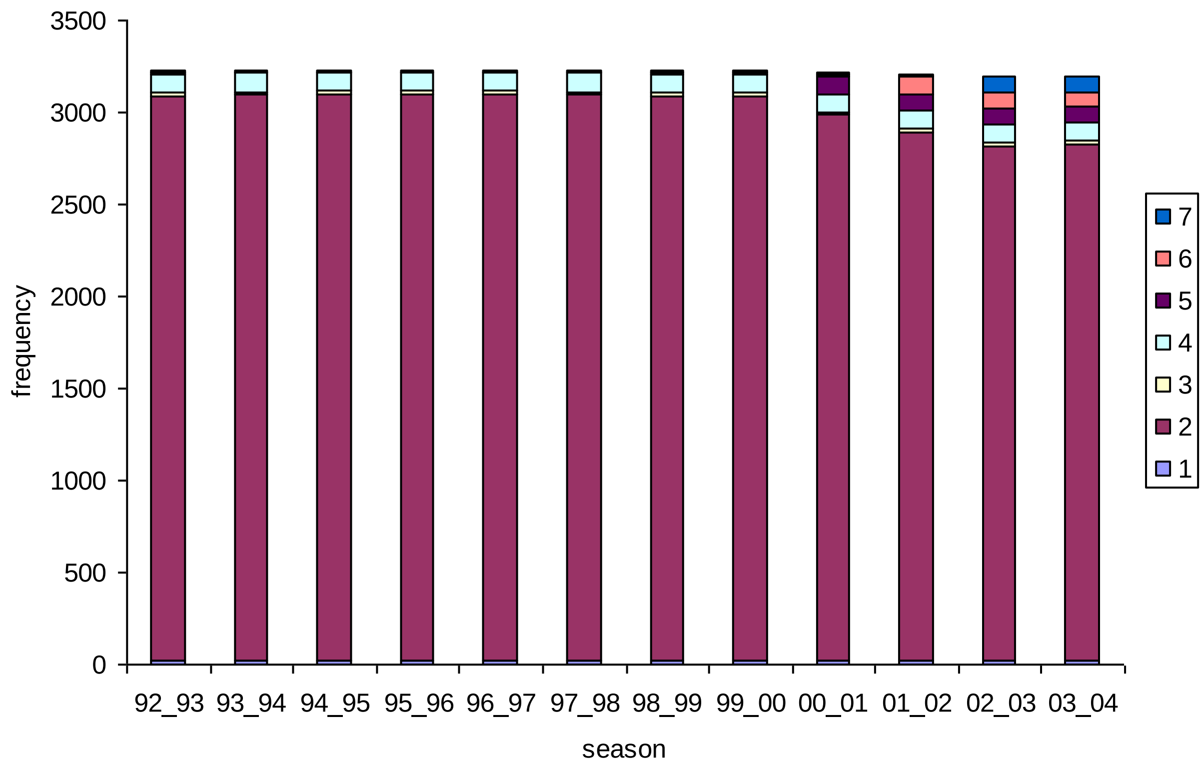

Figure 3.4.3. Variation between the winters of 1992/93 and 2003/04 in the number of fields on Islay under different crop types. (Key: 1 =bog areas; 2 = older grassland; 3 = *Juncus*; 4 = permanent pasture; 5 = grassland reseeded in the current year; 6 = grassland reseeded in the previous year; and 7 = grassland reseeded two years previous.)

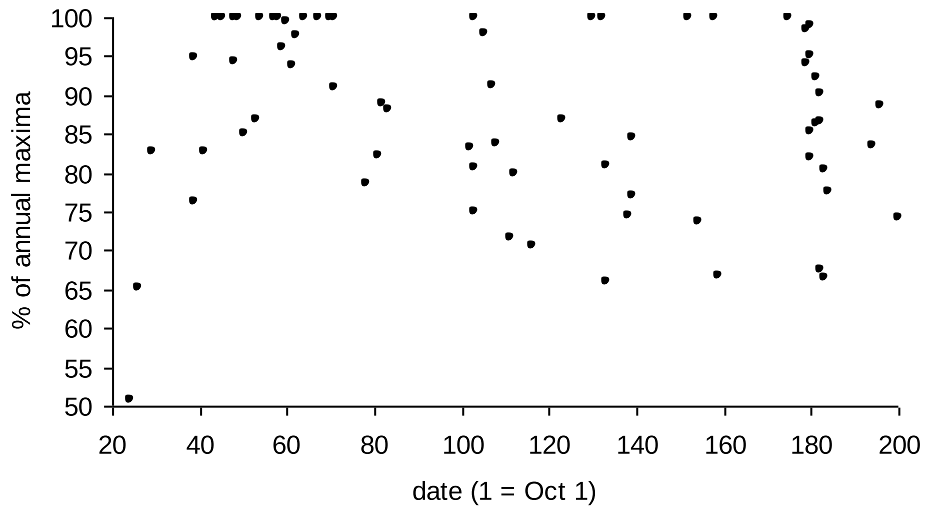

Figure 4.1.5.1. Percentage of the recorded annual maximum on Islay for each Greenland White-fronted Goose count against date through the winter (data for the winters of 1987/88 to 2003/04 pooled).

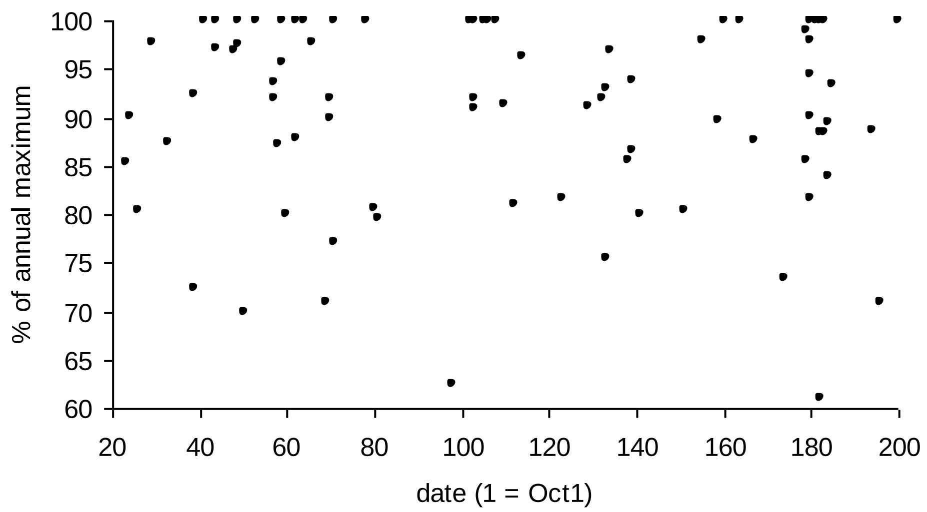

Figure 4.1.5.2. Percentage of the recorded annual maximum on Islay for each Greenland Barnacle Goose count against date through the winter (data for the winters of 1987/88 to 2003/04 pooled).

