# MANIPULATION OF THE FEEDING BEHAVIOUR OF DIVING DUCKS ON MUSSEL FARMS

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I declare that the work recorded in this thesis is entirely my own, unless otherwise stated, and that it is of my own composition. No part of this work has been submitted for any other degree.

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# CONTENTS

# Summary

1. Eider numbers in the North Clyde area remain quite constant throughout the winter, with an influx of birds, mainly juveniles, in the late summer. These birds subsequently disappear from the area either as a result of increased mortality or by competitive exclusion by adult birds. Attendance at a mussel farm in the area was highest throughout the winter, and male to female sex-ratio was higher here than in other areas. Some breeding eiders from the North and West of Argyll move into the Clyde during the winter, but these represent only a small proportion of the wintering population. Eider wintering distribution can be influenced by aquaculture sites in some areas, although the effect on population growth is unclear.

2. The activity patterns of foraging eiders on natural mussel beds is strongly influenced by tidal height whereas on mussel farms there is no such effect. In wild-feeding flocks, different areas are utilised at differing periods of the tidal cycle, perhaps as a method of keeping a uniform optimal dive-depth. Birds feeding on natural mussel beds dived on average three times as frequently as those feeding on mussel farms, and so clearly had to work harder to meet energy requirements.

3. 97% of Scottish mussel farmers contacted reported eiders as a pest species, and 21% also suffered damage from goldeneyes. Losses of stock to feeding eiders can be huge, and the financial cost considerable, averaging £4000 per farm per year (1994-1998). Attendance at farms tended to peak during early spring and late autumn. Many damage limitation measures were employed by farmers, with only one, netting, giving unambiguous success.

4. Worker presence on mussel farms decreased eider attendance by 95%. Chasing the birds by boat significantly reduced numbers of feeding eiders and goldeneyes in the short-term, by 91 and 51% respectively. This effect was short-lived, particularly with goldeneyes. There was also evidence to suggest that disturbance lowers the subsequent feeding rate of goldeneyes on mussel farms.

5. Laser light significantly reduced numbers of diving ducks on mussel farms, however its efficacy is reduced as ambient light levels increase. As a result, its use is often restricted to periods around sunrise and sunset. Different populations of eiders showed significantly different sensitivities to laser light. Sequential trials of the laser light on adjacent farms showed that birds were initially scared from one site to the next, but repeated regimes moved birds out of the area.

6. Trials of an Underwater Playback System (UPS), replaying recordings of chase-boat engines, gave significant reductions in eider numbers of 50-80%. A control trial with the playback of an unassociated noise gave no significant reduction in numbers. The mean return time of birds to the farm after chasing by boat also increased significantly during UPS trials. The long-term habituation of ducks to this system was negligible with occasional reinforcement by boat chasing.

7. On the basis of these scientific trials and observations, recommendations to mussel farmers are made in an advisory booklet (Appendix III). Netting designs are presented and possible use of UPS or laser light on farms is reviewed.

# Chapter 1

# General Introduction

## Introduction

This thesis is set out with the intention that each chapter can be read in isolation, with no need for cross-reference, and chapters are thus presented in a journal format. This general introductory chapter will outline the background information relevant to this study, beginning with a brief overview of the mussel farming industry. This is followed by brief descriptions of the ecology of the relevant ducks. Finally, the actual and potential interactions between the two will be discussed, and the aims and scope of the project will be described.

## Mussel farming, diving ducks and reduction of losses

There are two main methods of mussel (*Mytilus edulis*) farming; bottom culture and suspended culture on ropes. It is the latter that is generally practised in Scotland. Suspended culture has two main designs. Raft culture involves hanging a large number of the ropes, or droppers in a dense grid from a moored floating platform. Long-line farms consist of one or more long rope head-lines, supported by a series of large floats, from which the droppers are hung at regular intervals.

*Mytilus* spawn in the spring, the larvae of the young mussel (spat) then settle on a suitable surface and attach themselves with secreted byssus threads. In some areas, where there are low densities of larvae in the surrounding water, young mussels can be imported and 'grafted'/'tubed' to suspended ropes using a net 'stocking'. This holds the mussels around the rope, and allows them time to attach themselves before the net disintegrates, leaving them bound to the rope. Growth is fastest as water temperature increases in the spring, and slows down dramatically or ceases throughout the winter. Mussels are considered marketable when they reach around 60mm. From the settlement of spat to the harvesting of marketable mussels takes approximately 2½ years. At the time of harvest, an undamaged rope may hold up to 40 kg of mussels (Pillay 1993).

Because cultivated mussels are continually immersed in seawater, they are not limited in the amount of time that they can spend feeding nor are they restricted by the constraints involved with air exposure such as desiccation. As a result, cultured mussels tend to be thinner-shelled and of a higher flesh content than intertidal mussels of the same size (Dunthorn 1971; Galbraith 1987).

Mussel farming in Scotland started in the 1960s with trials in Loch Sween. Now there are over one hundred farms, mainly in the sheltered sea-lochs of the West Coast and on the Outer-Hebrides (Galbraith 1992). In 1998, 1355 tonnes of mussels were harvested by Scottish mussel farmers, resulting in a revenue of around £1.5m (Fraser 1999). Such an industry provides valuable income and employment to many areas with relatively fragile economies. The potential for further development of the industry is great, and demand for the product is growing. Recent developments in the Scottish fin-fish aquaculture industry (e.g. Infectious Salmon Anaemia, ISA), and the view of mussel farming as a 'greener' alternative, may also serve to increase the number of Scottish mussel farms.

Dunthorn (1971) first documented eider, *Somateria mollissima* predation on a mussel farm in Loch Sween in 1968 (the first commercial mussel farm in Scotland), and since then the problem has escalated dramatically as the number of farms has increased. In 1987, Colin Galbraith produced a detailed study of the problem of eiders on mussel farms, although since then the problem has received relatively little attention. Flocks in excess of 200 birds are now not an uncommon site on a number of Scottish mussel farms. This poses a serious problem to mussel farmers, many of whom report large losses of stock to eiders. There have already been reports in the popular press of farmers going out of business as a result of eider predation.

Milne & Galbraith (1986) estimated that one eider could remove 2.6kg (wet weight) of mussels per day from a farms ropes. This figure however may not reflect the actual intake of mussels by each bird, as an unknown percentage of the mussels taken from the ropes may drop off or be shaken off as the eider feeds. Bustnes and Erikstad (1990) suggested that, depending on the size-class of mussels taken, eiders would have to eat between 1 and 2.5kg of intertidal mussels each day to satisfy their daily energy requirements. Sizes of mussels taken by eiders in Dunthorn's study (1971) ranged from 19-33mm, though the choice of a particular size-class may depend on several factors such as salt content (Nystrøm and Pehrsson 1988, Nystrøm *et al.* 1991), handling time (Draulans 1982; De Leeuw and Van Eerden 1992; Guillemette *et al.* 1992) or shell weight (Bustnes and Erikstad 1990).

Eiders are large sea ducks found along the coast of much of northern Europe, including the northern half of Britain, the majority of the UK breeding population being in Scottish waters (Gibbons *et al.* 1993; Cramp & Simmons 1977). The Scottish population could be in excess of 60,000 individuals and slowly increasing, with around 20,000 birds wintering in the Clyde in 1997 (C. Waltho, *pers. comm.*).

The main prey of eiders is molluscs, particularly *Mytilus* in depths usually less than 10 metres, but they have been recorded feeding over 40 metres below the surface (Guillemette *et al.* 1993). They also commonly feed on echinoderms and crustacea, and there may be small changes in diet through the year according to availability and condition of prey (Cramp & Simmons 1977; Ydenberg & Guillemette 1991). When diving for prey, those food items captured are generally stored whole in the distensible oesophagus. Prey items are crushed in the muscular gizzard before both digestible and indigestible (shell) components are passed into the intestinal tract for assimilation (Guillemette 1994). Shell fragments are passed out in the faeces.

Feeding tends to occur in well-defined bouts, with resting periods in-between. Resting periods allow the store of food held in the oesophagus to be processed by the gizzard before another feeding bout can commence (Ydenberg & Guillemette 1991, Beauchamp *et al.* 1992, Guillemette 1994). Similar 'digestive bottlenecks' have been observed in oystercatchers, *Haematopus ostralegus* (Kersten and Visser 1996), whimbrel *Numenius phaeopus* (Zwarts and Dirksen 1990) and hummingbirds (Diamond *et al.* 1986). In each case it is observed that such constraints to digestion impose associated constraints to the foraging regime of the individual or group. Another important factor associated with eiders feeding on such prey is the food's shell content. Eiders have a very high wing loading, and any increase in weight could have marked effects on flight and take-off ability (and therefore possible predator evasion) of that bird (Bustnes and Erikstad 1990). The aforementioned differences between cultured and intertidal mussels would relax the constraints detailed above, making mussel farms potentially profitable feeding grounds for eiders.

Recently, in some areas, wintering flocks of Goldeneye *Bucephala clangula* have been reported to be using mussel farms as feeding stations on the West Coast of Scotland. Goldeneye are a much smaller species than eiders, breeding on freshwater sites but often wintering in sheltered coastal areas (Cramp & Simmons 1977). The first breeding record of goldeneye in Scotland was in 1970 and since then numbers have increased dramatically (Dennis and Dow 1984). Their diet is more varied than that of the eider, although for those birds wintering on brackish water or the sea, *Mytilus* can constitute a large part of the diet (Cramp & Simmons 1977). The size of prey consumed is much smaller than that taken by eiders, and mussels taken from farms tend to be very small, first year growth, around 5mm long (J. Holmyard *pers. comm.*).

Although eiders are a protected species in the UK, the Scottish Executive Rural Affairs Division, SERAD, issue a small number of licenses to shoot a limited number of eiders on farms where they are a particular problem. Alternative, non-lethal methods of deterrence of eiders on mussel farms have generally received little attention. However, some preliminary work regarding bird pests at mussel farms has been carried out in Canada (Parsons 1990; Lidster *et al.* 1994; Lien and Pittman 1996; Lien and Hennebury 1997).

**Aims and structure of thesis**

Despite the wealth of literature on pest species, their economic impact, ecology and control, little has been written about diving ducks as pests on mussel farms since the work of Galbraith (1987). This thesis is designed to build on that initial work, to examine the feeding behaviour of diving ducks (particularly eiders) on farms and to investigate non-lethal remedial measures. **Chapter 2** examines eider population movements on the Scottish West Coast throughout the year, and discusses how this may be of relevance to mussel farmers. In attempt to investigate why diving ducks feed at mussel farms, **chapter 3** compares eider feeding behaviour between natural mussel beds and farms.

While it is clear that eiders do feed at mussel farms, the extent of the problem has never been accurately established. Any means of reducing the amount of damage that may occur to a farm as a result of diving ducks must be based on a firm understanding of the problem relative to that site. **Chapter 4** uses the results of a questionnaire to examine the scale of the problem in Scotland as perceived by mussel farmers, and the methods commonly used as deterrents.

The final three chapters of the thesis then go on to examine how damage can be minimised and how well novel deterrent techniques may work. **Chapter 5** looks at the effect of human activity on farms, and the efficacy of chasing the birds by boat (one of the most common methods of deterrence). **Chapter 6** investigated the efficacy of a novel deterrent, laser light, on both eiders and goldeneyes on two levels. Immediate responses of birds, and the longer-term effect on attendance of laser light were examined with respect to different populations and ambient light levels. **Chapter 7** details experiments with another deterrent, an underwater playback system initially developed in Canada by Lien & Hennebury (1997).

**Chapter 8** brings together the results of the previous chapters, discusses the results and suggests areas of further research in this field.

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# Chapter 2

# Eider population movements and distribution in relation to aquaculture facilities

## Abstract

Twice-monthly counts of eiders were carried out from November 1996 to August 1997 along the north side of the Clyde to study the movements of birds along different habitats in the area and the utilisation of a mussel farm in Loch Striven. Winter and Summer distributions of eiders in the Clyde and the isles and western sea-lochs of Argyll were also compared to examine movements of birds between the two areas, and the effect of aquaculture installations on their distribution in winter. There was an average male to female ratio of 1.4 in the north Clyde study area in winter, although the ratio was significantly higher for flocks feeding at the mussel farm (1.7). Such a difference is likely to be due to competitive exclusion of females by male birds at such high-quality feeding grounds. Numbers of birds in the area during winter remained reasonably constant at around 1200, followed by a large increase of birds in the late autumn, partly as a result of an increase in numbers of juvenile birds (increasing from 1.6 to 32.3% of the total population). Small islands, and to a lesser extent sea-lochs were used by female eiders during the nesting period. 17,996 and 16,449 eiders were counted in April and September respectively in the whole of the Clyde and North-west Argyll. Small movements of birds occur between these two areas, with a small number of birds moving out of the Clyde to breed, but birds return to winter in the more productive waters of the Clyde. 25% of birds in the North-west regions were found around aquaculture installations, and the relevance of this, particularly in reference to population growth and distribution is discussed.

## Introduction

Large-scale, predictable movements of birds generally occur in order to exploit different geographical areas at different stages of the annual cycle and in response to seasonal changes in population density and in the environment (Evans 1985). These movements are known as migrations, and with respect to this, birds can either be sedentary, migratory or partially migratory.

Eiders are described as a partially migratory and dispersive species, with different populations showing differing degrees of movement (Cramp & Simmons 1977). In more northerly latitudes, distribution can often be influenced by factors such as ice-cover (Frimer 1993), as this can have great effects on mortality rates (Robinson & Gilchrist 1998). Noer (1991) found that eiders wintering in Danish waters came from breeding populations in Holland, Sweden, Norway, Finland and Estonia, representing movements of up to and over 800 km between wintering and breeding grounds. However, in the U.K., movements tend to be on a much smaller scale. Birds breeding on the Northumberland coast and at Forvie move as far north as the Firths of Tay and Forth to winter (Baillie & Milne 1989, Gibbons *et al.* 1993), whereas in Shetland birds tend to make only very short annual movements, rarely leaving Shetland (Hope-Jones & Kinnear 1979). Faroese eiders are also thought to remain in that archipelago all year round (Cramp & Simmons 1977). Birds from West Coast populations generally move less than 160 km between breeding and wintering grounds (Galbraith 1987).

Pair-formation in Scottish eiders occurs during the winter, some time before the breeding season, with egg-laying commencing at the end of April / start of May (Milne 1965). Females remain on the nest almost constantly during incubation (c26 days), relying almost entirely on body reserves during this period (Milne 1976, Korschgen 1977). At the onset of laying, males abandon the females and move *en masse* to moulting areas generally in quiet, sheltered areas of coastline (Campbell & Milne 1983, Owen & Black 1990). Females tend to aggregate on moulting grounds after offspring become independent, approximately 8 weeks later. In late summer or early autumn, birds then move to wintering grounds, where they remain until the following breeding season.

Although there has been some survey work carried out on eider distribution on the West Coast of Scotland (e.g. Sharrock 1976, Galbraith 1987), there have been no intensive studies of population movements through the year, particularly in relation to birds in the Clyde Estuary. In this respect, we carried out fortnightly surveys along the north coast of the Firth of Clyde over a period of ten months. The aim of these censuses was to describe the movements of this sub-population of eiders, and to relate this to the problems faced by Scottish mussel farmers.

Another important factor in the study of population movements along the west coast is the larger scale movements of eiders that have been suggested to occur between birds breeding in the relatively exposed north-western areas of Argyll moving into the Firth of Clyde to winter. There is however little quantification of eider breeding and wintering distribution in both areas, and the scale of movement between the two areas is unclear. We examined data collected in September 1998 to represent numbers and distribution of wintering birds. Finding eider nests is not a practical way of trying to census the population over a large area, so we decided to carry out a count of eiders during April 1999 on the assumption that the distribution of birds would then be closely related to where they would breed. Nest building and laying normally occurs during May, so that in April there should probably not be any eiders inland, but they are likely to be on coast in areas close to their nesting grounds.

Anecdotal evidence from the September 1998 survey had suggested an unexpectedly strong influence of aquaculture on local eider distribution. Another survey the following September (1999) allowed closer investigation of the distribution of birds along the west coast in relation to the distribution of aquaculture installations (mussel and salmon farms) in these areas.

## Methods

### Population movements along the Cowal Peninsular and L. Striven mussel farm

Fortnightly counts were carried out along the coast of the Cowal peninsular, Argyll, (see Map, Appendix I) from Ardentinny to Loch Riddon, the Burnt Islands and the East Coast of the Isle of Bute, including the long-line mussel farm in Loch Striven (this being the only aquaculture site in the survey area). The counts started in November 1996, and continued until August 1997. The survey area was split into 25 roughly equal lengths of coastline in 2 main sections, and numbers of male, female, and immature eiders were counted in each area. Counts took two days to complete, one day for each section, with counts beginning at 9am, and ending around 3pm each day.

Areas were then grouped into four categories as follows;

1. Sea-Lochs – All sea-lochs in area; Lower half of Loch Long, Holy Loch, Loch Striven (excluding birds feeding on the mussel farm) and Loch Riddon.
2. Islands – The Burnt Islands; Situated at the south end of Loch Riddon, this group of 3 small, low-lying islands (the largest about 100m in length), are covered in rough grass, small bushes and a few trees, and are known locally as a major breeding site for eiders.
3. Open Coastline – The longest stretch of coast in the survey area; From the end of Loch Long in the east to the Kyle's of Bute and the East side of the Island of Bute down to Scoulag Point, excluding all sea-lochs mentioned above.
4. The mussel farm opposite Glenstriven, Loch Striven.

**Clyde and Argyll eider surveys – September 1998 and April 1999**

Counts of eiders were made along almost the entire coastline from Loch Ryan in the south-east to Ardnamurchan Point in the north-west. The whole of the Clyde up to Erskine, all the islands of Argyll and Bute, and all of the sea lochs of Argyll and the whole of Loch Linnhe and Loch Eil were included in the census area. The coastline was broken up into a number of subsections for compiling results (See Table 3). September counts were mostly made over a ten-day period in mid-September 1998. April counts were made during the period 8-24 April 1999, with most being made during the period 15-18 April. The assumption was made that eiders will not move between islands or between distant parts of coast within this survey period, but wherever possible, counts on adjacent areas were arranged to be made on the same date. All counts were of adult male eiders, immature male eiders and female eiders, providing information on the age and sex ratio in each area. We assumed that eiders would all be visible from the shore rather than being far out to sea. This assumption was tested to some extent by those counters who travelled by ferries to the islands and were able to watch for eiders further offshore during these crossings. Counts were made by a team of volunteers, all using the same procedure.

**September 1999 counts – Importance of Aquaculture sites**

Mostly between 11 and 19 September, 1999, counts were undertaken along the whole of the North and West of Kintyre coastline and islands as described above. During this survey however, the presence of eiders in the immediate vicinity of any salmon or mussel aquaculture installations (within 200m) was noted separately from counts of eiders not associated with aquaculture sites.

## Results

### Population movements in the Cowal peninsular and L. Striven mussel farm

Results of the Cowal peninsular surveys indicated that different areas showed different changes in both population numbers and composition throughout the ten-month study period (Figure 1). The general trend seen in the area as a whole was that the total number of birds remained constant from the start of the survey (November) through until the following March, followed by some minor fluctuations from April until June, then a large increase in numbers from July to August.

### November-March

The total number of eiders found in the study area from November until March was remarkably constant (1218 ± 26sd), with the average number of males to each female also remaining quite static (1.40 ± 0.06). The distribution of birds throughout the study area (expressed as the percentage of the total number of birds in each habitat-type) also remained quite constant throughout this period (Table 1), with the exception of the mussel farm which showed a slight drop in numbers, but no real change in sex-ratio.

When the male to female ratios were compared for the period between November 1996 and March 1997 (selected as a period of stasis with regard to numbers of birds) with a repeated measures ANOVA, there were significant differences between areas ($F_{2,4} = 25.87$, $p < 0.001$). Subsequent Tukey tests showed that the male to female ratio was significantly higher at the mussel farm ($p < 0.01$), than in the other two habitats (Figure 2).

Table 1. Changes in the distribution of eiders on Cowal peninsular, Argyll between four different habitats from November 1996 to March 1997.

| | Percentage of total number of birds in each habitat | | | |
|---|---|---|---|---|
| Month | Coastal | Sea-Lochs | Mussel-farm | Islands |
| November | 47 | 35 | 17 | 1 |
| December | 57 | 26 | 17 | 1 |
| January | 54 | 24 | 20 | 1 |
| February | 59 | 28 | 12 | 1 |
| March | 57 | 28 | 12 | 3 |
| Mean value | 55 | 28 | 16 | 1 |

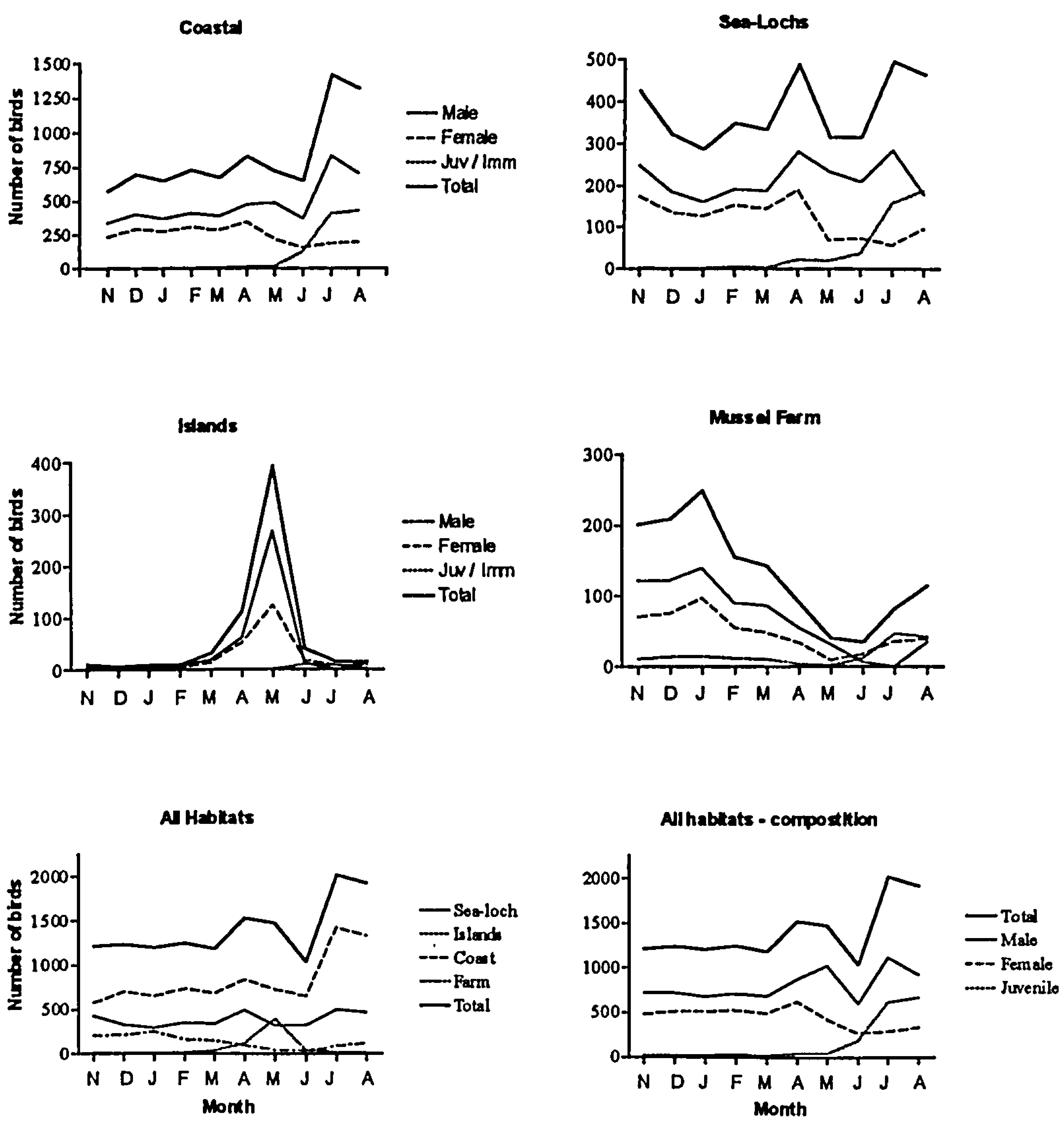


**Figure 1.** Monthly changes in numbers of eiders in three habitat types within the Cowal peninsular, the Loch Striven mussel farm and the total numbers of birds in each habitat and the numbers of males, females and juveniles in the study area from November 1996 until August 1997.

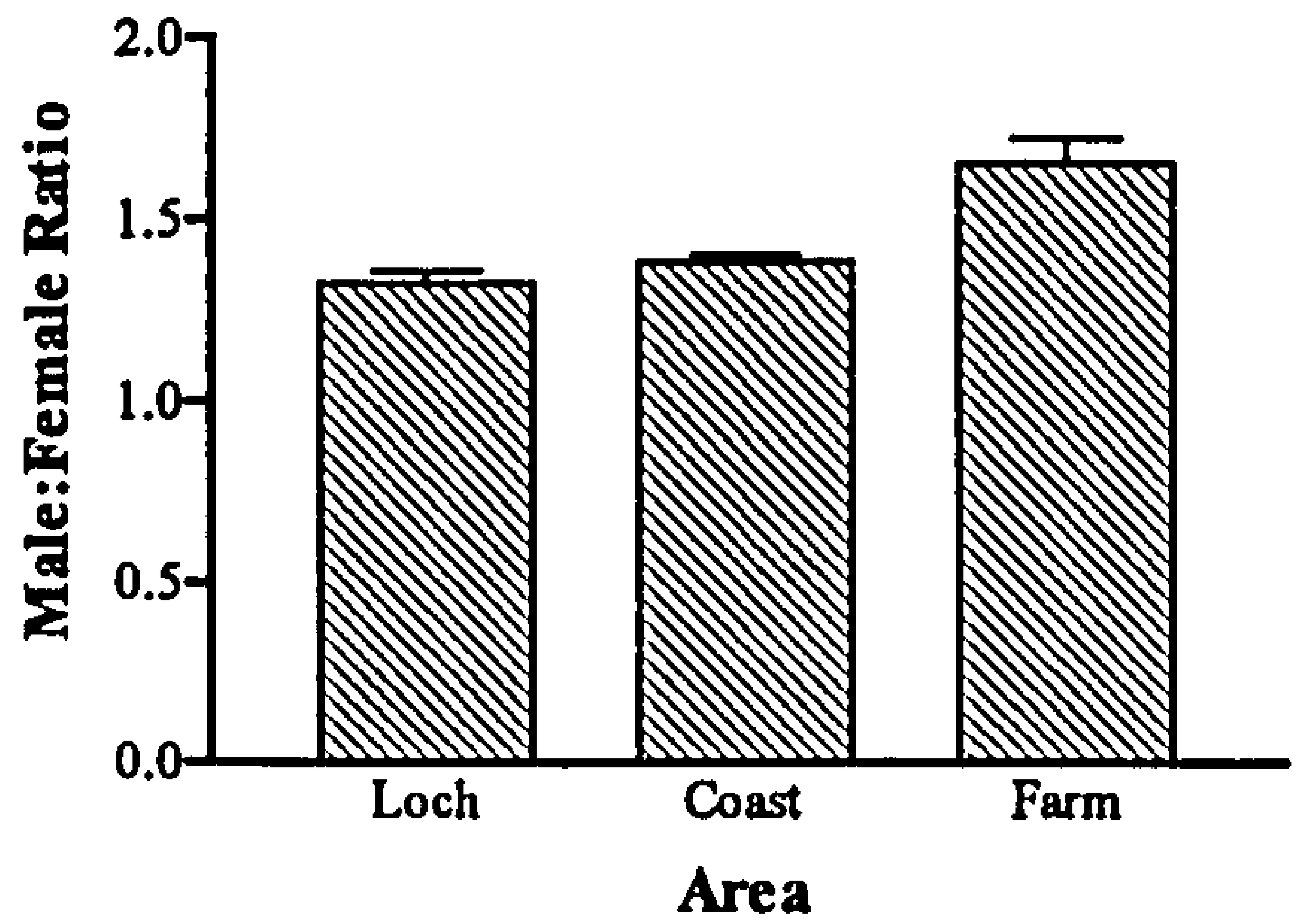


**Figure 2.** Male to Female ratios of eiders in three habitats (Sea-lochs, Open coastline, and the Mussel farm in Loch Striven) and SEMs on the Cowal Peninsular, Argyll, from November 1996 to March 1997.

## April-June

From April until June the patterns become a little more complicated. There is an increase in the total number of birds in April, the numbers remain similar in May, and then decline rapidly in June. The increase in April is largely as a result of increasing numbers of males in all areas apart from the mussel farm (where both male and female numbers decline throughout this period). In May, numbers of males continue to rise, but female numbers decline for this month and the next. In June there is also a large drop in the number of males in all areas.

The habitat displaying the most radical changes in numbers during this period is around the Burnt Islands. Previously there were extremely few eiders (Nov-March; mean number = 14.6 ± 9.9), the numbers increased slightly in April, then peak in May at just under 400 individuals (an increase of over 2500%, and from 1.2% of the total population in November-March to 26.7% in May). Following this increase there is an equally rapid decline in numbers to similar levels as before. Other important changes during this period are that numbers of birds at the mussel farm continued to decline, and the total number of juveniles began to increase in all areas in June.

**July-August**

In July and August the total number of birds in the study area increased to around 2000, an increase of 62% from the November-March levels. This increase was largely due to a great increase in the numbers of juveniles in all areas (Table 2). These increases were mainly along the open coastline and within sea-lochs, and looked to begin to level out in August.

**Table 2.** Changes in the number and percentage make-up of the total population of juvenile eiders in Cowal Peninsular from November 1996 to August 1997.

| | November-March | April-June | July-August |
|---|---|---|---|
| Mean (±SD) no. Juveniles | 19.7 ± 3.5 | 86.1 ± 83.7 | 641.9 ± 35.9 |
| % as Juveniles | 1.6% | 6.4% | 32.3% |

Numbers of males also rose rapidly in July, mainly in coastal areas, to a similar level to that observed in May, but began to drop again in August. Numbers of females in all areas remained reasonably low, but showed signs of increasing slightly again in August.

**September and April counts - Argyll**

Over the whole study area, the April count gave an estimate of 17,996 eiders. The distribution of these birds is shown in Table 3. 12,743 (71%) of these birds were within the Clyde, and only 5,253 (29%) were in the rather larger area west and north of Kintyre to Ardnamurchan. The September count gave a total of 16,449 eiders. Only 1,910 eiders were counted in the west and north of Kintyre, whereas in April there were 5,253 birds in that area, an increase of 3,343. There was a decrease in numbers in the Clyde, from 14,539 to 12,821 (12% decrease).

**September 1999 counts – Importance of Aquaculture sites**

Counts in North and West Kintyre in September 1999 gave a total of 3167 eiders (Table 4). Of this total, 197 birds were found feeding on, or in close vicinity to mussel farms (6.2% of the total in the survey area), and 595 were found at salmon farms (18.8%). This represents 25% of the eiders in this survey area, and 53% of birds in the locations that do have salmon or mussel farms.

**Table 3**. Summary data from counts of Eiders in April 1999.

| Location | Number in Sept. 1998 | Number of eiders in April 1999 | % immature | Males per female | Change in number Sept. 98 to April 99. |
|---|---|---|---|---|---|
| Loch Ryan to Largs, Clyde | 2089 | 3351 | 5.6 | 1.85 | +1262 |
| Largs to Gourock, Clyde | 1059 | 403 | 2.6 | 1.61 | -656 |
| Estuary, Gourock-Craigendoran | 797 | 262 | 7.6 | 1.72 | -535 |
| Arran, Clyde | 318 | 1161 | 6.5 | 2.28 | +843 |
| Great and Little Cumbrae, Clyde | 685 | 1510 | 1.4 | 1.57 | +775 |
| Gareloch, Clyde | 2156 | 719 | 7.8 | 1.63 | -1443 |
| Loch Long/Goil, Clyde | 2960 | 954 | 15.7 | 2.24 | -2006 |
| Holy Loch, Clyde | 344 | 147 | 15.0 | 2.29 | -197 |
| Bull Rock to Loch Striven, Clyde | 796 | 400 | 6.5 | 1.49 | -396 |
| Loch Riddon and Kyles, Clyde | 249 | 309 | 3.2 | 1.41 | +60 |
| Bute & Inchmarnock, Clyde | 949 | 2197 | 1.0 | 1.76 | +1248 |
| Loch Fyne, Clyde | 1558 | 916 | 3.7 | 1.85 | -642 |
| East coast of Kintyre, Clyde | 579 | 492 | 16.8 | 3.24 | -87 |
| **Clyde Total** | **14539** | **12821** | **7.2** | **1.92** | **-1774** |
| West coast of Kintyre | 354 | 236 | 1.7 | 1.21 | -118 |
| Gigha | 25 | 498 | 7.6 | 1.61 | +473 |
| West Loch Tarbert | 110 | 213 | 0.0 | 1.37 | +103 |
| Islay | 283 | 594 | 5.4 | 1.97 | +311 |
| Jura | 35 | 30 | 6.7 | 3.80 | -5 |
| Colonsay | 30 | 416 | 3.8 | 1.67 | +386 |
| Ardpatrick Point to Oban | 213 | 180 | 3.3 | 1.29 | -33 |
| Scarba, Seil, Luing | 0 | 380 | 3.1 | 1.35 | +380 |
| Kerrera | 0 | 180 | 3.0 | 1.44 | +180 |
| Lismore | 54 | 220 | 4.2 | 1.58 | +166 |
| Loch Etive | 0 | 40 | 10.0 | 2.00 | +40 |
| Mull | 528 | 581 | 9.3 | 1.93 | +53 |
| Coll | 45 | 339 | 2.4 | 1.38 | +294 |
| Tiree | 159 | 668 | 5.4 | 1.32 | +509 |
| Connel to Loch Eil | 66 | 245 | 4.9 | 1.48 | +179 |
| Morven coast to Ardnamurchan | 8 | 433 | 6.5 | 1.60 | +425 |
| **N & W. Kintyre Total** | **1910** | **5253** | **4.8** | **1.69** | **+3343** |
| **Total (all areas)** | **16449** | **18074** | **5.9** | **1.79** | **+1569** |

**Table 4.** Counts of eiders in September 1999 in relation to mussel farms and salmon farms

| Location | Total count | Aquaculture present? | Number at mussel farms | Number at salmon farms | % on aquaculture installations |
|---|---|---|---|---|---|
| West Loch Tarbert | 62 | ✗ | 0 | 0 | 0 |
| Islay | 490 | ✗ | 0 | 0 | 0 |
| Jura | 0 | ✗ | 0 | 0 | 0 |
| Colonsay | 517 | ✗ | 0 | 0 | 0 |
| Scarba, Seil, Luing | 0 | ✗ | 0 | 0 | 0 |
| Lismore | 0 | ✗ | 0 | 0 | 0 |
| Coll | 289 | ✗ | 0 | 0 | 0 |
| Tiree | 306 | ✗ | 0 | 0 | 0 |
| West coast of Kintyre | 247 | ✓ | 0 | 0 | 0 |
| Loch Etive | 0 | ✓ | 0 | 0 | 0 |
| Ardpatrick Point to Oban | 162 | ✓ | 0 | 22 | 14 |
| Gigha | 31 | ✓ | 0 | 10 | 32 |
| Mull | 248 | ✓ | 159 | 9 | 68 |
| Connel to Loch Eil | 645 | ✓ | 16 | 423 | 68 |
| Morven to Ardnamurchan | 148 | ✓ | 0 | 141 | 95 |
| Kerrera | 22 | ✓ | 22 | 0 | 100 |
| **TOTAL** | 3167 | | 197 | 595 | 25% |

## Discussion

Movements of eiders along the Cowal Peninsular described in this study tend to fit in with the descriptions of the birds annual cycle given in general literature (e.g. Milne 1976, Galbraith 1987). It has been hypothesised that prey depletion can drive changes in the winter distribution of eiders (Guillemette and Himmelman 1996), although it seems that in this study it has not occurred on any large scale. However, the decline in eider numbers feeding at the L. Striven mussel farm is consistent with this. That farm went out of business during winter 1996-1997 and eiders removed a very high proportion of the mussel stock by spring 1997 (R. Clarke, *pers. comm.*)

As with many wildfowl species, there was an observed bias in the sex ratio towards males. There are a number of possible explanations for these biases (as discussed by Choudhury and Black, 1991), although many are based upon females migrating further south than males (which seems unlikely in a population with very small migratory movements). One of the most feasible explanations in this case may be increased mortality for females, particularly during the incubation period.

Another possible reason for differences in the magnitude of this bias between adjacent areas may be due to behavioural dominance of one sex over the other (Gauthreaux 1978). Eider attendance at the mussel farm tended to be highest in the middle of winter, and did not follow the same pattern in numbers shown in sea-lochs (in which it is situated). This difference suggests that eiders were using the mussel farm during periods when costs of foraging on natural mussel beds were particularly high. The high quality prey that mussel farms offer (Dunthorn 1971), particularly during such periods of stress to foraging birds may therefore increase competition and aggression within flocks. The higher proportion of males to females feeding at the mussel farm may be due to a higher degree of female exclusion by males, particularly as flock sizes increase and aggressive interactions become more common (Galbraith 1987).

Birds on the East Coast of Scotland tend to nest on the mainland in large colonies (Milne 1974, Pounder 1974). The large number of islands on the West Coast of Scotland provide good nesting grounds for eiders, decreasing the risk of predation from terrestrial predators, and reducing human disturbance (Laurila 1989). However, the birds in this study may not be solely island nesting. As the breeding season approached, the number of birds in the island area in this study increased dramatically, but a small peak was also noted in the sea-lochs. Competition for nesting space on the islands may lead to some birds nesting on the mainland, the least disturbed areas of these tending to be around the sea-lochs. However, if the increases in numbers in sea-lochs during this period are due to birds seeking nesting areas, then the potential effect to mussel farmers (whose farms are generally sited within these lochs) should be minimal. Females do not feed during incubation, and will leave the nest only to drink, metabolising up to 40% of their body weight during this period (Milne 1976). Even after hatching, more emphasis is placed upon provisioning chicks than on female feeding. Post-nesting feeding site fidelity tends to be stronger than nest-site fidelity in eiders (Bustnes & Erikstad 1993) because recruitment and survival is strongly related to duckling condition (Mendenhall & Milne 1985, Christensen 1999). The reduction in numbers of females immediately after nesting could be due to movement to those feeding areas high in invertebrate prey for ducklings (which may be outside of the study area), or to a lesser extent as a result of increased female mortality during this period (Garden *et al.* 1964, Flint *et al.* 1999).