APPENDIX

TABLES A1-A14

Table A1. Test of whether differences between predicted and observed counts of Greenland White-fronted Geese (as a proportion of the predicted count; PWWCD, see Section 2.3.2) varied between fields within a scaring zone ('scaring' and 'buffer' areas combined) and those in within the zone where scaring was not permitted ('feeding' areas), for the four winters of 2000/01 to 2003/04. The GLM used a Normal error (and identity link function) and controlled for the repeated measure of field number.

	d.o.f.	**χ^2**	***p*-value**
Year	3	53.52	<0.0001
Excluded terms			
Scaring zone	1	0.52	0.47
Scaring zone-by-year	3	1.09	0.78

Table A2. Test of whether differences between predicted and observed counts of Greenland White-fronted Geese (as a proportion of the predicted count; PWWCD, see Section 2.3.2) varied between fields within each of the three zones ('scaring', 'buffer' and 'feeding' areas) for the four winters of 2000/01 to 2003/04. The GLM used a Normal error (and identity link function) and controlled for the repeated measure of field number. Means and s.e. are presented for the coefficients.

Term		**Coefficient**	**d.o.f.**	**χ^2**	***p*-value**
Intercept		1.17 ± 0.06			
Year	2000/01	-0.379 ± 0.066	3	51.66	<0.0001
	2001/02	-0.145 ± 0.061			
	2002/03	-0.352 ± 0.062			
	2003/04	0			
Excluded terms					
Zone			2	5.59	0.06
Zone-by-year			6	5.40	0.49

Table A3. Test of whether differences between predicted and observed counts of Greenland White-fronted Geese (as a proportion of the predicted count; PWWCD, see Section 2.3.2) varied between fields potentially subjected to different types of shooting (only non-lethal shooting; lethal and non-lethal shooting; or no shooting) for the four winters of 2000/01 to 2003/04. The GLM used a Normal error (and identity link function) and controlled for the repeated measure of field number. Means and s.e. are presented for the coefficients.

Term		**Coefficient**	**d.o.f.**	χ^2	***p*-value**
Intercept		1.16 ± 0.06			
	2000/01	-0.374 ± 0.07			
Year	2001/02	-0.145 ± 0.06	3	54.01	<0.0001
	2002/03	-0.352 ± 0.06			
	2003/04	0			
Excluded terms					
Shooting type			2	1.72	0.42
Shooting type-by-year			6	5.65	0.46

Table A4. Test of whether differences between predicted and observed counts of Greenland White-fronted Geese (as a proportion of the predicted count; PWWCD, see Section 2.3.2) varied between fields potentially subjected to different types of scaring (shooting and non-shooting scaring and combinations of these) for the two winters of 2002/03 and 2003/04. The GLM used a Normal error (and identity link function) and controlled for the repeated measure of field number. Means and s.e. are presented for the coefficients. Effects of the scaring type-by-year interaction are shown in Figure 3.3.1.1.

Term		**Coefficient**	**d.o.f.**	χ^2	***p*-value**
Intercept		2.44 ± 0.001			
	All	-1.27 ± 0.51			
	Lethal + non-lethal	0.65 ± 0.60			
	Non-shooting only	0.05 ± 0.24			
Scaring type	Non-lethal + non-shooting	0.62 ± 0.47	5	19.44	0.0016
	Non-lethal only	1.28 ± 0.06			
	No scaring	0			
Year	2002/03	-0.35 ± 0.06	1	9.92	0.0022
	2003/04	0			
	All (02/03)	1.70 ± 0.55			
	Lethal + non-lethal (02/03)	-0.51 ± 0.63			
Scaring type-	Non-shooting only (02/03)	-0.94 ± 0.45			
by-year	Non-lethal + non-shooting (02/03)	-0.11 ± 0.58	5	29.51	<0.0001
	Non-lethal only (02/03)	-1.52 ± 0.34			
	No scaring (02/03)	0			

Table A5. Test of whether differences between predicted and observed counts of Greenland Barnacle Geese (as a proportion of the predicted count; PWWCD, see Section 2.3.2) varied between fields within a scaring zone ('scaring' and 'buffer' areas combined) and those in within the zone where scaring was not permitted ('feeding' areas), for the four winters of 2000/01 to 2003/04. The GLM used a Normal error (and identity link function) and controlled for the repeated measure of field number. Means and s.e. are presented for the coefficients.

Term		**Coefficient**	**d.o.f.**	χ^2	***p*-value**
Intercept		-0.322 ± 0.137			
Scaring zone	Yes	-0.647 ± 0.119	1	29.41	<0.0001
	No	0			
Year	2000/01	0.15 ± 0.11	3	16.88	0.0007
	2001/02	0.31 ± 0.11			
	2002/03	0.47 ± 0.12			
	2003/04	0			
Excluded terms					
Scaring zone-by-year			3	0.45	0.93

Table A6. Test of whether differences between predicted and observed counts of Greenland Barnacle Geese (as a proportion of the predicted count; PWWCD, see Section 2.3.2) varied between fields within each of the three zones ('scaring', 'buffer' and 'feeding' areas) for the four winters of 2000/01 to 2003/04. The GLM used a Normal error (and identity link function) and controlled for the repeated measure of field number. Means and s.e. are presented for the coefficients. Effects of scaring zone across the four winters are shown in Figure 3.3.2.1.

Term		**Coefficient**	**d.o.f.**	χ^2	***p*-value**
Intercept		0.321 ± 0.106			
Scaring zone	'Scaring'	-0.902 ± 0.147	2	38.02	<0.0001
	'Buffer'	-0.135 ± 0.178			
	'Feeding'	0			
Year	2000/01	0.151 ± 0.112	3	16.32	0.0010
	2001/02	0.295 ± 0.113			
	2002/03	0.469 ± 0.122			
	2003/04	0			
Excluded terms					
Scaring zone-by-year			6	7.86	0.25

Table A7. Test of whether differences between predicted and observed counts of Greenland Barnacle Geese (as a proportion of the predicted count; PWWCD, see Section 2.3.2) varied between fields potentially subjected to different types of shooting (only non-lethal shooting; lethal and non-lethal shooting; or no shooting) for the four winters of 2000/01 to 2003/04. The GLM used a Normal error (and identity link function) and controlled for the repeated measure of field number. Means and s.e. are presented for the coefficients. Effects of the scaring type-by-year interaction are shown in Figure 3.3.2.2.

Term		**Coefficient**	**d.o.f.**	χ^2	***p*-value**
Intercept		-2.80 ± 0.85			
	Lethal + non-lethal	-0.47 ± 0.45			
Shooting type	Non-lethal only	-3.04 ± 0.85	2	10.48	0.0053
	No shooting	0			
	2000/01	0.17 ± 0.12			
Year	2001/02	0.30 ± 0.12	3	17.29	0.0006
	2002/03	0.48 ± 0.13			
	2003/04	0			
	Lethal + non-lethal 2000/01	-1.23 ± 0.77			
Shooting type-by-	Lethal + non-lethal 2001/02	0.02 ± 0.88			
year	Lethal + non-lethal 2002/03	-0.70 ± 0.61	6	15.03	0.0201
	Non-lethal only 2000/01	2.71 ± 0.91			
	Non-lethal only 2001/02	2.80 ± 0.89			
	Non-lethal only 2002/03	2.99 ± 0.95			

Table A8. Test of whether differences between predicted and observed counts of Greenland Barnacle Geese (as a proportion of the predicted count; PWWCD, see Section 2.3.2) varied between fields potentially subjected to different types of scaring (shooting and non-shooting scaring and combinations of these) for the two winters of 2002/03 and 2003/04. The GLM used a Normal error (and identity link function) and controlled for the repeated measure of field number. Means and s.e. are presented for the coefficients. Effects of scaring type across the two winters are shown in Figure 3.3.2.3.

Term		**Coefficient**	**d.o.f.**	χ^2	***p*-value**
Intercept		0.29 ± 0.11			
	All	-0.86 ± 0.47			
	Lethal + non-lethal	-1.21 ± 0.41			
Scaring type	Non shooting only	-0.81 ± 0.30	5	41.27	<0.0001
	Non-lethal + non-shooting	-2.19 ± 0.58			
	Non-lethal only	0.29 ± 0.36			
	No scaring	0			
Year	2002/03	0.44 ± 0.13	1	11.93	0.0006
	2003/04	0			
Excluded terms					
Scaring type-by-year			4	3.32	0.51

Table A9. Test of whether differences between predicted and observed counts of Greenland White-fronted Geese and Barnacle Geese combined (as a proportion of the predicted count; PWWCD, see section 2.3.2) varied between fields within a scaring zone ('scaring' and 'buffer' areas combined) and those in within the zone where scaring was not permitted ('feeding' areas), for the four winters of 2000/01 to 2003/04. The GLM used a Normal error (and identity link function) and controlled for the repeated measure of field number. Means and s.e. are presented for the coefficients.

Term		**Coefficient**	**d.o.f.**	χ^2	***p*-value**
Intercept		-0.469 ± 0.086			
Scaring zone	Yes	-0.550 ± 0.075	1	54.12	<0.0001
	No	0			
Year	2000/01	0.13 ± 0.08	3	34.95	<0.0001
	2001/02	0.25 ± 0.06			
	2002/03	0.36 ± 0.07			
	2003/04	0			
Excluded terms					
Scaring zone-by-year			1	0.14	0.99

Table A10. Test of whether differences between predicted and observed counts of Greenland White-fronted Geese and Barnacle Geese combined (as a proportion of the predicted count; PWWCD, see Section 2.3.2) varied between fields within each of the three zones ('scaring', 'buffer' and 'feeding' areas) for the four winters of 2000/01 to 2003/04. The GLM used a Normal error (and identity link function) and controlled for the repeated measure of field number. Means and s.e. are presented for the coefficients. Effects in the three zones across the four winters are shown in Figure 3.3.3.1.

Term		**Coefficient**	**d.o.f.**	χ^2	***p*-value**
Intercept		0.0802 ± 0.0645			
Zone	'Scaring'	-0.667 ± 0.087	2	64.01	<0.0001
	'Buffer'	-0.380 ± 0.115			
	'Feeding'	0			
Year	2000/01	0.129 ± 0.069	3	34.96	<0.0001
	2001/02	0.249 ± 0.062			
	2002/03	0.358 ± 0.065			
	2003/04	0			
Excluded terms					
Zone-by-year			6	1.64	0.95

Table A11. Test of whether differences between predicted and observed counts of Greenland White-fronted Geese and Barnacle Geese combined (as a proportion of the predicted count; PWWCD, see Section 2.3.2) varied between fields potentially subjected to different types of shooting (only non-lethal shooting; lethal and non-lethal shooting; or no shooting) for the four winters of 2000/01 to 2003/04. The GLM used a Normal error (and identity link function) and controlled for the repeated measure of field number. Means and s.e. are presented for the coefficients. Effects of the three shooting types across the four winters are shown in Figure 3.3.3.2.

Term		**Coefficient**	**d.o.f.**	χ^2	***p*-value**
Intercept		0.003 ± 0.064			
	Lethal + non-lethal	-0.51 ± 0.16			
Shooting type	Non-lethal only	-0.41 ± 0.13	2	14.29	0.0008
	No shooting	0			
	2000/01	0.13 ± 0.07			
Year	2001/02	0.26 ± 0.06	3	33.27	<0.0001
	2002/03	0.36 ± 0.07			
	2003/04	0			
Excluded terms					
Shooting type-by-year			6	5.11	0.5297

Table A12. Test of whether differences between predicted and observed counts of Greenland White-fronted and Barnacle Geese combined (as a proportion of the predicted count; PWWCD, see Section 2.3.2) varied between fields potentially subjected to different types of scaring (shooting and non-shooting scaring and combinations of these) for the two winters of 2002/03 and 2003/04. The GLM used a Normal error (and identity link function) and controlled for the repeated measure of field number. Means and s.e. are presented for the coefficients. Effects of the scaring type-by-year interaction are shown in Figure 3.3.3.3.