The large rise seen in numbers of juvenile birds observed during June and July accounts for a large proportion of the large increase in total number of birds in the study area during this period. These will be first year birds, not only those raised within the study area, but also immigrant birds searching for good feeding grounds. During this period, competition for resources may not be too high, as adults move to quiet moulting grounds. As a result of this decreased competition, we see a great increase in the proportion of immature birds on the mussel farm during this period. This proportion begins to decrease again in August, as adults return from their moulting grounds and competition for this resource increases.

Numbers of immature birds in the study area in September and October are likely to fall to similar levels as seen the previous winter. This should occur as birds either move out to other - perhaps less profitable - feeding grounds (Swennen 1990), or as the higher mortality generally seen in juvenile birds takes its toll (e.g. Coleman & Milton 1980).

The results of the September and April counts suggest that there is a very much larger breeding population of eiders in the Clyde than in the isles and western sea-lochs of Argyll. However, there is some evidence from these counts to support the view that many eiders from the north and west of Argyll move into the Clyde for the winter. However, seen in the context of a population of about 17,000 birds wintering within the Clyde, this movement of about 3,000 represents only a small proportion of the birds wintering in the Clyde that apparently move to breed outside the Clyde. The much greater concentration of eiders in the Clyde may perhaps be due to differences in coastal productivity between the Clyde, with many sources of natural and human enrichment of nutrients, and the less rich waters of the open west-coast sea and sea-lochs.

It is difficult to infer seasonal movements from only two counts per year, and the distribution pattern throughout winter may differ from that in September. Colin Galbraith (1987) found evidence for movements of eiders from west coast sea lochs into the Clyde by marking individual eiders and observing their movements. The numbers marked were small, and there would be some interesting observations to be made if it was possible to mark eiders from areas such as Coll, Tiree, Gigha and Colonsay, where breeding season numbers are very much higher than autumn numbers. Probably marking birds and following individual movement patterns would be more likely to tell us how eiders move around this region than making counts over the whole area in more months of the year. Arranging one or two counts is a major undertaking and mid-winter weather would be likely to make counts at that time of year impractical.

The *Atlas of breeding birds* data suggest that the UK eider population has been increasing by about 2.5% each year from the late sixties (Sharrock 1976, Gibbons *et al.* 1991). Historical data on eiders in the west of Scotland, currently being reviewed by Chris Waltho, also show that eider numbers in this area have been, and are still, increasing. Despite these overall increases, in some areas, such as Shetland, populations of eiders are falling, although it is not understood why this may be so (Heubeck 1993, Johnstone 1999). Dramatic reductions in prey availability have been previously associated with mass starvation of eiders in the Dutch Wadensee (Suter & Van Eerden 1992, Beukema 1993), but no such reductions seem to have been documented in Shetland. In contrast to this, the increasing population of eiders in the rest of Scotland suggests that the birds are not yet limited by the amount of bivalve prey available.

It could be argued that these population increases could be due to the expanding aquaculture industry in Scotland, but this is unlikely, as these trends were evident before the industry had become properly established. However, this is not to say that it may not have an effect on population growth in the future.

Large-scale changes in the utilisation of the Wadensee (including massive increases in numbers of cultured mussels) over the past fifty years has undoubtedly altered the numbers and community structure of birds wintering there (De Jonge *et al.* 1993). In the southern U.S. states, marked changes in the wintering distributions of cormorants and wading birds have also been associated with the aquaculture industry (Fleury & Sherry 1995, Glahn & Stickley 1995). Because eider are long-lived birds, they have plenty of scope to learn that mussel and salmon farms are profitable feeding grounds, and birds may become established at a site over a period of years if they are not deterred. This survey has shown that the provision of such feeding stations does affect the distribution of wintering eiders, although large numbers were also noted away from aquaculture. The high proportion of eiders feeding at salmon farms was an unexpected finding, and has not been reported before. Salmon farmers, unlike mussel farmers, have no reason to scare eiders away, and indeed may be pleased to have large flocks of eiders present, both because the ducks are attractive and interesting birds, and because their feeding on mussels and other fouling organisms on salmon cages will help to keep these structures relatively free from biofouling.

While local distribution of eiders is clearly affected by the presence of aquaculture, it is not clear whether overall numbers are affected since too few data exist on eider population trends at the local level in west Scotland.

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# Chapter 3

# A comparison of the feeding behaviour of eiders on natural mussel beds and at mussel farms

**Abstract**

This study compared the behaviour and foraging patterns of eiders feeding on suspended-culture mussel farms and on wild mussel beds. Activity patterns of wild-feeding eiders were related to tidal height, whereas feeding was independent of the tide for eiders feeding at mussel farms, as tidal activity has no effect on the depth of the mussels. Habitat utilisation changed with tidal height for wild-feeding birds, with different habitats showing different feeding profitabilities (defined as frequency of dives carried out by each bird). Dive frequency was much higher in the channel of the loch (17.82±0.82SEM dives per hour) and along the steep sides of the loch (22.26±1.47), than in the centre of the loch or along the shore (2.46±0.59 and 2.271±0.89 respectively). Feeding activity peaked at high tide, whereas at lower tidal heights birds often roosted on the shore, probably a behavioural adaptation to aid recovery from the costs of diving. Wild-feeding birds showed a preference for feeding at depths between 4.50 and 6.75m. Eiders feeding on mussel farms exhibit more 'cautious' feeding behaviour than those feeding on natural food sources, presumably as a result of continual disturbance from mussel farm owners. However, the advantages of feeding at mussel farms, in terms of the high quality prey and independence of tidal constraints to the foraging regime apparently outweigh the costs in most farms. Birds feeding on natural mussel beds dived on average over three times as frequently as those feeding on mussel farms, and so clearly had to work harder to meet energy requirements.

## Introduction

Daily patterns in the foraging behaviour of most terrestrial animals are generally related to daylight, with animals exhibiting diurnal, nocturnal or crepuscular activity budgets. Only factors such as the weather and/or scarcity of resources may alter these general patterns. However, for animals living in, or utilising the marine environment, the action of the tides can play a large part in determining their activity budgets.

Tidal action can operate on many levels in determining the behaviour patterns of animals, and is usually more pronounced in coastal areas. Along the coast, tidal action is responsible for movement of nutrients between different habitats and for the exposure of the intertidal zone to water or air and the predators adapted to each respective environment. For example, gulls (*Laridae*) feeding on intertidal mussels (Irons *et al.* 1986), or intertidal mudflats that provide extremely important feeding grounds to many species of wintering wading birds. Only at low-tide are the prey items living in the mud or sand available to the birds (Boates & Smith 1989). As a result, the feeding patterns of these birds are strongly influenced by tidal stage, with some wading birds feeding at low tide during the night as well as the day to maximise their daily intake (Hoetker & Hermann 1999, Fasola & Biddau 1997, Dodd & Colwell, 1996).

For piscivorous birds feeding in coastal habitats, their feeding regime is likely to be influenced by that of their prey, which are also often influenced by the tidal cycle. Many small fish move up and down the intertidal zone with the ebb and flow of the tide, either as a method of increasing food intake or as a means of escaping piscine predators (Fowler *et al.* 1999, Gibson and Robb 1996, Sogard *et al.* 1989). As a result, these species can become more accessible to avian predators (Coyle *et al.* 1992, Watson *et al.* 1991, Draulans & Hannon 1988).

Eiders, generally feed on sessile or slow moving prey, their major food source being the blue mussel, *Mytilus edulis*. Because *Mytilus* is a sessile organism, their own susceptibility as a prey item will be governed by exposure or submersion by the tide if in the intertidal zone, and in the subtidal zone would be available to feeding eiders at all times. However, the energetic cost of diving is greatly affected by the depth at which the birds are feeding (Carbone 1996, Stephenson 1994). It could therefore be hypothesised that foraging eiders would maximise foraging effort when the tidal height minimises the energetic cost of diving.

In Scotland, the main method of mussel farming is suspended culture, which means that mussels are at a constant depth throughout the tidal cycle. The availability of such resources to foraging eiders may therefore prompt a change in their feeding pattern. The main aims of this chapter are to describe and compare the feeding behaviour of eiders feeding on wild mussel beds to that of birds feeding on farmed mussels.

## Methods

Flocks of feeding eiders were observed for eight days during March 1999 at Loch Creran Head, Argyll, an area with extensive natural mussel beds. Every ten minutes, from dawn until dusk, the number of eiders feeding in this area was recorded. The total number of dives carried out in a two-minute period by the whole flock was also recorded every ten minutes. From these data, the mean number of dives made per bird within the flock was then calculated for each ten-minute period.

Furthermore, the position of the flock was recorded every ten-minutes as being in one of four defined habitats within the loch. Preliminary observations of the feeding birds had shown that they would spend their time either on or very close to the shore (hereafter referred to as 'shore', between 0.5m and 1m in depth), in the main narrow channel of the loch ('channel', between 2 and 3m deep at chart datum), close to the steep sides of the loch ('loch sides', 3 to 5m deep at chart datum), or in the open water of the loch ('open water', over 20m deep at chart datum).

The dive data were used as a measure of feeding intensity, and compared with tidal height and flow direction, hour of the day, and the area or habitat being utilised.

Observations of the feeding activity of eiders on mussel farms were carried out on two adjacent long-line farms in the upper basin of Loch Etive for ten days during March 1998. The total number of eiders in the vicinity of the farms (within 200 metres) was recorded every five minutes from dawn until dusk, and the time, and total number of dives made by individual groups of eiders was recorded whenever the birds came in to feed at the mussel farm. From these data, hourly totals for the numbers of dives for each group of birds were calculated. In turn it was possible to calculate the mean number of dives carried out by a single eider each hour, or every two-minutes for comparison with the 'wild-feeding' birds. Diving frequency was then compared with tidal height and hour of the day. Data were only used for analysis for hours that preceded any disturbance caused to the birds by mussel farmers, or when there had been no disturbance to the birds by mussel farmers that day.

General observations of feeding behaviour, both on natural mussel beds and on farms were also recorded.

## Results

### General observations of feeding behaviour

The feeding behaviour of birds at mussel farms was very similar to that described by Galbraith (1986). Birds would arrive at the mussel farm shortly after first light, and would approach the farm in a tight flock. Shortly before reaching the lines, the birds would form into a single-file, before aggregating again within one or two metres from the header line, before making a series of reasonably synchronous dives and then moving back out into more open water again in a tight group. Birds were never seen to dive outwith the farm. Once in open water 200-300 metres from the farm, the flock would become less tightly packed, and would either sleep or preen for around half an hour before approaching the farm again to feed. Birds would tend to leave the site around dusk each day.

When feeding on the natural mussel beds in Loch Creran, as with the above, eiders would generally feed from dawn until dusk. However, unlike those birds feeding at mussel farms, when feeding on natural mussel beds, birds tended to remain in the area where feeding (diving) occurred, even during inter-bout intervals. The diving cycle of these birds was also a little less predictable than with individuals on mussel farms, with the inter-bout interval being considerably more variable.

Birds tended to arrive in both areas in small flying flocks, and leave in a similar manner. Once the birds had arrived, flight was an extremely uncommon observation, with the number of birds in each area remaining quite constant throughout the day.

**Feeding behaviour on natural mussel beds**

Diving rate per bird was initially examined with respect to tide height above chart datum, tide-direction and hour of the day using a three-way ANOVA. However, the direction of the tide seemed to have very little effect upon feeding rate ($F = 0.445$, df = 2, $p = 0.502$), so the calculation was repeated with the data on tidal direction removed, the results of which are displayed in table 1.

**Table 1.** Results of a two-way ANOVA to assess the factors that have an effect upon diving rate of eiders feeding upon natural mussel beds in Loch Creran, Argyll.

| | | SS | df. | F | Significance |
|---|---|---|---|---|---|
| Covariate | Tidal Height | 5.128 | 1 | 11.462 | 0.001 |
| Factor | Hour | 5.435 | 8 | 1.519 | 0.150 |
| Model | | 8.124 | 9 | 2.018 | 0.037 |

Therefore it can be said that the feeding regime of these 'wild-feeding' birds is governed by the height of the tide, and that the hour of the day has little or no effect. However, to examine why the diving rate of these birds varies with the tide, we must first compare the habitats that are utilised by the birds at different tidal heights (see figures 1, 2). A one-way ANOVA showed that there were significant differences in tidal height when birds were feeding in different areas ($F = 73.53$, df. = 3, $p<0.0001$). Tukey-tests revealed that birds utilised the main channel of the loch when the tide was higher than when all other habitats were preferred ($p<0.001$), and use the shore when the tide was lowest ($p<0.001$), birds tended to be found on the steep sides of the loch and in open deep water at intermediate tidal height ($p<0.001$).

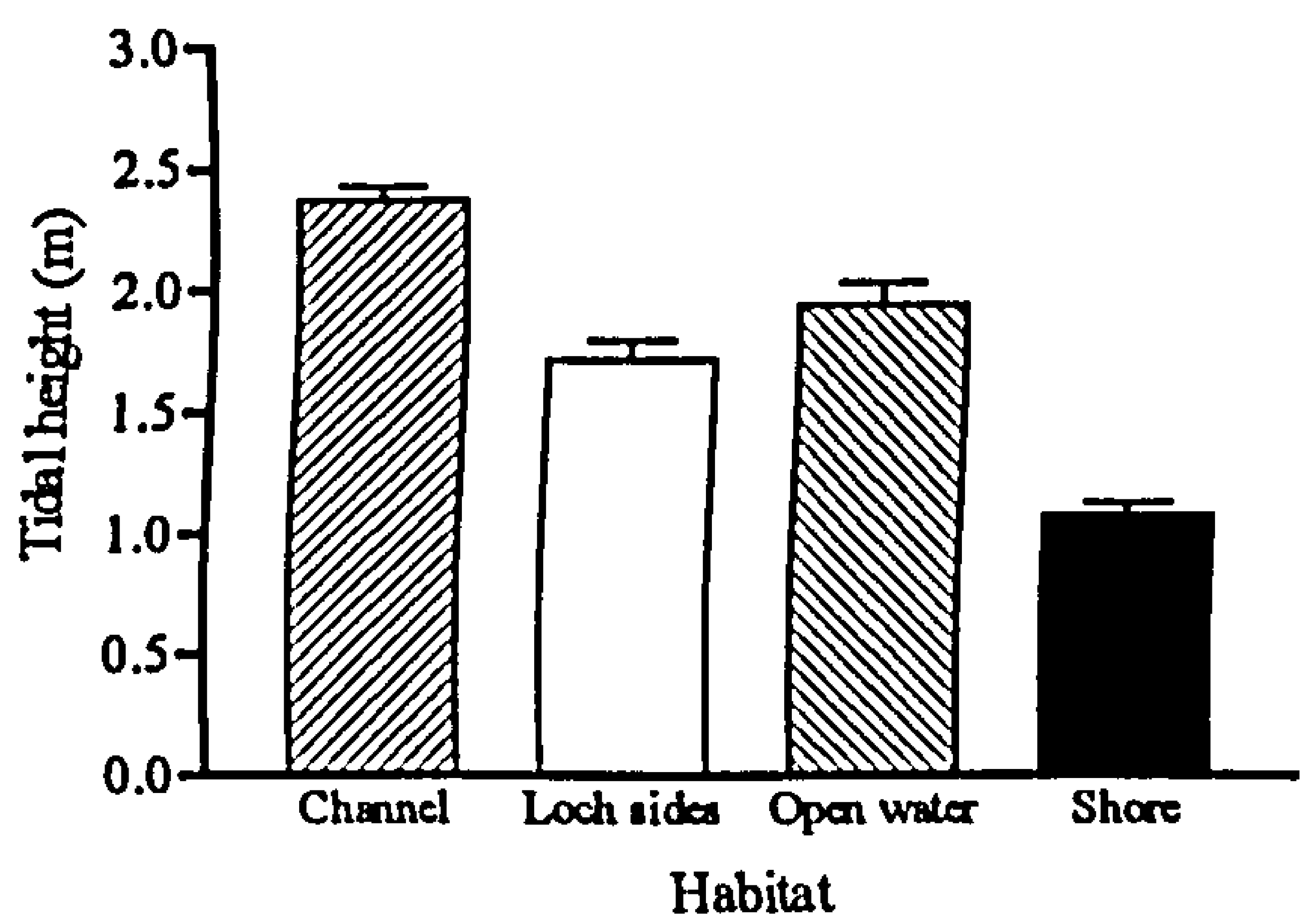


**Figure 1.** Mean (and SEM) of tidal height above chart datum observed for each habitat used by eiders in L. Creran.

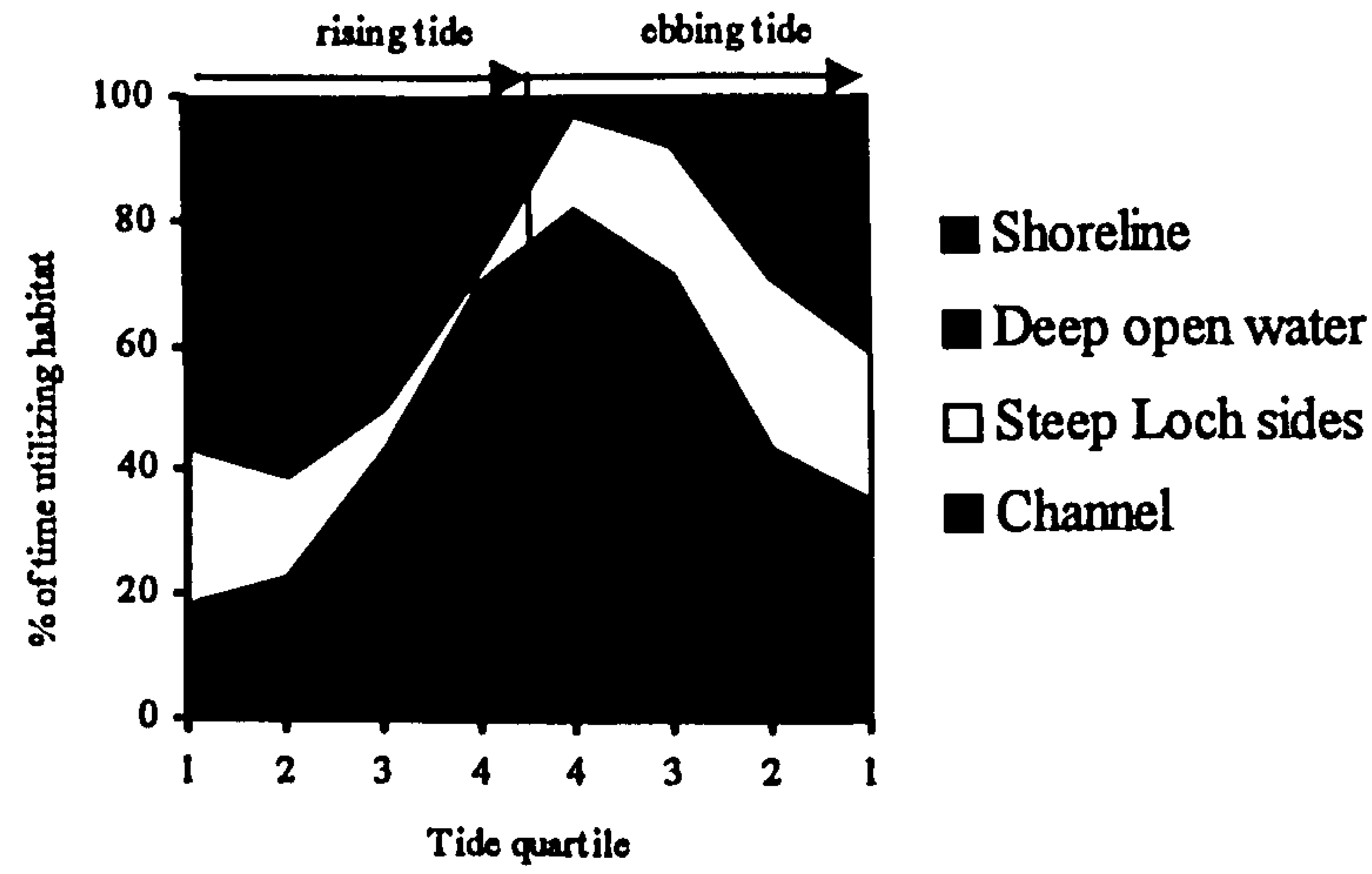


**Figure 2.** Area chart showing the percentage of time spent by eiders in each of four habitats in each tidal cycle (split into four quartiles, where 1 = low tide and 4 = high tide)

Feeding intensity, defined as dive frequency was significantly different across the four different habitats (Kruskal-Wallis, $U = 161.3$, df. = 3, $p<0.0001$, see figure 3). The mean number of dives made per bird was significantly higher when birds were in the channel or on the steep sides of the loch than when they were on the shore or in deep open water ($p<0.001$).