Term		**Coefficient**	**d.o.f.**	χ^2	***p*-value**
Intercept		0.0096 ± 0.066			
	All	0.15 ± 0.34			
	Lethal + non-lethal	-0.12 ± 0.55			
Scaring type	Non-shooting only	-0.39 ± 0.26	5	21.32	0.0007
	Non-lethal + non-shooting	-0.29 ± 0.35			
	Non-lethal only	0.27 ± 0.07			
	No scaring	0			
Year	2002/03	0.37 ± 0.07	1	1.73	0.1883
	2003/04	0			
	All (2002/03)	-0.89 ± 0.50			
Scaring type-by-year	Lethal + non-lethal (2002/03)	-0.37 ± 0.58			
	Non-shooting only (2002/03)	-1.16 ± 0.56	5	13.38	0.0200
	Non-lethal + non-shooting (2002/03)	-0.64 ± 0.47			
	Non-lethal only (2002/03)	-0.47 ± 0.33			
	No scaring (2002/03)	0			

Table A13. Minimal supported GLM of Greenland White-fronted Goose proportional 'count discrepancy' (arcsine transformed) against year. The model used a Normal error distribution (and identity link function). The density and aggregation measures were placed in separate maximal models since these terms are correlated. Means ± s.e. are presented for the coefficient.

Term	**Coefficient**	**d.o.f.**	χ^2	***p*-value**
Year (1983 = year 1)	-0.0031 ± 0.0014	1	4.92	0.026
Excluded terms				
Linear function of date		1	0.71	0.40
Quadratic function of date		1	0.91	0.34
Cubic function of date		1	1.05	0.30
Linear function of mean White-fronted Goose count		1	0.04	0.85
Quadratic function of mean White-fronted Goose count		1	<0.01	0.99
Day-length		1	1.23	0.27
Mean Barnacle Goose count		1	0.09	0.76
Rainfall		1	1.03	0.31
Rainfall, including previous day		1	2.82	0.09
Mean temperature		1	0.77	0.38
Mean temperature, including previous day		1	1.53	0.22
Minimum temperature		1	0.18	0.67
Minimum temperature, including previous day		1	0.38	0.54
Number of 1-km squares occupied by White-fronted Goose		1	< 0.01	0.95
White-fronted Goose density		1	0.01	0.91
Number of fields occupied by White-fronted Goose		1	0.01	0.91
Quadratic function of 1-km square occupancy		1	0.01	0.93
Quadratic function of density		1	0.03	0.86
Quadratic function of field occupancy		1	0.01	0.94
Scaring		1	1.11	0.29

Table A14. Minimal supported GLM of Greenland Barnacle Goose proportional 'count discrepancy' (arcsine transformed) against year. The model used a Normal error distribution. The density and aggregation measures were put in separate maximal models since these terms are correlated. Means ± s.e. are presented for the coefficient.

Term	Coefficient	d.o.f.	χ^2	*p*-value
Year (1983 = year 1)	0.0026 ± 0.0011	1	5.88	0.015
Excluded terms				
Linear function of date		1	0.03	0.86
Quadratic function of date		1	0.01	0.91
Cubic function of date		1	0.01	0.93
Linear function of mean Barnacle Goose count		1	1.07	0.30
Quadratic function of mean Barnacle Goose count		1	3.08	0.08
Day-length		1	0.03	0.87
Rainfall		1	0.24	0.63
Rainfall, including previous day		1	1.74	0.19
Mean temperature		1	1.27	0.26
Mean temperature, including previous day		1	1.68	0.20
Minimum temperature		1	2.27	0.13
Minimum temperature, including previous day		1	2.53	0.11
Number of 1-km squares occupied by Barnacle Goose		1	< 0.01	0.96
Barnacle Goose density		1	0.11	0.73
Number of fields occupied by Barnacle Goose		1	< 0.01	0.96
Quadratic function of 1-km square occupancy		1	0.05	0.83
Quadratic function of density		1	0.01	0.94
Quadratic function of field occupancy		1	< 0.01	>0.99
Scaring		1	2.93	0.09

Table A15. Global GLM for field usage by Greenland White-fronted Geese (whole-island analysis). The model used a Negative Binomial error distribution (and logarithmic link function), controlled for the repeated measure of field number and included an offset (the natural log of the number of counts per month).

Term	**d.o.f.**	χ^2	***p*-value**
Significant			
Intercept			
Crop type	6	36.76	<0.0001
Distance to nearest loch	1	13.49	0.0002
Distance to nearest road	1	57.98	<0.0001
Month	4	15.19	0.0043
Gradient	1	18.93	<0.0001
Mean goose count	1	127.3	<0.0001
Field area	1	3.85	0.0498
Gradient-by-month	4	54.36	<0.0001
Distance to road-by-month	4	9.52	0.0493
Non-significant			
Distance to nearest roost site	1	2.98	0.0866
Distance to nearest woodland	1	0.73	0.3915
Degree of undulation	1	0.48	0.4873
Distance to woodland-by-month	4	7.36	0.1183
Distance to roosts-by-month	4	2.99	0.5592

Table A16. Statistical comparisons between the effects of the seven levels of crop type on field usage by Greenland White-fronted Goose, from the global GLM (see Table A15). *p*-values for the differences between each pair of crop types are presented. Using these results, the crop types were reduced to two levels (bog areas and all others combined) in the reduced model (Table 3.1.1.5).

	reseed 2	reseed 1	reseed 0	pasture	*Juncus*	grass	bog
bog	<0.0001	<0.0001	<0.0001	0.0160	<0.0001	<0.0001	
grass	0.7843	0.1209	0.1240	0.1157	0.5752		
Juncus	0.8383	0.5885	0.6297	0.1154			
pasture	0.1718	0.0299	0.0314				
reseed 0	0.4723	0.9315					
reseed 1	0.4583						
reseed 2							

Table A17. Global GLM for field usage by Greenland Barnacle Geese (whole-island analysis). The model used a Negative Binomial error distribution (and logarithmic link function), controlled for the repeated measure of field number and included an offset (the natural log of the number of counts per month).

Term	**d.o.f.**	χ^2	***p*-value**
Significant			
Intercept			
Crop type	5	177.95	<0.0001
Distance to nearest loch	1	4.66	0.0309
Distance to nearest roost site	1	31.22	<0.0001
Month	4	25.47	<0.0001
Gradient	1	15.31	<0.0001
Degree of undulation	1	7.48	0.0062
Mean goose count	1	89.02	<0.0001
Field area	1	255.92	<0.0001
Crop type-by-month	20	49.08	0.0003
Gradient-by-month	4	12.80	0.0123
Distance to road-by-month	4	23.57	<0.0001
Distance to roost sites-by-month	4	9.85	0.0431
Non-significant			
Distance to nearest wood	1	2.36	0.1246
Distance to nearest road	1	0.11	0.7392
Distance to woodland-by-month	4	7.29	0.1214

Table A18. Statistical comparisons between the effects of the seven levels of crop type on field usage by Greenland Barnacle Goose, from the global GLM (see Table A17). *p*-values for the differences between each pair of crop types are presented. Using these results, the crop types were reduced to four levels ('group 1' = old grassland; 'group 2' = J*uncus*; 'group 3' = pasture; and 'group 4' = re-seeds) in the reduced model (Table 3.1.1.6).

	reseed 2	reseed 1	reseed 0	pasture	*Juncus*	grass
grass	<0.0001	<0.0001	<0.0001	<0.0001	0.0488	
Juncus	0.3793	0.0230	0.1001	<0.0001		
pasture	<0.0001	<0.0001	<0.0001			
reseed 0	0.1557	0.7002				
reseed 1	0.0092					
reseed 2						

APPENDIX

FIGURES A1-A12

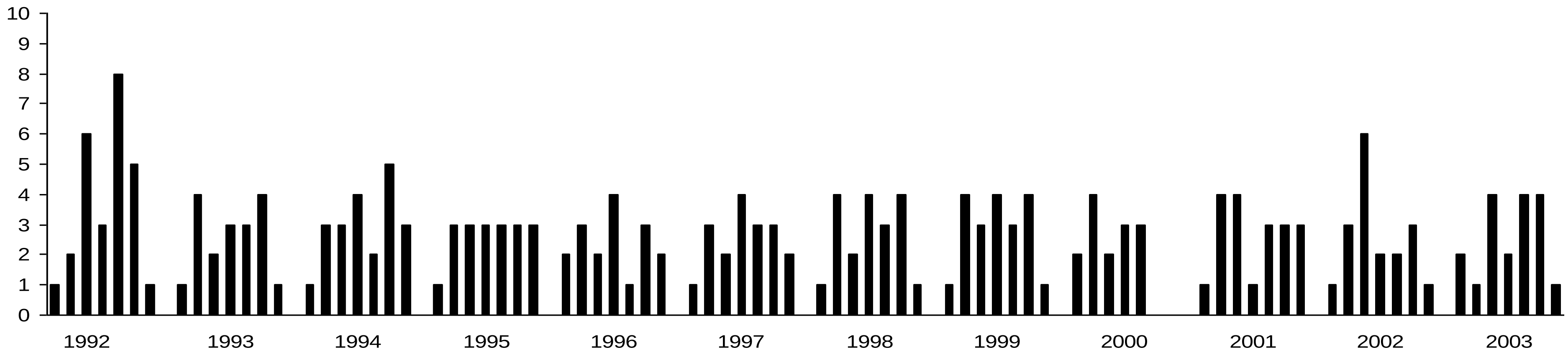

Figure A1. Number of survey counts (International Counts and Scheme Counts combined) for each winter month (October to April) for the period between 1992/93 and 2003/04, for area A.

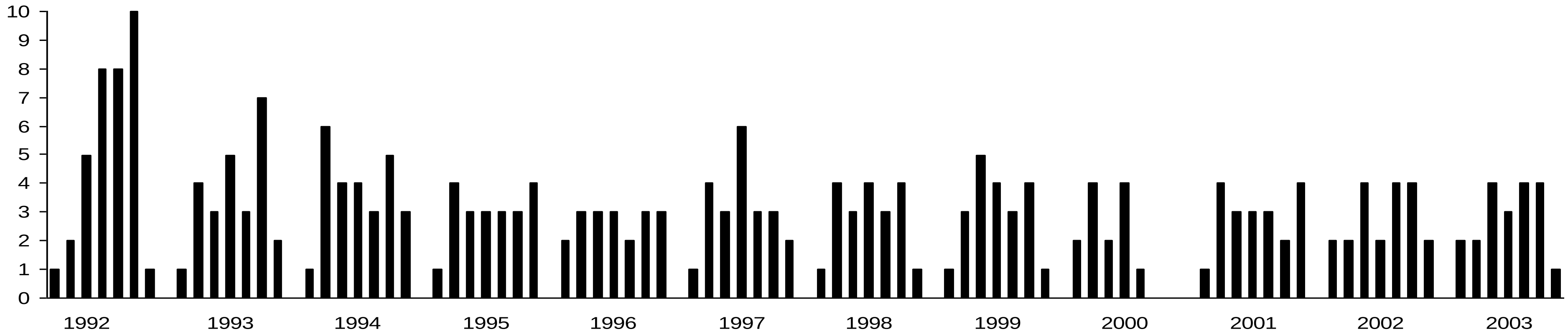

Figure A2. Number of survey counts (International Counts and Scheme Counts combined) for each winter month (October to April) for the period between 1992/93 and 2003/04, for area B.

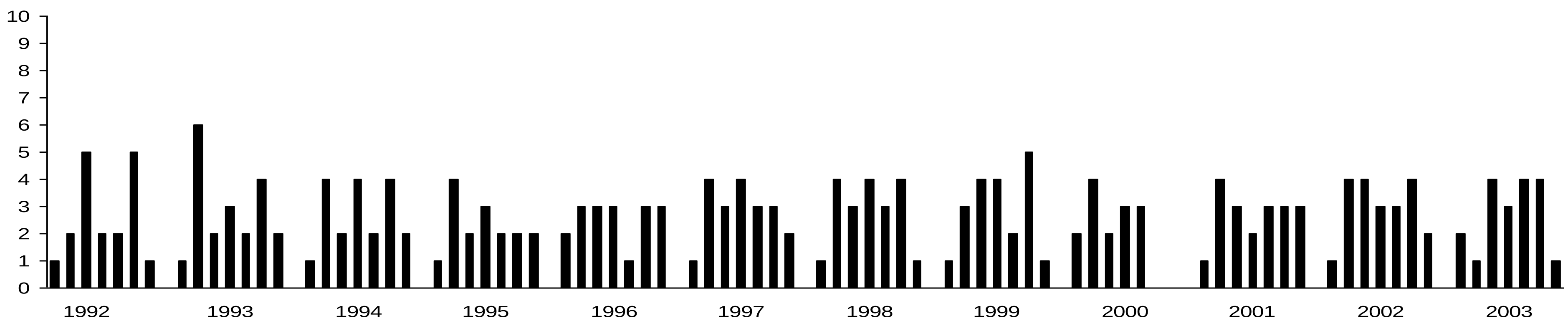

Figure A3. Number of survey counts (International Counts and Scheme Counts combined) for each winter month (October to April) for the period between 1992/93 and 2003/04, for area C.