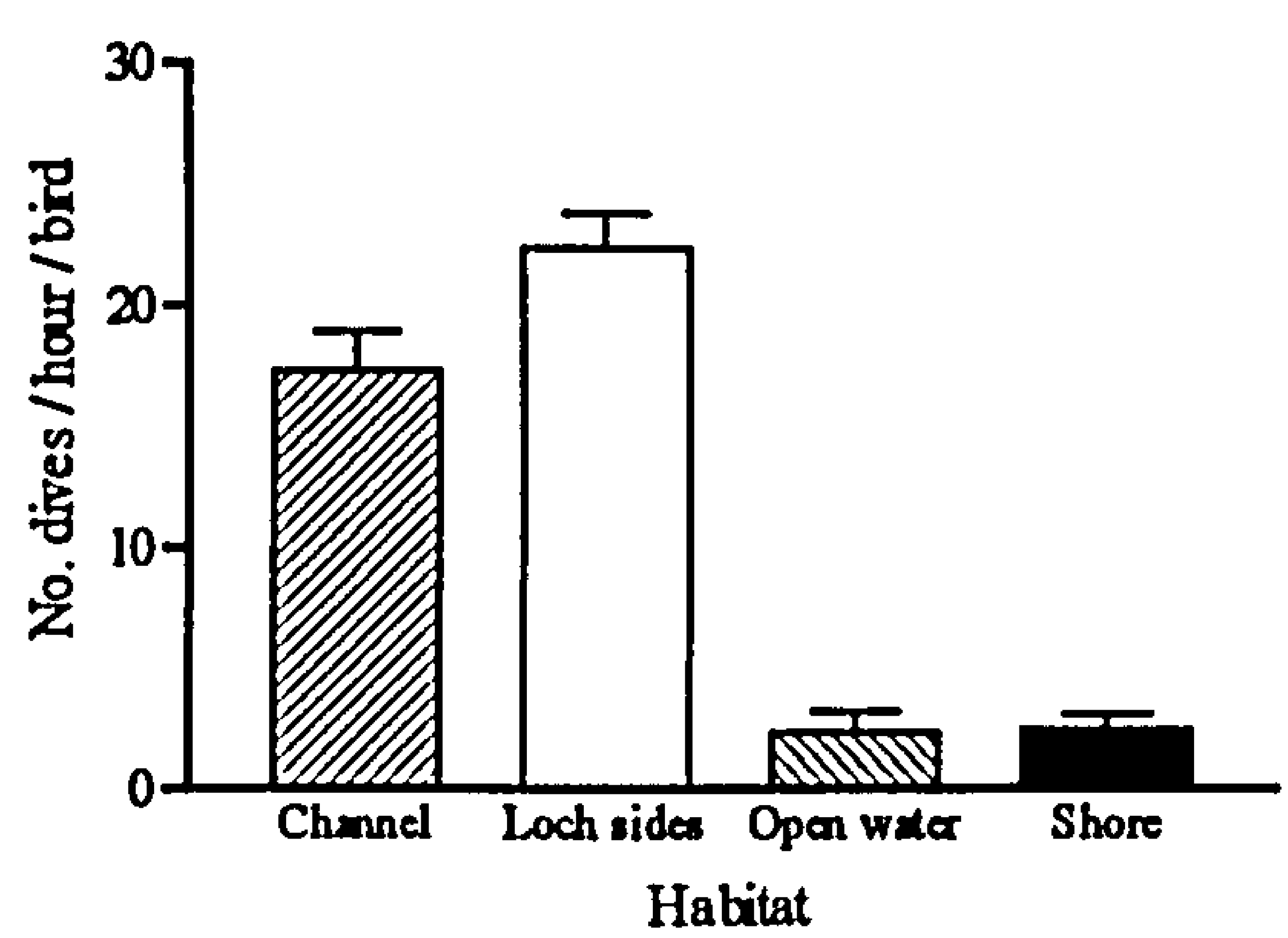


**Figure 3.** Mean (and 95% CI) number of dives per 2 minutes per eider feeding in each of the four designated habitats within L. Creran.

When this information is combined with that of the utilisation of the different habitats at different stages of the tidal cycle (figs 1 and 2), it is possible to estimate the number of dives each bird is likely to make throughout a full tidal cycle (figure 4 a, b).

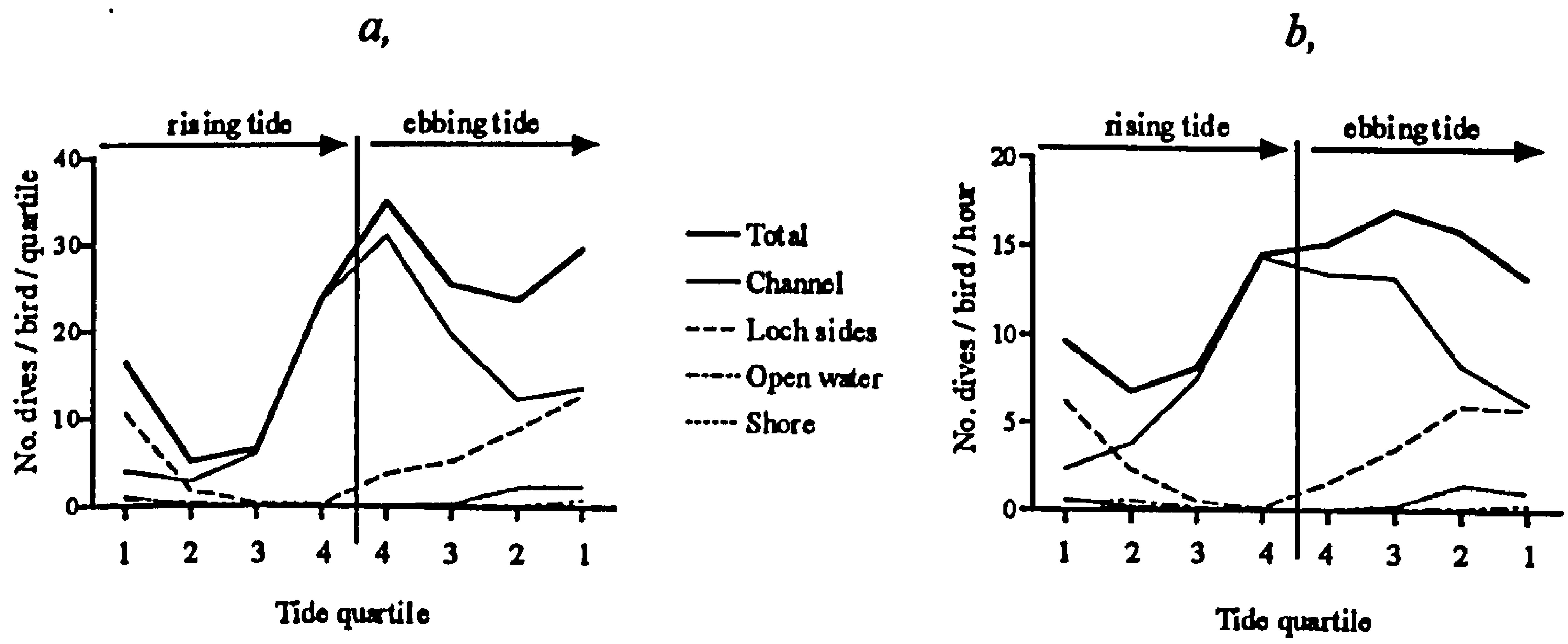


**Figure 4**. The effect of tide on diving frequency of wild-feeding eiders in Loch Creran, Argyll; a, The total number of dives predicted per bird in each quartile, and b, The mean number of dives predicted per hour in each quartile. The large difference in values between the rising and ebbing tide in *a* is a consequence of the prolonged ebb of the tide observed in Loch Creran (and many other sea-lochs). Chart *b* controls for this effect.

**Feeding behaviour at mussel farms**

A two-way ANOVA on the data collected from observations of feeding birds at the Loch Etive mussel farm showed no significant effect of tidal height or time of day on eider diving frequency (table 2). However, when the day was split into three periods, early morning (before workers would generally arrive), during the day (when workers would be on site), and late afternoon (workers would have left), there was a significant difference in feeding for different periods of the day ($F_{2,29}$=3.452, $p<0.05$, see Figure 5).

**Table 2**. Results of a two-way ANOVA to assess the factors that have an effect upon diving rate of eiders feeding upon natural mussel beds in Loch Creran, Argyll.

| | | *SS* | *df.* | *F* | Significance |
|---|---|---|---|---|---|
| Covariate | Tidal Height | $1.157e^{-3}$ | 1 | 0.458 | 0.504 |
| Factor | Hour | $1.748e^{-2}$ | 3 | 2.308 | 0.099 |
| Model | | $1.777e^{-2}$ | 4 | 1.760 | 0.166 |

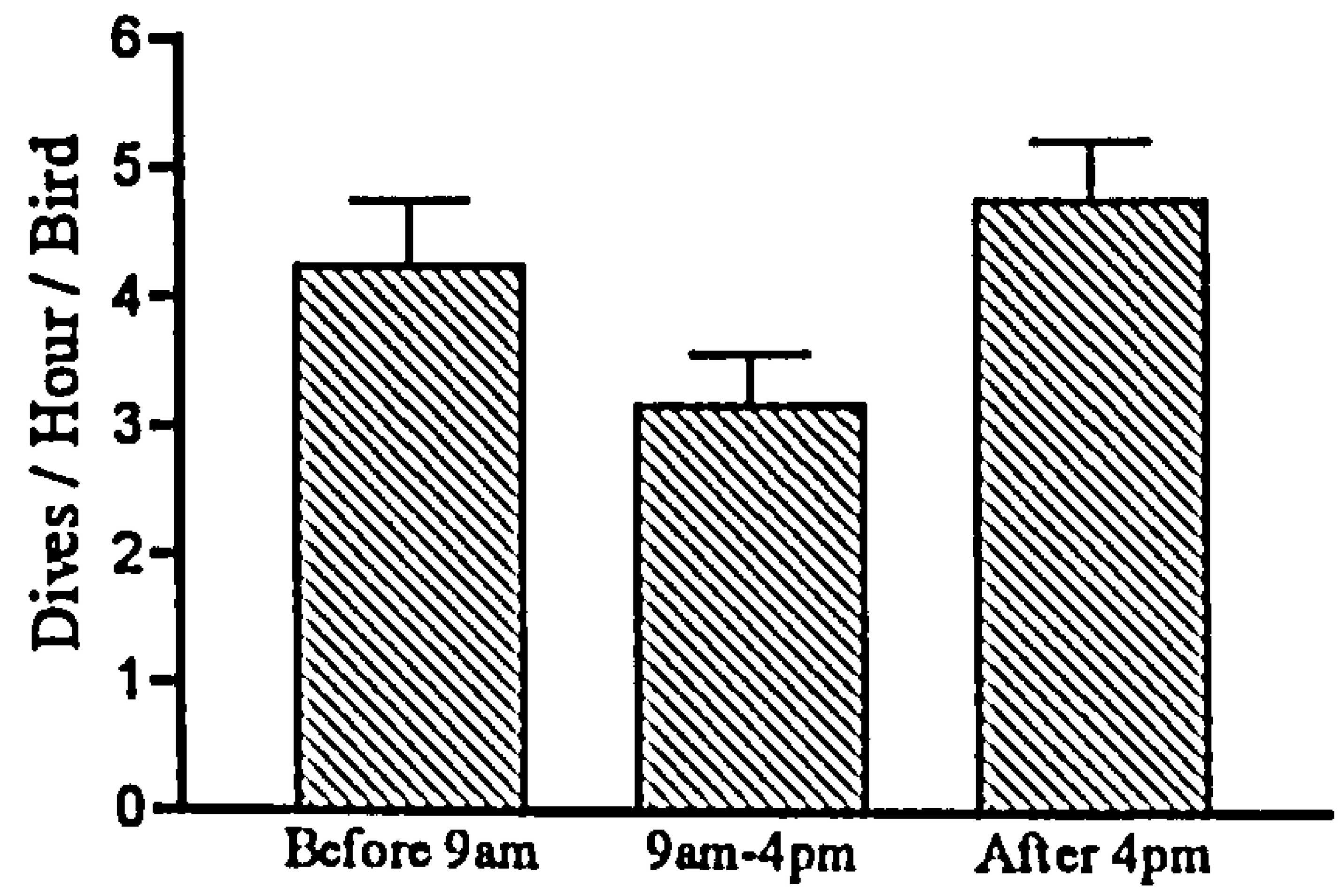


**Figure 5.** Mean (and SEM) number of dives made by individual eiders per hour in three periods of the day on a mussel farm, L. Etive, Argyll, March 1998.

**Comparison of foraging effort of eiders feeding on natural mussel beds and on mussel farms**

When the mean number of dives made per hour each day was compared, the dive rate of eiders feeding on natural mussel beds was significantly lower than that of birds feeding on wild mussel beds (Welch's corrected $t = 7.090$, df. = 6, $p<0.001$), the rate at the farm being only one-third of that on natural mussel beds (figure 6). Welch's t-test is used as there were significant differences in the variances of each group ($F_{6,8} = 10.82, p<0.01$).

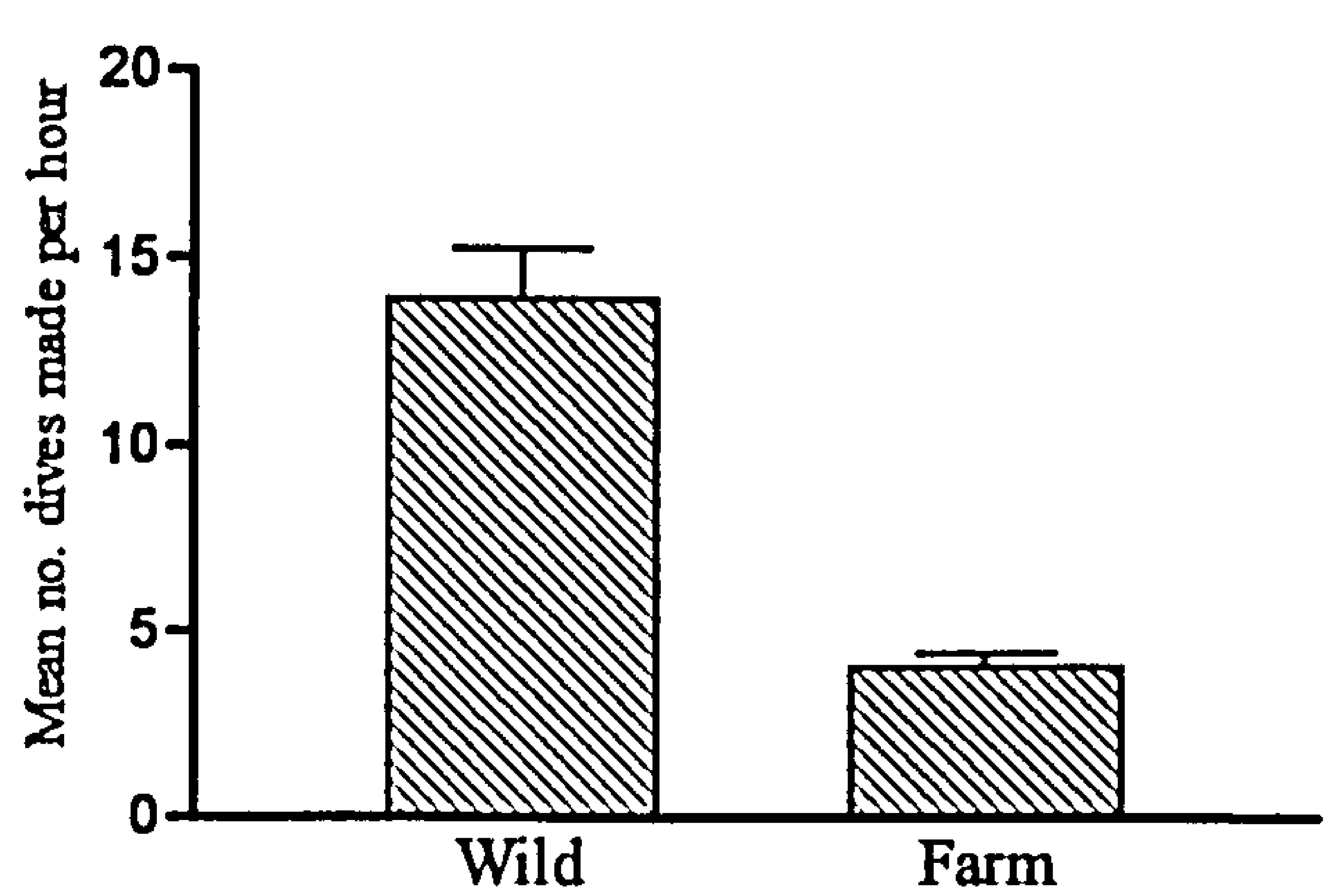


**Figure 6.** Comparison of diving frequency for foraging eiders between mussel farms and natural mussel beds.

**Discussion**

These results showed that the feeding regime of eiders on wild mussel beds is greatly influenced by tidal cycle. The differences that were recorded in diving frequency at different stages of the tide were attributed to differential use of habitats. There was a clear difference in the utilisation of the four habitat types, with two (the channel and the loch sides) being used for feeding, and the other two (open water and shore) being used when the birds were not feeding.

The two habitats utilised for feeding were preferred at significantly different tidal heights, although the mean dive frequency in each area was similar. Although the loch side habitat was used for feeding much less than the main channel, this suggests that as the tide drops, the relative profitability of feeding in the channel decreases. Guillemette *et al.* (1993) showed that foraging eiders would select areas with the highest concentrations of prey, generally less than six metres in depth. The depth of the water around the loch sides is slightly deeper than that in the channel (by 1 or 2 metres). This information, combined with the lower tide height observed when birds feed there, may suggest that the depth to which eiders dive remains reasonably constant. The general range of feeding depths observed in this study was therefore between 4.5 and 5.5 metres in the channel, and 4.75 and 6.75 when feeding near the loch sides. This may represent the optimal depth for eiders in this area, maximising the various cost/benefit trade-offs associated with diving depth, including energy expenditure to counteract buoyancy changes (Stephenson, 1994), thermoregulatory costs (DeVries & VanEerden, 1995), and prey selection (DeLeeuw & VanEerden 1992). However, habitat utilisation (and therefore dive-depth) may change throughout the year as prey depletion occurs (Guillemette *et al.* 1996).