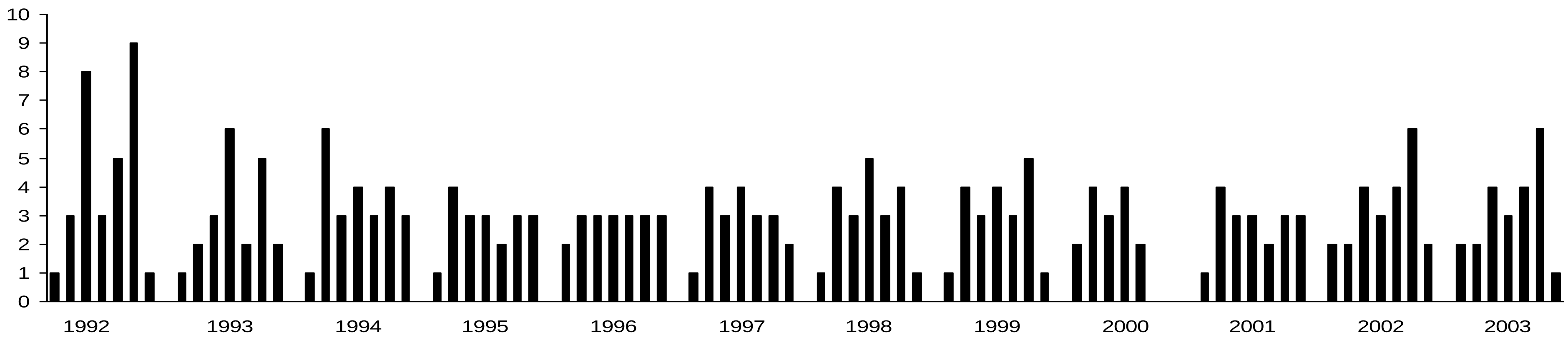

Figure A4. Number of survey counts (International Counts and Scheme Counts combined) for each winter month (October to April) for the period between 1992/93 and 2003/04, for area D.

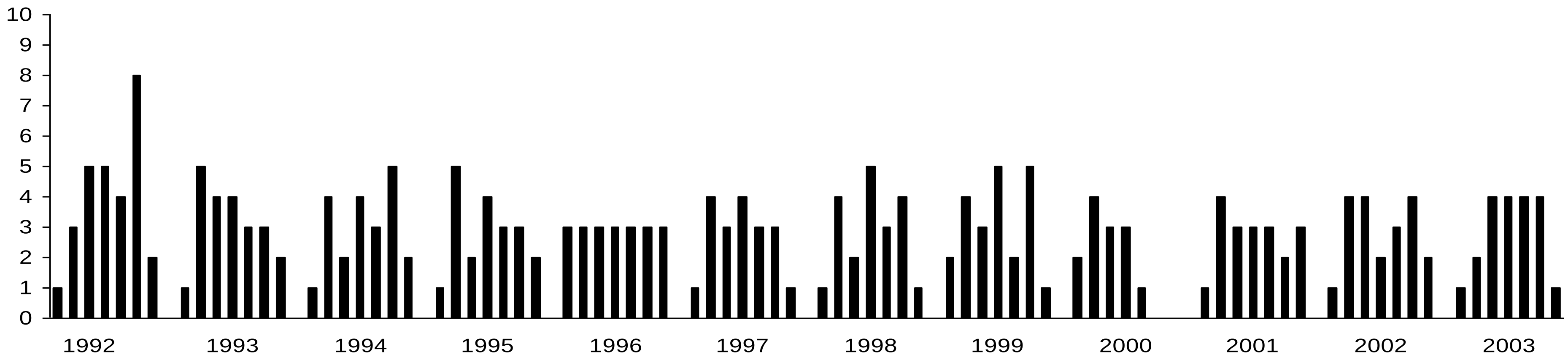

Figure A5. Number of survey counts (International Counts and Scheme Counts combined) for each winter month (October to April) for the period between 1992/93 and 2003/04, for area E.

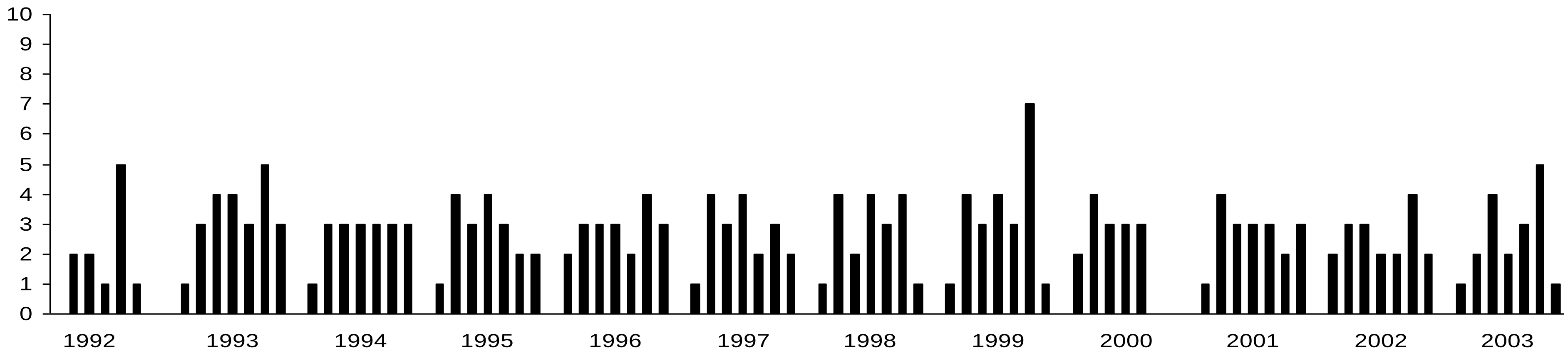

Figure A6. Number of survey counts (International Counts and Scheme Counts combined) for each winter month (October to April) for the period between 1992/93 and 2003/04, for area F.