Activities observed in the two habitats where feeding was minimal tended to be sleeping or preening. These periods could also be associated with prey digestion after prolonged periods of feeding, or with metabolic recovery after diving bouts.

Mussels are a relatively low energy prey in relation to their size. To satisfy their daily energy demands, foraging eiders therefore have to consume vast quantities of mussels. Because the mussels have to be processed whole, the ingestion rate often exceeds the digestion rate. This phenomenon is referred to as a digestive bottleneck and has been described in a number of other species, such as oystercatchers *Haematopus ostralegus* (Kersten &Visser 1996), whimbrels *Numenius phaeopus* (Zwarts & Dirksen 1990) and hummingbirds (Diamond *et al.* 1986). Such digestive constraints limit the pattern of feeding, and as a result, the foraging behaviour of eiders tends to consist of alternating bouts of feeding and resting (Guillemette *et al.* 1992).

DeLeeuw (1996) demonstrated energetic constraints of diving to tufted ducks, *Aythya fuligula* where water temperature was an important factor, with colder temperatures increasing the time needed for recovery from feeding bouts. DeVries & Van Eerden (1995), who demonstrated the costs of diving in terms of thermal conductance, described similar results. They suggested that leaving the water in order to reduce thermoregulatory costs is a behavioural option that diving birds can use to make them more flexible in adjusting their feeding time to meet increasing energetic requirements.

There was no observed effect of time of day on the activity pattern of birds feeding on wild mussel beds. In the observed situations, it seems that birds were not feeding during the night (as they flew into the area each morning, and away each evening), as some shorebirds do (see introduction) and tended to stay in the area for the same amount of time each day. Changes in the timing of the tide means that the amount of time available for feeding in the preferred habitats each day will vary. Swennen *et al.* (1989), showed that oystercatchers, when faced by similar time stresses in relation to prey availability and tidal changes, would respond by increasing their intake rate during foraging bouts to obtain the same mean consumption per tide. Guillemette (1998) showed that to compensate for seasonal changes in day-length, wild-feeding eiders would increase or decrease intake rate accordingly. Similar strategies, on a shorter time-scale may exist in eiders to cope with time-stresses brought on by the tidal cycle.

Differences described in the general feeding behaviour of eiders feeding on natural mussel beds and on mussel farms are likely to be as a result of the risks associated with feeding on the latter. On the mussel farms described in this chapter, birds are regularly chased from the sites, and various deterrent devices have been employed in an effort to reduce predation by eiders. As a result, birds would only stay in the immediate vicinity of the farms whilst diving at the ropes. Time between diving bouts was spent in open water distant from the farm. This behaviour would serve to minimise the time spent near the farm and therefore the risk of detection by mussel farmers. The higher degree of diving synchronicity observed by birds at mussel farms may also serve the same purpose, as Schenkeveld & Ydenberg (1985) found that it was an adaptation to reduce kleptoparasitism by gulls in surf scoter, *Melanitta perspicillata* flocks. This is in marked contrast to that of birds feeding on the wild mussel beds, where diving and time between diving bouts often occurred in the same area, and diving synchronicity was less pronounced.

As hypothesised, intensity of feeding on farmed mussels was found to be independent of tidal height. Because of this fact, eiders feeding on mussel farms are only restricted by hours of daylight or by disturbance or deterrent by mussel farmers (see chapter 6). Although there was initially no significant effect of time of day, when these data were pooled, we found that feeding intensity was higher at the start and end of the day. This pattern is similar to that of many diurnal foragers, where these increases are associated with repletion of energy stores in the morning, and in anticipation of non-feeding at the end of the day. However, the observed pattern could also be due to the birds maximising their feeding rate at the times when mussel farmers are least likely to be on-site.

According to the work of Hamilton *et al.* (1999) and Bustnes & Erikstad (1989), foraging eiders select size-classes of mussels to minimise the amount of shell ingested each day, and not to maximise energy intake alone. Mussels grown by suspended culture grow on ropes from the top metre of the water column to eight or ten metres in depth. Because they are constantly submerged, they are not restricted in the amount of time that they can spend feeding each day. As a result, cultured mussels tend to be thinner-shelled and of a higher flesh content than similar sized intertidal individuals (Dunthorn 1971, Galbraith 1987). The constant relative depth of farmed mussels and the morphological differences outlined above therefore provide great benefits to foraging eiders. These benefits are demonstrated by the final set of results that diving frequency was more than three times higher for birds feeding on wild mussel beds than it was for those feeding at mussel farms. Such a difference represents a huge difference in the foraging effort of eiders feeding on the two different food sources.

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# Chapter 4

# Estimating the impact of diving ducks on the productivity of mussel farms in Scotland

**Abstract**

Questionnaires were sent to mussel farm leaseholders in Scotland to obtain farmers' assessments of the importance of diving duck consumption of farmed mussels. The most prevalent predator was the common eider *Somateria mollissima* with 97% of farmers reporting them as a pest. Loss of stock to goldeneyes *Bucephela clangula* was reported in 21% of replies. Whereas eiders take all size-classes of mussels, goldeneye concentrate upon very young mussels (<10mm shell length). There are about 80,000 eiders in Scotland, and mussels are their main food. About half of the population lives in areas where mussel farming is carried out. Individual eiders at mussel farms can remove up to 5 kg of mussels per day, as they drop a considerable amount while feeding. Many farms in Scotland attract 200 to 300 eiders during the spring. These birds may remove as much as a tonne of mussels per day if no action is taken to deter them. At such rates, the entire mussel crop can be lost in a few weeks of eider predation. The estimated direct cost to mussel farmers who try to minimise eider damage, in terms of lost stock, increased over the five years 1994-1998, averaging £4000 per farm per year. Seasonality of attendance of eiders at mussel farms showed a bimodal distribution, with a large peak in early spring (corresponding to a pre-breeding season increase in intake rate) and a smaller peak in the autumn. Completed questionnaires identified ten damage-reducing measures employed by farmers experiencing loss of stock to eiders. Perceived efficacies of such measured varied, with only the complete netting of farms giving unambiguous success. 69% of farmers suffering damage stated that there was a major further cost to deterring eiders in terms of labour and fuel.

## Introduction

Mussel farming is now a well-established industry in many areas of Europe, North America, Australia and Asia. In Northern Europe, the main cultivar is *Mytilus edulis*. In Scotland, mussel farming has been practised for over 30 years, and continues to grow annually, both in numbers of farms and in production (Fraser 1999). The industry is centred around the sheltered sea-lochs of the west coast, the Hebridean islands, and Orkney and Shetland. In Scotland, suspended mussel culture is employed, using either long-line farms or using floating moored rafts.

Mussel farming provides valuable income and employment in many areas of Scotland with often fragile economies. However, despite these benefits, mussel farming is not without its problems, those suffered by Scottish shellfish growers include storm damage, pollution and disease, fouling and predation.

Because of the higher relative energy content of farmed mussels over those growing on 'wild' mussel beds (Galbraith 1987), it is unsurprising that they may be favoured by species whose diet naturally includes mussels. Eiders, *Somateria mollissima*, feed almost exclusively on *Mytilus* in the wild and as a result are often attracted to mussel farms to feed. Dunthorn (1971) first documented eider predation on a Scottish mussel farm, and as the number of farms has increased, the problem seems to have escalated. Flocks in excess of 200 birds have been seen feeding on mussel culture sites on numerous occasions (*pers. obs.*). Numbers of eiders in the UK are probably in excess of 60,000 individuals, and are increasing at the rate of around 2.5% *per annum* (Sharrock 1976, Gibbons *et al.* 1993).

The increasing occurrence of eiders using mussel farms as feeding stations (Galbraith 1992) has led to calls for the development of effective deterrent and exclusion measures to reduce their impact. There are a number of anti-predator devices currently on the market and being used by mussel farmers in Scotland, but their respective efficacies have not been researched. SERAD, the Scottish Executive Rural Affairs Department issue a limited number of shooting licenses each year to farmers who can provide evidence of serious damage occurring to their farm. The licenses only permit a small number of birds to be shot each year as a deterrent measure.

Although it is clear that many Scottish mussel farmers do have a problem with loss of stock to diving ducks, the extent of the problem has never been accurately established. Any method to be developed to reduce the amount of damage caused by diving ducks must be based on a solid understanding of the nature of the problem specific to that site. Galbraith (1987) showed that attendance of birds at the mussel farms in his study tended to peak in the winter and in the spring. However, he suggested that the location of mussel farms in relation to wintering, breeding or moulting grounds of local populations might influence the seasonality of attendance. Obtaining information on the scale of the problem to farmers in different areas, and factors such as the numbers of birds in attendance, seasonality, farm size and age and amounts of stock lost, would help to give a wider understanding of the problem as a whole. The aim of this chapter is to review the problem and possible solutions as perceived by mussel farmers in Scotland. This was achieved by means of a questionnaire sent out to mussel farmers.

## Methods

Questionnaires were designed to collate information in four main areas; the nature of each leaseholder's farm, predators they experience losses from, damage specifically done by eiders, and the methods they use to deter problem species. A list of leaseholders for mussel farms was supplied by the Crown Estates Office for Scotland, in Edinburgh. In September 1997, one copy of the questionnaire (Appendix II), a covering letter and a stamped, addressed envelope was sent to all leaseholders listed. After sufficient time had elapsed, leaseholders that had not replied were contacted and the questionnaire conducted over the phone.

In addition to the questionnaire results, observations of numbers of eiders feeding at a mussel farm in Loch Striven, Argyll, were made throughout 1997 every two weeks. Counts were made and recorded in early afternoon on days with no workers on the mussel farm, using a telescope from a distance of about 300m. Estimates of the losses of stock from farms as a result of eider damage were made using data from Galbraith (1987) and Bustnes and Erikstad (1990), combined with the observations of birds feeding at the Loch Striven mussel farm.

**Results**

30 questionnaire forms were completed either by mussel farmers themselves or on the phone. 22 farmers contacted grew other shellfish (Scallops and Pacific oysters) and reported no loss of stock to birds.

Of the 30 leaseholders contacted, 21 owned exclusively long-line sites, 4 sites were raft-based and 5 sites were a combination of raft and long-line installations. The size of the mussel farms varied widely, the average number of droppers per farm was just less than 5000, but figures ranged from 50 to 22000.

97% of farms reported some loss of stock due to eiders. Only one farm (3% of replies received) reported no loss of stock to predators. All other farmers contacted experienced loss of stock to predators (See Fig. 1.). 21% of farms reported problems with Goldeneye, *Bucephela clangula* taking mussels from lines. From personal communication with mussel farmers experiencing problems with goldeneye, it seems that they take only the very young mussels (up to a few millimetres in length) from lines. This is unlike the problems associated with eiders, which seem to take mussels of all age groups, though mainly one to two year old mussels (See Fig. 2).

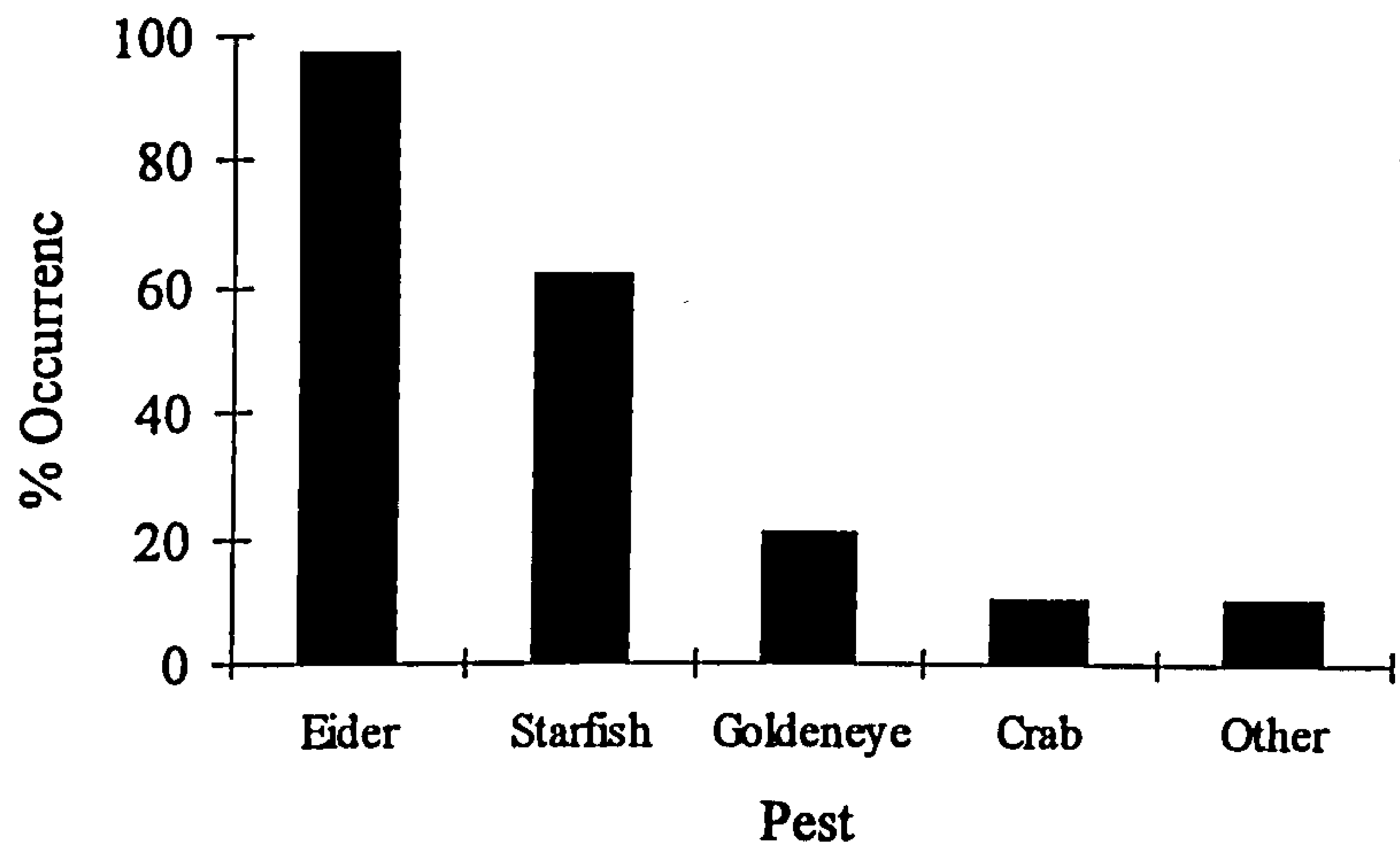


**Figure 1.** Pest species of mussel farms and their occurrence

Farmers were asked to indicate how serious the problem of eider damage to mussel stock was to them. The scale of the problem was ranked from zero (no problem) to ten (severe) rather than to look at absolute losses, to allow for varying sizes of farm. The results are shown in table 1.

**Table 1.** Severity of eider predation perceived by mussel farmers.

| Damage | None - V. Slight | Slight | Moderate | Severe |
|---|---|---|---|---|
| Rank | 0-1 | 2-4 | 5-7 | 8-10 |
| % of Farms | 13% | 20% | 20% | 47% |

Site age varied from 2 - 25 years, though there was no clear relationship between age of site and severity of eider damage (Spearman's rank; $r = -0.1240$, $p>0.05$).

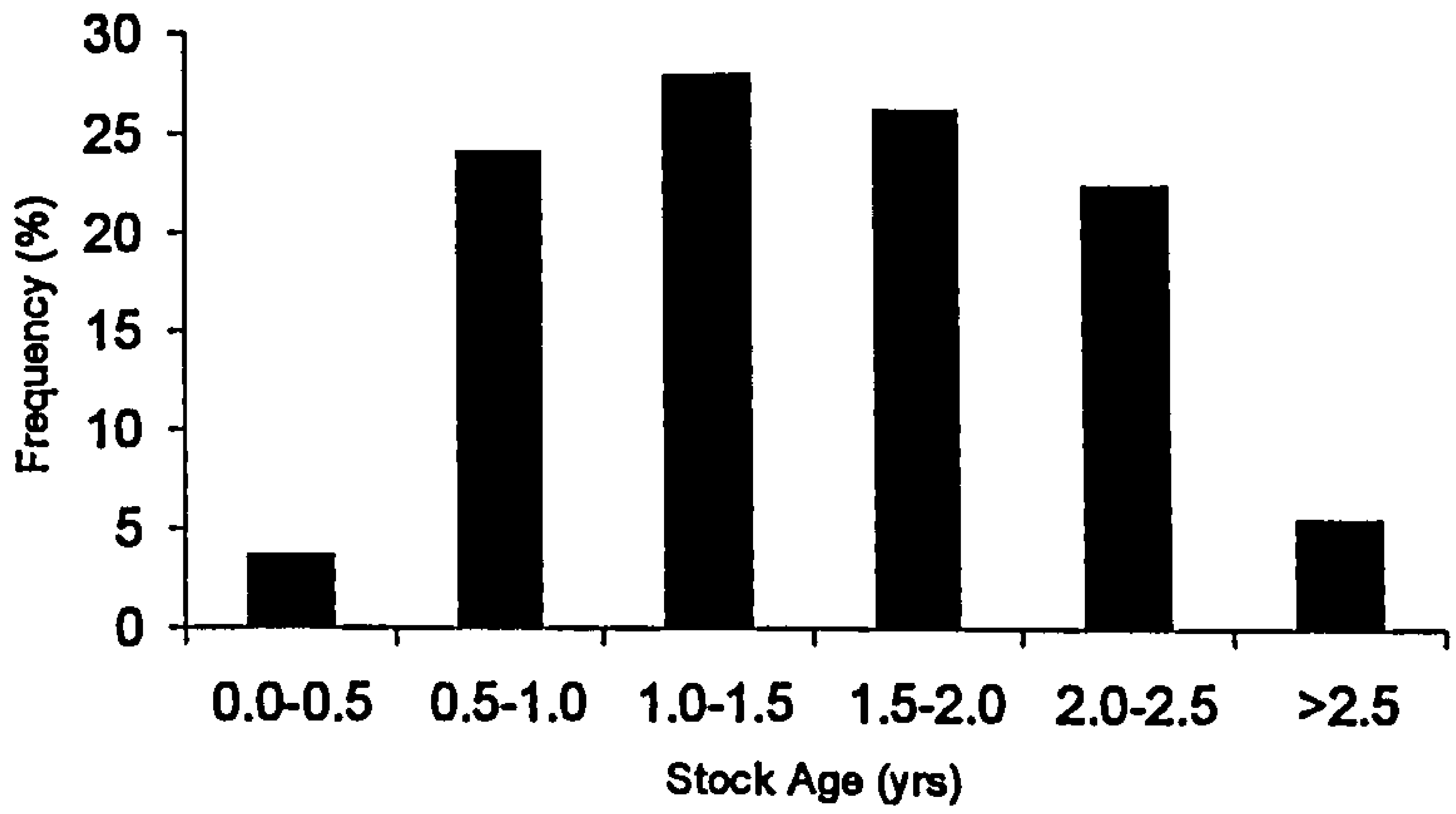


**Figure 2.** Frequency distribution of eider predation on different ages of mussel stock.

The cost of eider damage to the mussel farms has increased annually over the five-year period, although the average percentage loss of stock has, in general, shown a decrease (Figure 3).

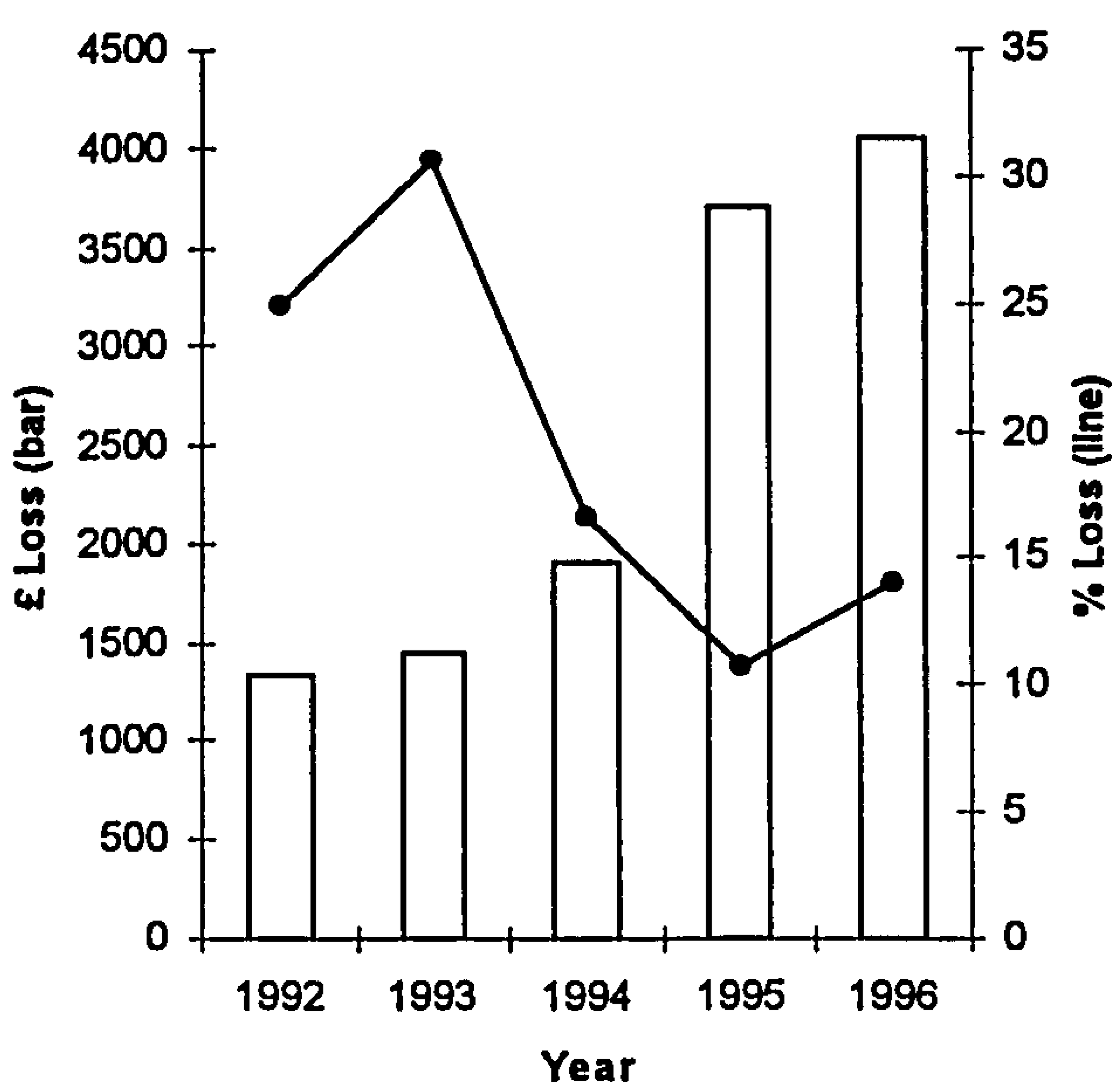


**Figure 3.** Average percentage loss of stock and financial cost per farmer as a result of eider predation (1992-1996)

To examine general trends in attendance with all replies irrespective of geographic location, the frequency of 'high damage' months were plotted and shown in Figure 4.

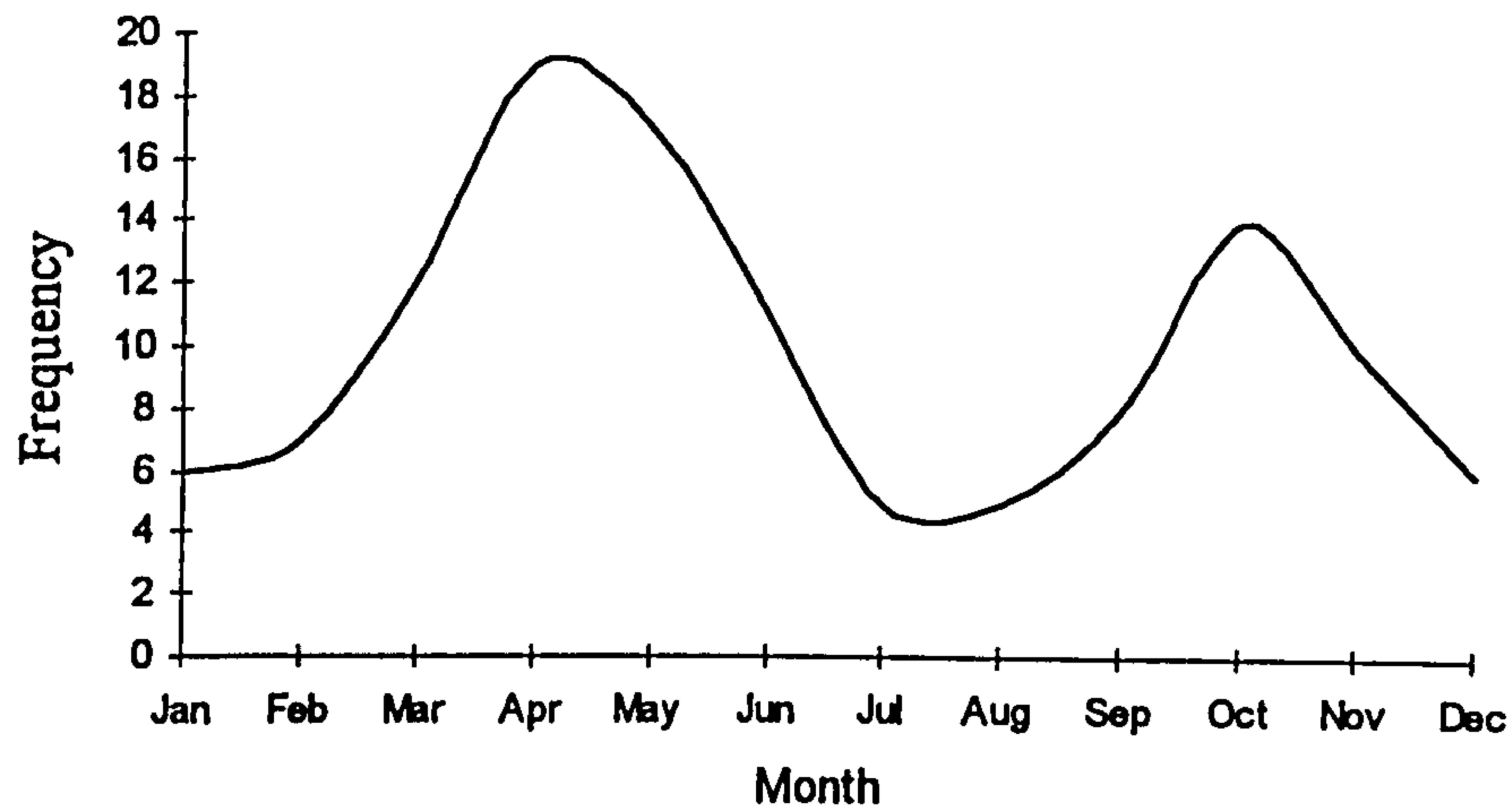


**Figure 4.** Seasonality of attendance of eiders at mussel farms.

With regard to daily patterns of attendance of eiders on mussel farms, 45% of those farmers who answered the question said that eiders would remain on-site all day. 18% of replies indicated that eider attendance was very adaptable, depending on the presence or absence of workers. 27% said that they could see no obvious patterns in attendance, and one reply indicated that attendance depended on tidal state.

Completed questionnaires indicated ten different deterrent methods employed by mussel farmers to reduce damage caused by eiders (Table 3). Chasing the birds by boat was the most commonly employed approach, and had a limited effect in that birds would fly off the respective lease when approached by a boat, but return after one or two hours. The approach that yielded the best results seemed to be the netting of farms, but there can be significant logistical problems associated with the use of antipredator netting, particularly on long line farms.

**Table 3.** Deterrents employed by farmers and their perceived efficacy.

| Deterrent | No. Farms | Perceived Efficacy | | | |
|---|---|---|---|---|---|
| | | Very Effective | Limited Effect | Poor Effect | Not Indicated |
| Boat Chasing | 12 | 1 | 6 | 2 | 3 |
| Nets | 7 | 5 | 1 | 0 | 1 |
| Shoot to Scare | 5 | 0 | 3 | 2 | 0 |
| Mannekin/Scary Man | 5 | 0 | 0 | 3 | 2 |
| Gas Cannon | 5 | 0 | 3 | 2 | 0 |
| Shoot to Kill | 3 | 0 | 1 | 1 | 1 |
| Pyrotechnics | 3 | 0 | 0 | 2 | 1 |
| Siren/Noises | 3 | 0 | 1 | 2 | 0 |
| Scary Eye | 1 | 0 | 0 | 0 | 1 |
| Ultrasonic UPS | 1 | 0 | 0 | 1 | 0 |

Estimates of the costs of different deterrents fell into two distinct categories – the initial cost of the purchase (if applicable), and subsequent running costs and the time or labour involved. Nets are expensive to buy and install, and due to fouling, require considerable time and effort to maintain. Conversely, although the initial outlay on a boat is likely to be covered in the setting up of a farm, all farmers chasing away birds by boat said that their fuel costs were significant. With regard to labour costs, because mussel farming as an industry generally requires a small workforce, 69% of those farmers contacted stated that in deterring eiders, time or labour was a major cost.

Only 6% of farmers who replied said that they had had SERAD licenses to shoot a specified number of birds on their lease. However, some farmers who had not owned a license suggested that farmers should be able to shoot at eiders.

When asked what measures that they would consider using to reduce predation at their sites, many farmers expressed the need for an effective, automated scaring device. Other points that were raised included a need for devices that are not annoying to people living nearby, and many farmers said that they would try literally anything to reduce the damage.

Observations of eiders feeding at a mussel farm in Loch Striven, showed that during peak periods of eider attendance, numbers could be in excess of 250 birds (see fig. 5).

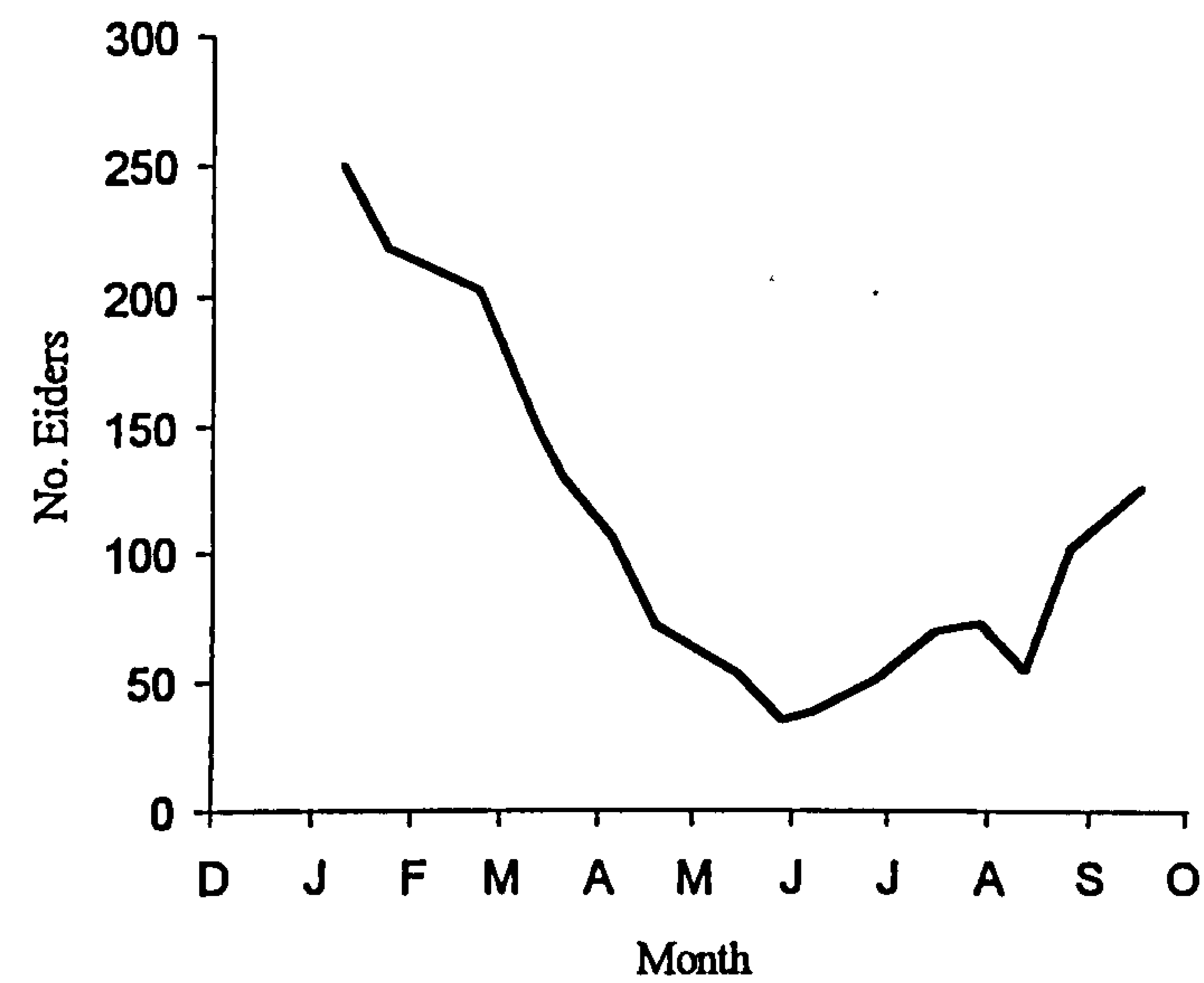


**Figure 5**. Changes in the numbers of eiders present on mussel farm, L. Striven during 1997.

Milne and Galbraith (1986) estimated that one eider could dislodge 2.5kg (wet weight) of mature mussels per day from farm ropes. However, depending upon how well mussels are attached to ropes or to each other (i.e. the strength of byssal attachment) the amount knocked off or dropped from ropes as eiders feed could be great. Clarke (*pers. comm.*) suggested that eiders feeding at his farm in Loch Striven dropped at least as much stock as they swallowed, in which case losses could be twice as much as that actually consumed. Bustnes and Erikstad (1990) suggested that, depending on the size-class of mussels taken, eiders would have to eat between 1.5 (small mussels; 9-15mm) and 2.7kg (larger mussels; 41-43mm) of intertidal mussels each day to satisfy their daily energy requirements. Using these data we can gain a rough estimation of potential loss of stock to flocks of different sizes feeding on different sizes of mussel, and with varying amounts of mussels dropped (fig. 6).

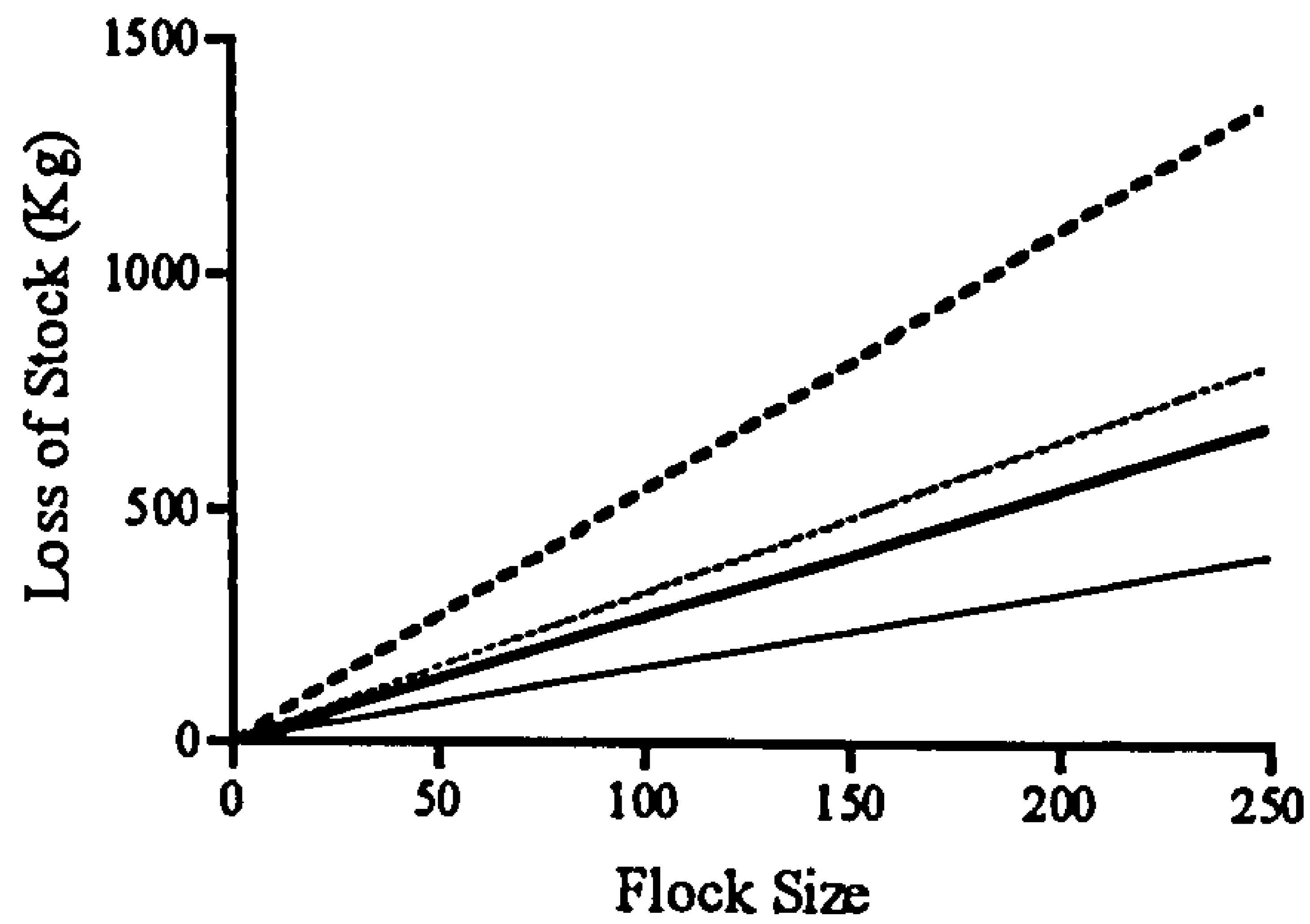


**Figure 6.** Potential daily loss of mussel stock to eider flocks, for large (bold lines) and small (normal thickness) mussels with no uneaten drop-off (continuous lines) and with 100% uneaten drop-off (dashed lines). Based upon data from Clarke (*pers. comm.*) and Bustnes and Erikstad (1990).