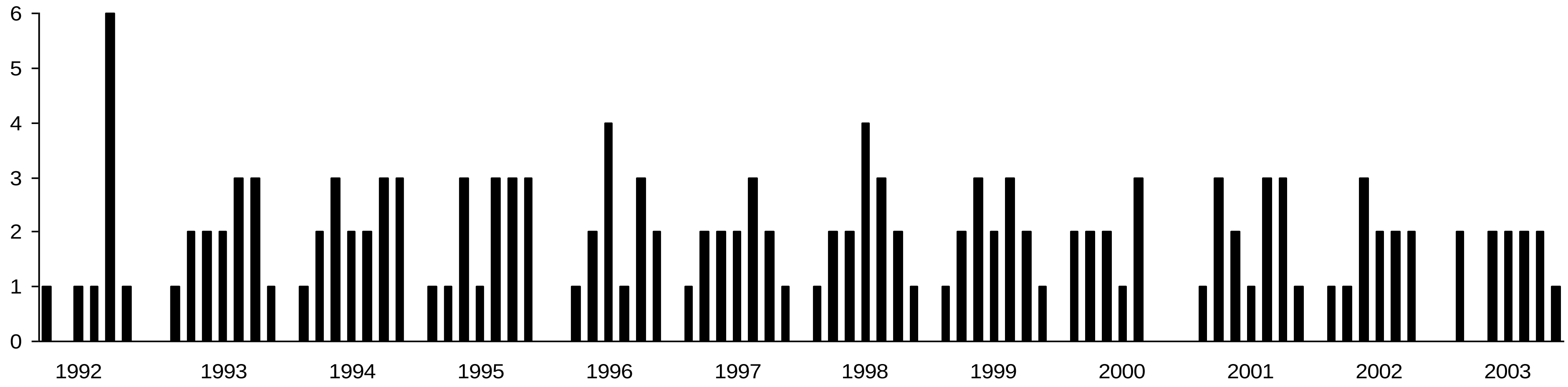

Figure A7. Number of scheme counts for each winter month (October to April) for the period between 1992/93 and 2003/04, for area A.

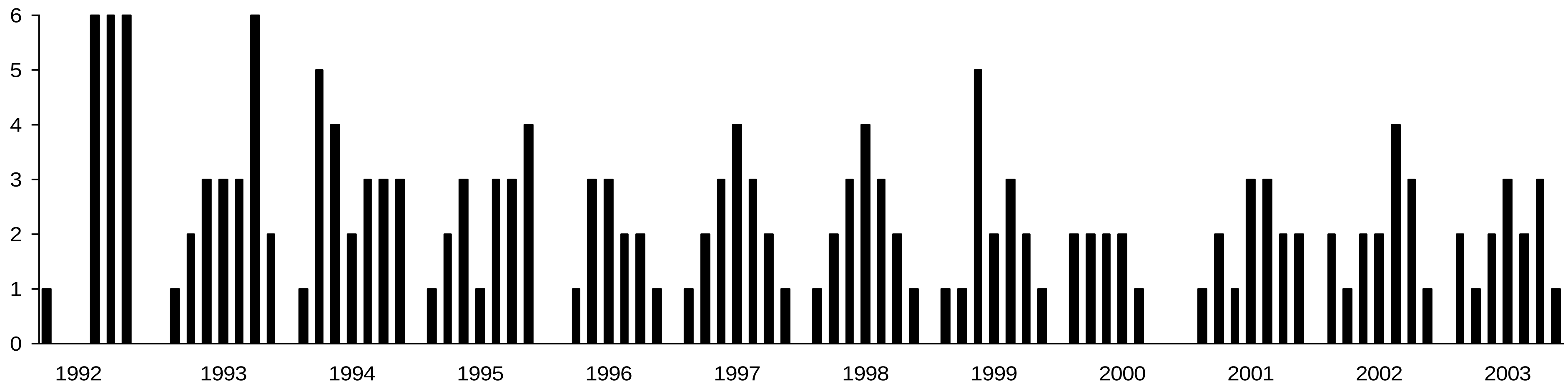

Figure A8. Number of scheme counts for each winter month (October to April) for the period between 1992/93 and 2003/04, for area B.

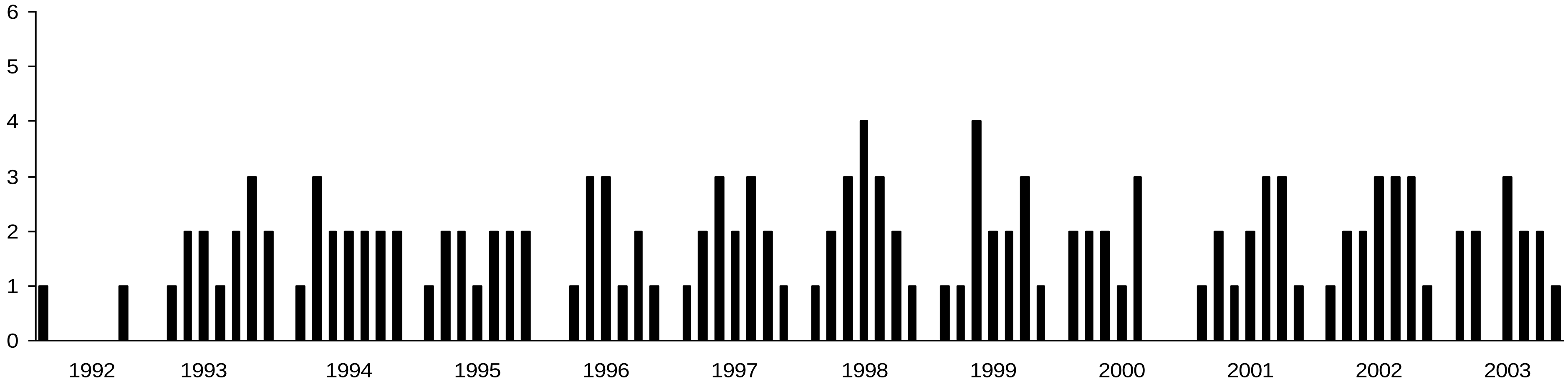

Figure A9. Number of scheme counts for each winter month (October to April) for the period between 1992/93 and 2003/04, for area C.