Using this information, and the data shown in figure 4, we can estimate the possible costs of eider predation at the L. Striven mussel farm during the 10-month observation period in 1997 (Table 4).

**Table 4.** Estimation of potential losses (weekly and over the 10 month observation period) at L. Striven mussel farm in 1997 for two size classes of mussels, with no drop-off of mussels. Figures are based on assumptions that birds took all their food from the mussel farm, that birds fed wholly on one size-class of mussels, and that no workers were present to prevent them feeding. Losses are also expressed financially, based upon 1999 market price of £1000 per tonne of mussels.

| | | Weekly loss (Kg) | |
|---|---|---|---|
| Period | Mean no. birds/day | Small mussels | Large mussels |
| Jan-Feb | 224 | 2505 | 4227 |
| Mar-Apr | 114 | 1277 | 2155 |
| May-Jun | 45 | 499 | 843 |
| Jul-Aug | 75 | 844 | 1424 |
| Sep-Oct | 126 | 1406 | 2372 |
| 10 Month Total loss | | 52 244 Kg | 88 162 Kg |
| Financial Loss | | £52 244 | £88 162 |

**Discussion**

There is a large degree of subjectivity to be dealt with when compiling the results of a questionnaire. However, the incidence and perception of the problem of eiders at mussel farms as reported here is striking. Mussel farms can act as high quality feeding stations, often in very sheltered conditions, for birds such as eiders and goldeneye. As the Scottish eider population has been slowly increasing over time (Thom 1986, Gibbons *et al.* 1993), one must ask the question as to how this links in with the simultaneous expansion of the nation's mussel farming industry? Has the provision of such high quality feeding stations help bolster populations and has the distribution of eiders around our coast changed as a result (see chapter 1)?

Although the problem of eiders as pests has received some documentation in Scotland (Dunthorn 1971, Galbraith 1987, 1992, Furness 1996), the similar problems reported with goldeneyes have not received any discussion. Goldeneyes are much smaller ducks than eiders, breeding on freshwater sites but often wintering in sheltered coastal areas (Cramp & Simmons 1977). Their diet is more varied than that of the eider, although for those birds wintering on brackish water or the sea, *Mytilus* can constitute a large part of the diet (Cramp & Simmons 1977). Goldeneyes take much smaller prey items than eiders, generally taking the previous year's spatfall from ropes (J. Holmyard *pers. comm.*). The first breeding record of goldeneye in Scotland was in 1970 and since then numbers have increased dramatically (Dennis and Dow 1984). Although goldeneye are widespread along many areas of the west coat of Scotland where mussel farming occurs, it is interesting to note that that all but one of the farms to suffer predation by goldeneyes were located in Loch Etive, Argyll, the other being just north in L. Leven. It would seem that in other areas, goldeneyes have not yet learnt to forage on mussel farms.

Along the coast of Atlantic Canada, mussel farmers also have problems with diving ducks. Damage is caused not only by eiders, but also by long-tailed ducks, *Clangula hyemalis* and Scoters *Melanitta nigra* (Lidster *et al.* 1994, Lien & Pittman 1996, Lien & Hennebury 1997). Both species winter in Scottish waters, although they are found mainly off the East coast (Cramp & Simmons 1977, Gibbons *et al.* 1993). Mussel farming in Scotland is generally restricted to the West coast where numbers are much lower, although if it were to expand to the eastern side of the country, the existence of such populations could be an important consideration.

In contrast to the narrow size-distribution of *Mytilus* taken by goldeneye, the large spread in the size-classes of mussels lost to eiders means that there may be very little stock that is not susceptible to predation at any one time. Sizes of mussels taken by eiders in Dunthorn's study (1971) ranged from 19-33mm, though the choice of a particular size-class may depend on several factors such as relative abundance (Hamilton *et al.* 1999), salt content (Nystrøm and Pehrsson 1988, Nystrøm *et al.* 1991), handling time (Draulans 1982; De Leeuw and Van Eerden 1992; Guillemette *et al.* 1992) or shell weight (Bustnes and Erikstad 1990). Seasonal variation in condition of the mussels and relative values of flesh weights and shell can also result in temporal shifts in size-class preferences (Ens *et al.* 1996, Hamilton *et al.* 1999).

Damage to mussel ropes caused by eiders can be identified reasonably easily immediately after periods of predation is suspected, but it can be confused with storm drop-off, tangled equipment, poor growth etc. at a later date. (J. Church *pers. comm.*). It is for this reason, and the subjectivity of replies inherent with questionnaire studies, that the estimations of losses, both financial and in yield must be viewed with some caution. However, the fact that losses can be great, and that it can seriously threaten a farmer's livelihood is undisputed. There was an annual increase in cost per farm reported for eider damage, despite the reduction in percentage loss of stock. It is likely that this is due to an increasing market value of mussels and/or that farms have grown in size during this period.

The bimodal frequency distribution with regard to seasonality of attendance of eiders is in agreement with the findings of Galbraith (1987). In general, attendance increases in the late winter and early spring to reach a peak in April as birds increase their intake rate in preparation for the breeding season (Gorman and Milne 1972). The drop in numbers then observed corresponds to the movement to breeding grounds and incubation for females and the males move to moulting grounds shortly after (Galbraith 1992). The smaller, autumnal peak may correspond to movements of birds from moulting grounds to wintering areas. The understanding of seasonal fluctuations in numbers and distribution of eiders is vital for the mussel farmer in anticipating periods of potential damage before they occur. Such knowledge then allows the implementation and application of appropriate control measures before damage becomes too great and birds become established on a site.

The numbers of birds in attendance at the Loch Striven mussel farm was generally very high, and corresponds well with both the findings of Galbraith (1987) mentioned above and with the replies of the mussel farmers in this study. The losses estimated from the observations of the L. Striven site are great, although they are based upon the assumption that no efforts were made to deter eiders from the lease. However, they were also made assuming that no mussels are dislodged or dropped from ropes by eiders. The degree of 'drop-off' is likely to vary between farms as a result of differences in the strength of byssal attachment, which can change with factors such as temperature (Clarke & McMahon 1996), current (Taylor *et al.* 1997), season (Price 1980, 1982), stock age (Taylor *et al.* 1997), predator presence (Reimer & Tedengren 1997) and chemical composition of the water (Etoh *et al.* 1997). It is also important to note that the figures given will underestimate the eventual loss to the grower as even the large size-class of mussel (41-43mm) is below the 60mm market size for *M. edulis* in Scotland.

The range of deterrents tried by farmers was large, and showed varying degrees of success. The most effective method employed was the use of nets to exclude birds. Although expensive, and with drawbacks such as reduction of water flow and fouling, this may be the only way to ensure adequate crop protection. However, as the majority of Scottish mussel farms are long-line based sites, this can make protection more difficult (Chapter 9), as they tend to cover a greater area than raft systems, which can be grouped together.

The efficacies of devices such as the 'Scary Man™', pyrotechnics and sirens tend to show similarities with published results from studies of similar deterrents used on other birds pests (Draulans 1987, Ross 1988, Littauer 1990, Mott & Boyd 1995, Stickley *et al.* 1995, Curtis *et al.* 1996). The limited effect of most deterrent devices used is generally through habituation to the stimulus, often as a result of it's presentation (Inglis 1984), or the lack of association (particularly with audible deterrents) with any aversive stimulus ordinarily encountered by those birds in the population.

Only a small number of farmers had licenses to shoot eiders, and opinions vary as to the efficacy of shooting. Numbers of birds farmers are granted to shoot are usually very low – far below the numbers generally predating farms. Mussel farmers seem to give two opposing views to this. A number of farmers suggest that they should be granted permission to cull all eiders around their leases. Other growers say that shooting of small numbers of birds serves to prevent behaviour patterns becoming established throughout a flock, and that culling is not needed. The extent of illegal shooting of eiders by mussel farmers is not known. Shooting in the vicinity of birds is also widely used by mussel farmers as a deterrent, and seems to have a limited effect.

Even if they are effective, deterrents can be both expensive and time consuming. There is a need for an effective, environmentally friendly, automatic deterrent system requiring infrequent reinforcement that can be installed on a mussel farm at an inexpensive price.

The results of the questionnaire clearly show that problems with eiders taking mussels from farms are widespread in Scotland, and the numbers of goldeneyes taking mussels from farms are also significant. Financial losses to farmers can be great, and a number of those people contacted said that they had initially thought about mussel farming, but had changed to farming other shellfish as a result of the problems associated with diving ducks. If the Scottish mussel farming industry is to expand significantly, amongst other discussion points, a greater understanding of the problems of eiders as pests, and more scientific testing of deterrents is required.

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# Chapter 5

# The effect of human activity and boat chasing on the attendance and feeding of diving ducks at mussel farms

**Abstract**

Presence of workers and chasing birds by boat are often used as methods of reducing the impact of diving ducks on mussel farms. In this study it was found that worker presence reduced numbers of eiders feeding at mussel farms by over 95%. Boat chasing had a significant short-term effect on the numbers of feeding goldeneye and eiders, reducing them by 91 and 51% respectively in the first hour after chasing. The effect of chasing was still evident 2 hours after the initial chase with eiders, but disappeared after an hour with goldeneyes. These differences were also shown in the average time taken for birds to first return to the mussel farm after chasing, with eiders taking over four times as long to return compared to goldeneyes. There is evidence presented to suggest that such disturbance lowers the subsequent feeding rate of goldeneyes. These results are discussed with reference to implementing strategies to reduce the impact of diving ducks on mussel farms.

## Introduction

It has already been reported (Chapter 3) that one way of reducing the impact of eiders on mussel farms is human presence on-site, usually harvesting or grading mussels or carrying out general maintenance work. However, workers cannot be present on site all day, every day. Often, even if they can visit the site, they cannot stay for long periods. When workers are on site, or can visit the site, they may also chase any remaining birds in the vicinity of the farm by boat. Boat chasing is a very frequently used means of deterrent by mussel farmers (Chapter 3), however, it can be expensive both in terms of time and fuel.

Disturbance of birds from preferred feeding areas may also have an effect upon their feeding behaviour, activity budget and intake rate. Disturbance may serve to increase daily energy expenditure (Stock and Hofeditz 1997) and therefore intake rate (Draulans and VanVessem 1985), or alternatively increase the time spent feeding per day (Urfi *et al.* 1996). The effect that chasing diving-ducks from mussel farms by boat may have on their subsequent feeding rate is of great interest to mussel farmers, particularly if chasing could actually increase the amount of stock taken by ducks.

The aims of this chapter are to quantify the effects of presence/absence of workers on eider and goldeneye attendance and to assess the efficacy of chasing the birds by boat. Results from a questionnaire sent out to Scottish mussel farmers (Chapter 3) showed that it is a commonly employed deterrent, although its efficacy was considered to be limited. This chapter will examine how effective boat chasing is in both the long and short-term, investigating how long its effects persist, what the immediate reductions in numbers are, and how long it takes birds to return to the site after chasing. Attempts will also be made to investigate changes in feeding intensity of birds before and after boat chasing.

## Methods

Observations were made using telescopes from tents set up at least one hundred meters from respective farms. Tents were erected prior to the onset of any deterrent trial to allow the birds to get used to their presence. Data were collected every five or ten minutes (depending on the site and weather conditions) from dawn until dusk over a period of ten days. Watches involved two or three observers, gathering data in shifts to avoid any fatigue effects. The number of birds in each flock (one flock being defined as a group of birds with no individual more than ten metres from any other) was recorded. Individuals inside, or within 10 metres of the farm were recorded as feeding on the farm, whereas individuals between 10 and 200 metres from the boundary of the farm were recorded as not feeding on the farm.

The mean number of birds feeding every five or ten minutes was calculated for each hour of observations. Mean hourly values were then calculated for each section of each trial to describe trends in attendance at different stages of each experiment. Presence or absence of workers, scare-boat activity or other disturbances were also recorded. A 'boat-chase' event consisted of one run of the scare-boat within the farm, which was terminated when all birds in the farm had flown. The arrival of workers on-site was preceded by a boat-chase.

This general methodology was then used in different ways as follows to answer the questions posed in the introduction;

### What is the effect of worker presence/absence on diving-duck attendance?

Trials were carried out in L. Striven on eiders. Data were collected as detailed with the boat-chase investigation, comparing hourly means of attendance levels one hour before workers arrived on site with levels one hour immediately after workers have arrived.

**Does chasing the birds by boat reduce their attendance on mussel farms in both the long- and short-term?**

Trials were carried out in L. Etive on both goldeneyes and eiders. Numbers of birds feeding every five-minute period were recorded for one hour prior to a chase occurring, then an hourly mean was calculated. Only data collected between 0800 and 1000 hours were used, to control for variation in attendance patterns of birds on-site. Subsequent hourly means were then calculated in the same manner. Percentage reductions in the number of birds in attendance were calculated for each observation, comparing the attendance immediately before chasing with that for the hour immediately after chasing.

**Do return-times differ between species?**

Trials were carried out in L. Etive on both goldeneyes and eiders. Return-times were calculated as the time taken from the termination of a boat chase until the first return of a bird (or birds) to the site to feed, and were only taken for the first chase in the day.

**Does disturbance have any effect on feeding rate?**

Trials were carried out in L. Etive, on goldeneyes only, as gathering similar data for eiders was not possible for logistical reasons. Every five minutes, the number of birds visible on the water surface within the mussel farm was counted in a scan sample. From this figure and the total number of birds known to be in the site at the time, the percentage of birds underwater (i.e. those judged to be actively feeding at any one time) was calculated. Hourly means of feeding rate were then compared before and after a boat chase had occurred.

## Results

### What is the effect of worker presence/absence on diving-duck attendance?

The presence of workers on-site reduced numbers of eiders feeding on the Loch Striven farm by an average of 95.1% (See figure 1). A paired t-test showed that the presence of workers on-site significantly reduced the numbers of birds feeding ($p < 0.001$, df = 7, $t = 7.340$).

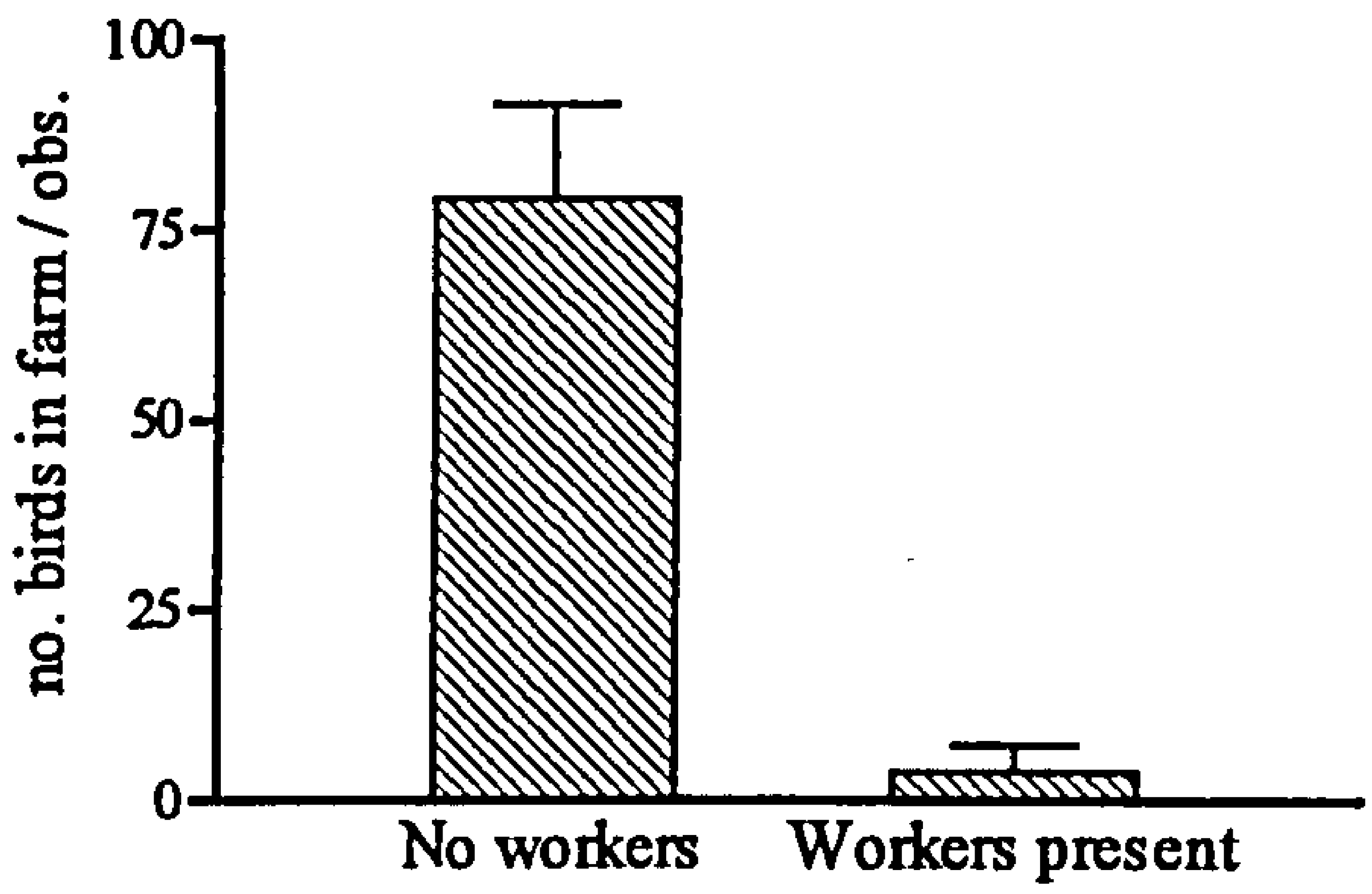


**Figure 1.** The effect of worker presence/absence on numbers of eiders feeding at L. Striven mussel farm.

### Does chasing the birds by boat reduce their attendance on mussel farms in both the long- and short-term?

In the short-term, immediate reductions in numbers of eiders and goldeneyes on L. Etive after boat chasing were by 91% and 51% respectively (figure 2.). Reductions in numbers of eiders were significantly higher than for goldeneyes *($p<0.05$, $U=6.00$)*.


**Figure 2**: Comparison of eiders and goldeneyes in the average reduction in numbers of birds feeding at the L. Etive mussel farm in the hour after a boat chase has been carried out.

Repeated measures ANOVAs for both goldeneyes and eiders (see figures 3a, 3b and 4) showed a significant effect of boat chasing on subsequent numbers of birds in attendance at the L. Etive farm ( $F_{2,5}$ = 6.478, $p < 0.05$ and $F_{3,4}$ = 8.147, $p < 0.01$ respectively). Tukey tests for goldeneyes revealed a significant reduction in numbers of birds feeding at the farm for the hour immediately following a chase ($q = 5.05, p < 0.05$), but no significant difference between pre-chase levels and subsequent hours. Similar post-hoc tests for eiders show a significant effect remaining for both the first and second hour following chasing ($q = 6.55, p < 0.01$, and $q = 5.37, p < 0.05$ respectively), with no significant difference between pre-chase numbers and those recorded in the third hour following chasing.