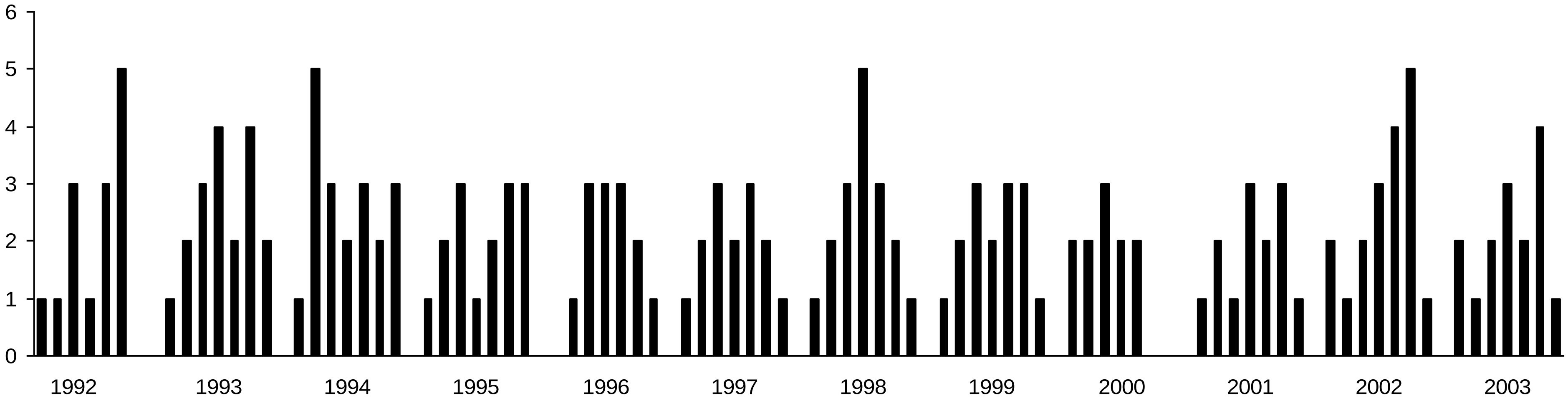

Figure A10. Number of scheme counts for each winter month (October to April) for the period between 1992/93 and 2003/04, for area D.

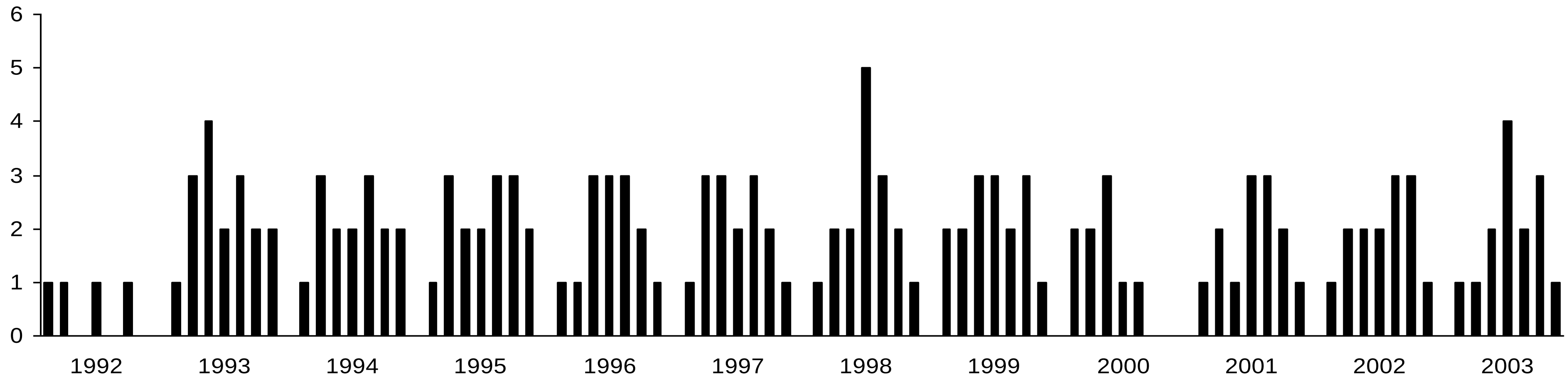

Figure A11. Number of scheme counts for each winter month (October to April) for the period between 1992/93 and 2003/04, for area E.

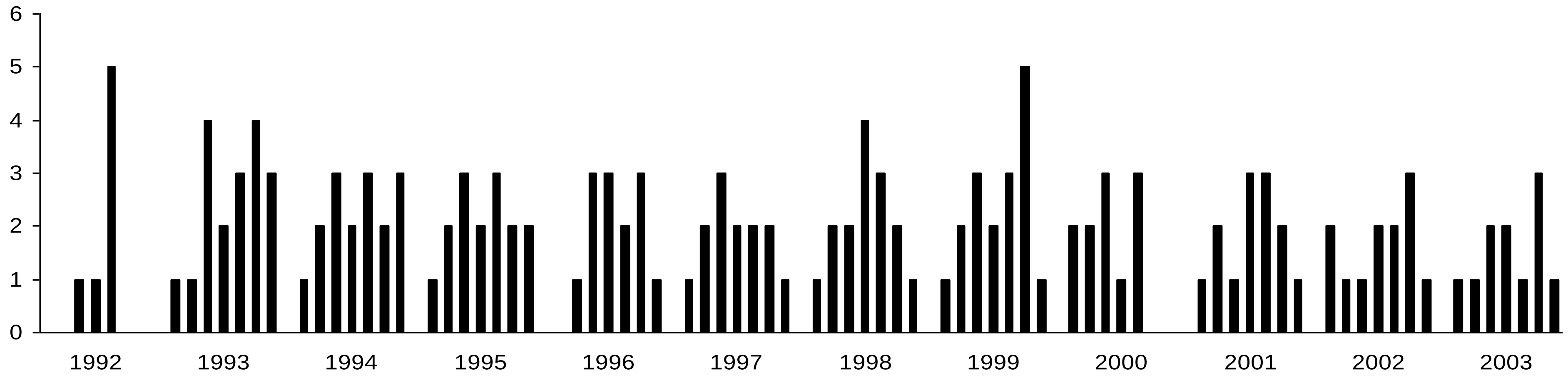

Figure A12. Number of scheme counts for each winter month (October to April) for the period between 1992/93 and 2003/04, for area F.