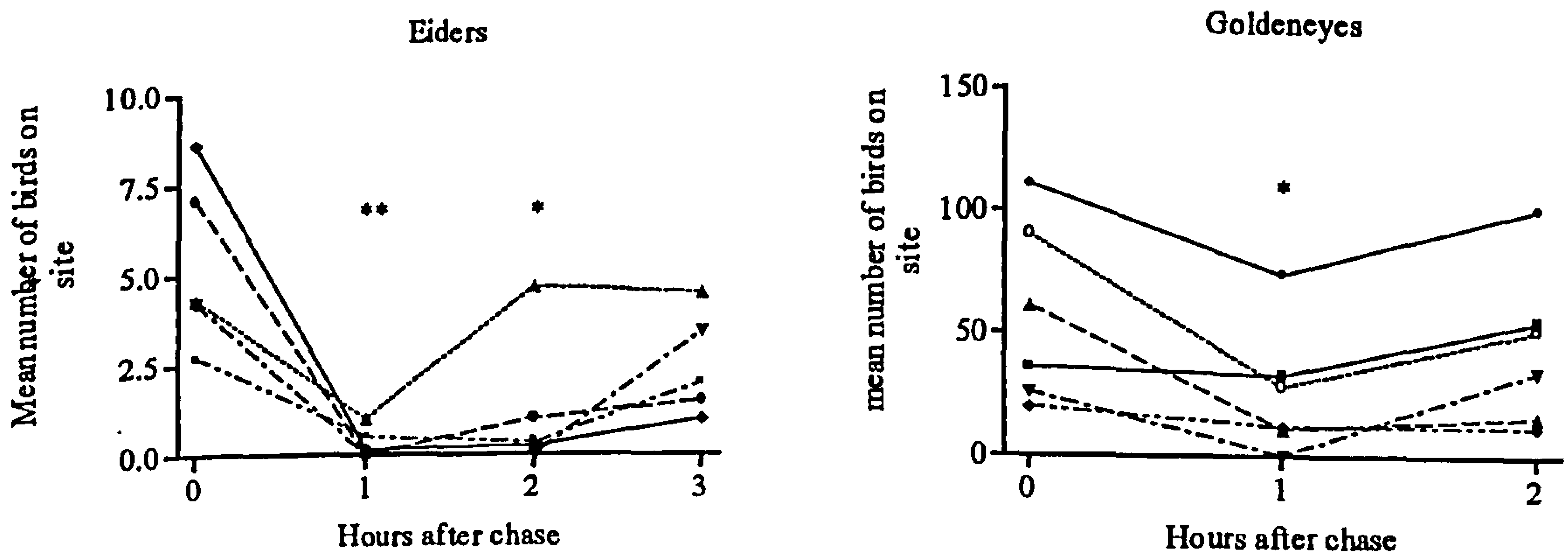


**Figure 3a,b**. Attendance of eiders and goldeneyes feeding on L. Etive mussel farm for the hour preceding chasing (hour after chasing = 0), and subsequent hours after the chase has ended. Asterisks indicate points that are significantly different from those before the chase was carried out ( ** $p < 0.01$, and * $p < 0.05$).

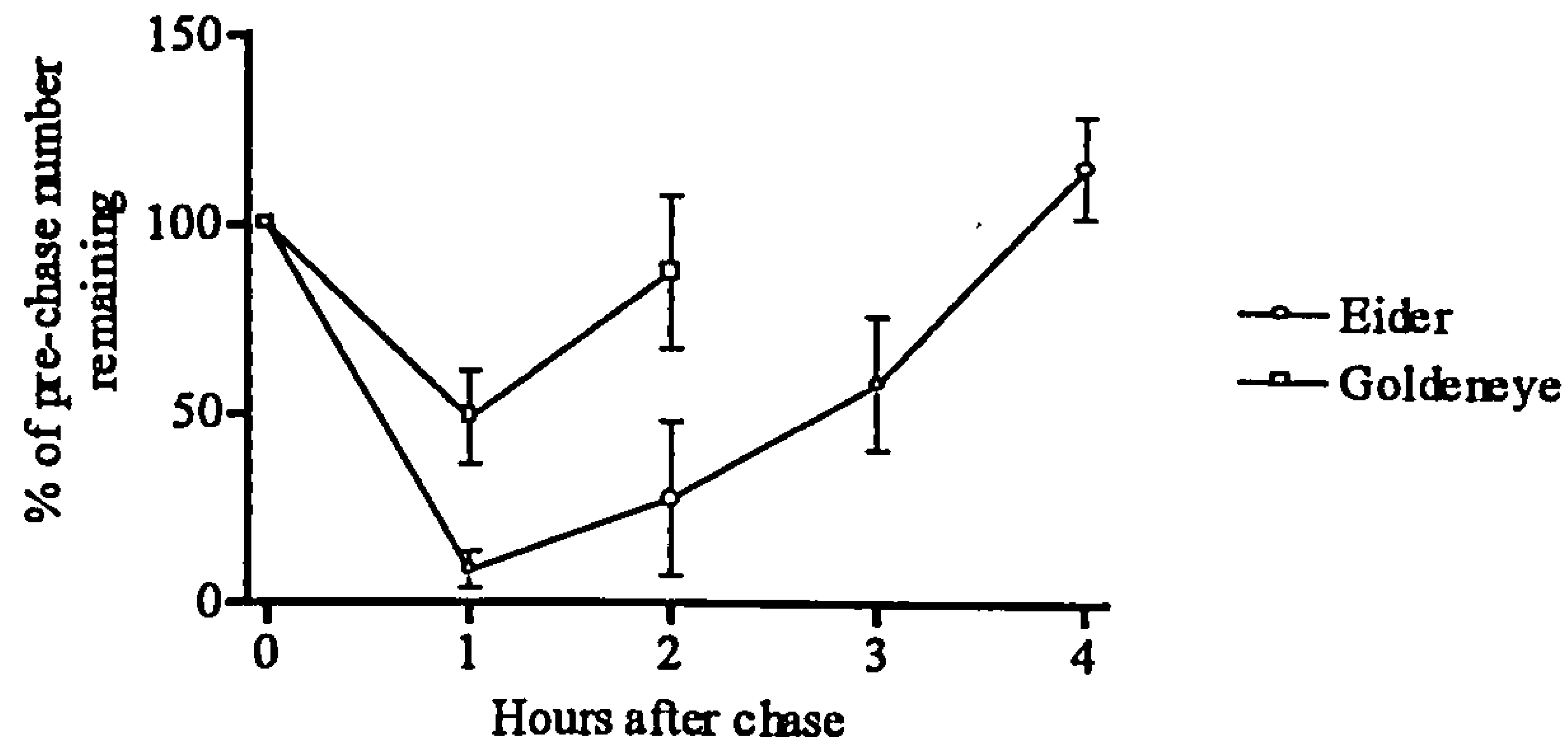


**Figure 4.** Direct comparison of the efficacy of boat chasing in reducing the attendance of eiders and goldeneyes on L. Etive mussel farm. Results are presented as a percentage comparing each hour with the numbers of birds present before chasing.

**Do return-times differ between species?**

Average return times for eiders in 1997 and for goldeneyes in 1997 and 1998 are shown in figure 5 below. A Kruskal-Wallis test showed that return-time after boat-chasing was significantly different across groups ($p$<0.01, d.f=2, $H$ = 13.67), and Dunn's multiple comparisons showed that the return time for eiders was significantly higher than those of the goldeneyes in both years ($p$ <0.01).


**Figure 5.** Comparison of return times of eiders and goldeneyes in 1997 and 1998 after boat chases.

**Does disturbance have any effect on feeding rate?**

There was no significant difference in feeding intensity (arcsine transformed) before or after boat chasing in L. Etive goldeneyes during the winter of 1997 and in 1998 or when both years were pooled (pooled; paired-t, $p$=0.1205, df=11, $t$=1.638). However, the feeding rate after chasing was 25.3% lower than before, a large difference, and subsequent power tests on the pooled data showed that the power value of the above test was 0.94. *Post-hoc* power tests showed that further fieldwork and the collection of more data may have yielded a significant difference.

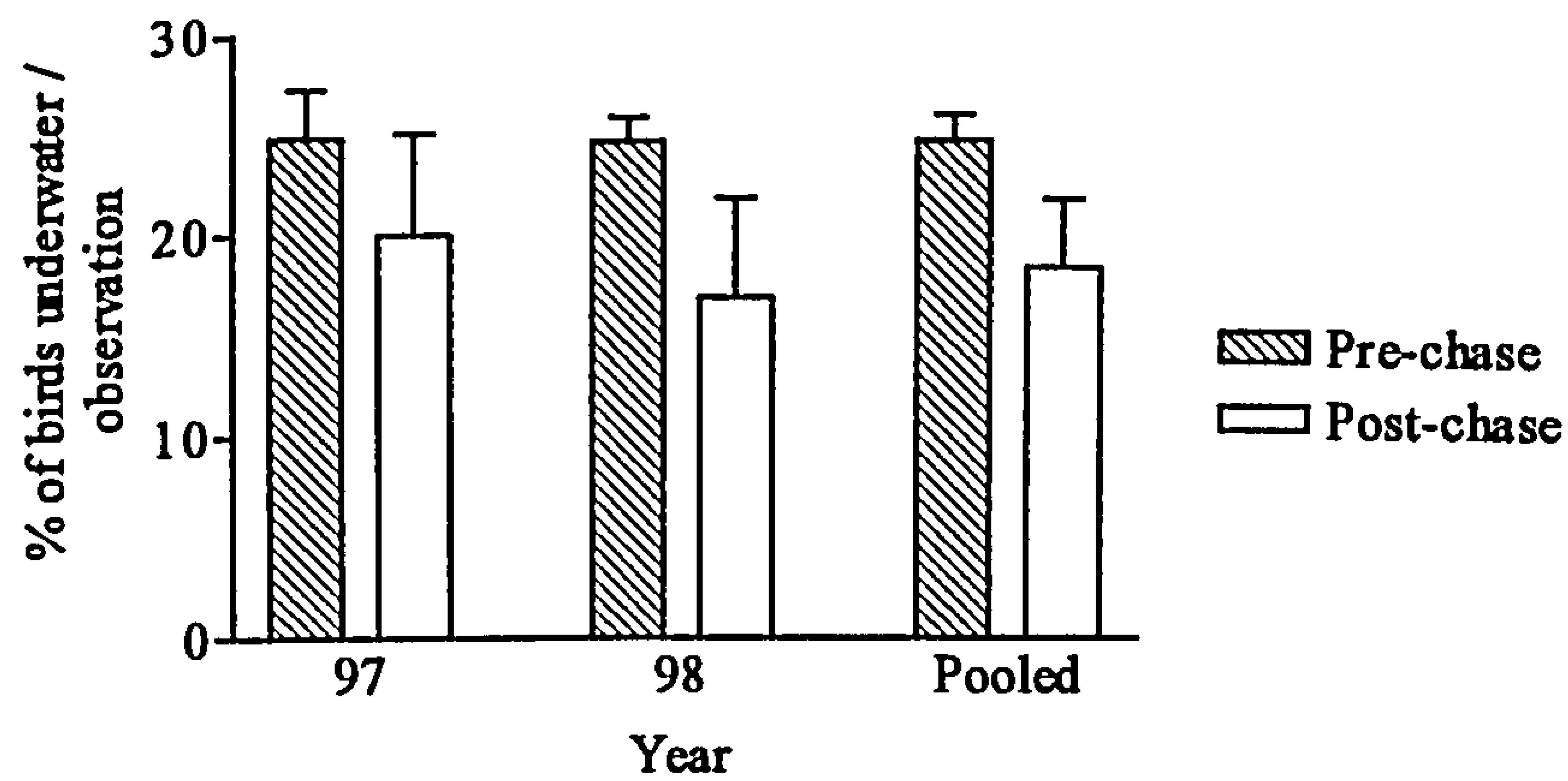


**Figure 6.** Mean number of goldeneyes underwater per observation period both before and after boat-chasing for 1997 and 1998.

There was also a significant positive relationship between flock size and feeding rate for all values before chasing occurred (Spearman's $r$ = 0.357, $n$ = 32, $p$ <0.05)

**Discussion**

It seems reasonably well accepted by most mussel farmers that the presence of workers on site will reduce the detrimental impact caused by diving ducks. The results presented here in this respect serve to reinforce this, although other factors will undoubtedly have an effect, such as the availability of alternative resources, the presence of any deterrents, and the size of the respective farm.

Pest species may often show some degree of plasticity with regard to their daily activity budget when faced with disturbance (as shown by Stock and Hofeditz 1997), and it seems that diving ducks may well do this in response to disturbance on mussel farms.

The most commonly employed approach to reducing numbers of eiders feeding on mussel farms in Scotland and also in Atlantic Canada tends to be the use of chasing the birds by boat (Chapter 3, Lidster *et al.* 1994, Lien & Pittman 1996, Lien & Hennebury 1997). This was reported to be of limited use, and farmers expressed concern over the use of this method due to the high cost in terms of both fuel and labour (Chapter 3, Galbraith 1987).

The efficacy of boat chasing has such a short latency that boat runs have to be carried out frequently, thus the cost in fuel can be high. If farms are in remote sites, then it is often only feasible to chase the birds by boat on days that work is due to be carried out on site. Less remote sites have the advantage that less time has to be spent reaching the area by boat and chasing can be carried out more frequently. Many mussel farms are situated out of view from the owners house or farm shore station, and so a boat trip to the farm to chase ducks must be made without knowledge of duck numbers actually present. A few farms sited close to the owners house allow closer attention to duck numbers, and more responsive chasing dependant on the amount of bird activity.

As with other deterrent measures, there are likely to be a number of factors that will affect how well boat chasing will work. The most important factor that will affect how effective a particular boat-chase will be is the availability of alternative resources, although other factors such as the amount of pre-exposure to chasing by boat will also have an impact on the efficacy of chasing.

Ferry and Deller (1996) showed that boating and human use was a major determinant in the numbers and distribution of waterfowl in Chesapeake Bay, essentially reducing the area of their feeding grounds. Burger (1998) looked at the effect of motorboats upon breeding colonies of common tern *Sterna hirundo*, showing that the speed and route of boats were two of the most important factors in eliciting flight responses of birds. Also important was the type of boat used i.e. a recreational boat or a normal workboat, and whether it was within the normal channel for boats. It is important to note that birds will often ignore boats that are not used to chase them, that are in the vicinity of a feeding flock, but will recognise cues about the boat that is usually used to chase them (*pers. obs.*).

Another important consideration when discussing these results is the behaviour of the birds when chased by boats. Eiders have a high wing loading, and therefore will expend more energy in flight than do goldeneyes. This is reflected by the observations of eiders and goldeneyes when chased; eiders tend to fly for a comparatively short time after being chased, low over the water. Goldeneyes on the other hand tend to circle for some time after being chased, and fly at least ten to twenty metres above the water surface. It could be speculated that this is the reason why goldeneyes have both a faster return time and a smaller drop in overall numbers after chasing than eiders.

Draulans and VanVessem (1985) found that slight disturbances to herons feeding at fish farms did not necessarily imply reduced damage and that intake could in fact increase when the birds returned. This result is partly attributed to the energetic costs of the birds flying from the site on presentation of the disturbance, and then flying back, and partly due to a greater success rate for smaller groups of feeding birds. However, it is unlikely that feeding success of goldeneyes would change in the same way, as their prey (in this case) is sessile. The results presented here show no difference between feeding rate before or after chasing, however, further study may show that feeding rate may in-fact decrease after chasing. However, the slight decrease in feeding rate may be as a result of the observed relationship between flock-size and feeding rate, with smaller flocks being recorded after chasing. Similar results were found by Urfi *et al.* (1996), where disturbance (either from predatory birds or from humans) did not increase the intake rate of oystercatchers, *Haematopus ostralegus*, rather that they would increase the amount of time spent feeding during the day.

Although it is clear that worker presence on-site is a very good deterrent to diving ducks on mussel farms, for logistical reasons it is not always a possibility. Chasing birds from farms by boat does have a significant effect on attendance, although it is only short-lived, and is expensive in both time and money. In the search for an effective deterrent to diving ducks, one of the major needs is the development of a system which birds show little habituation to, and that can be used effectively even when workers are not present on site.

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# Chapter 6

# The use of laser light to reduce the impact of diving ducks on mussel farms

## Abstract

Eider ducks, *Somateria mollissima* are a serious pest for many mussel farmers. The success of a laser light in scaring ducks from mussel farms was investigated with respect to the immediate responses of birds, and to its use in deterring birds for longer periods. The likelihood of a 'fly' response to use of the laser decreased with increasing ambient light intensity. In full daylight eiders showed little response to the laser, but shortly after dawn, or in midwinter conditions with heavy cloud cover, the laser scared eiders into flying away. Different populations of eiders showed different sensitivities to laser light, and the probability of a flight response at higher light levels was found to be more important than at low light levels in reducing overall numbers feeding at a farm. Daily use of the laser dramatically reduced predation pressure at mussel farms. Numbers feeding at farms were reduced by 50-98% during days in which the laser was used, and numbers remained low for several days when laser use ceased. Sequential trials of the laser light on adjacent farms showed that birds scared from one site were likely to settle on nearby sites at first, but repeated deterrent regimes moved birds out of the area. Similar results were obtained from trials on goldeneyes, *Bucephala clangula* at mussel farms, where numbers were reduced by 78%. Given the need for the laser to be operated manually, and in the hours immediately after dawn, this may not be a practical deterrent for most mussel farmers. However, laser light may be a useful tool to reduce the impact of diving ducks on farms where serious predation problems have developed and it has become difficult to change the habits of established birds.

## Introduction

Both eiders, *Somateria mollissima* and goldeneyes, *Bucephala clangula* have been described as pests on mussel farms in Scotland (Chapter 4). The superior quality of farmed mussels in comparison with intertidal mussels (Galbraith 1987, 1992), make feeding on mussel farms more profitable to such bird species. As a result, the potential losses attributable to feeding flocks of diving ducks can be very large, both in terms of the amount of stock, and financially.

Problems with avian pests are documented within both agriculture and aquaculture (e.g. Murton & Wright 1968, Furness 1996). Advances in farming often result in larger areas of monoculture and greater production and quality of the crop than would be found in 'natural' conditions. Such areas are likely to attract species that feed on the food in the wild (VanVeeren & Smallwood 1996).

Relative profitability, feeding behaviour and choice of feeding area is not only dependant upon prey availability, quality and distribution, but can vary with the degree of 'danger' (generally in terms of predation risk) associated with that site (e.g. Newman & Caraco 1987, Newman *et al.* 1988). Deterrents should work by increasing the degree of danger, or risk, associated with the respective feeding area so that alternative feeding areas become relatively more profitable.

A wide variety of bird deterrents and exclusion techniques have been suggested for many aspects of bird pest control. However, many of these have not been tested and documented in a controlled or industrial setting. A large amount of the study devoted to problems of birds as pests to aquaculture installations has been focussed on fin-fish culture and not on shellfish farming (e.g. Ransom and Beverage 1983; Draulans and Van Vessem 1985; Van Vessem *et al.* 1985; Draulans 1987; Moerbeek *et al.* 1987; Ross 1988; Carss 1989ab, 1994; EIFAC 1989; Littauer 1990; Marquiss and Carss 1994ab; Mott and Boyd 1995; Stickley *et al.* 1995; Dare 1996; Kirby *et al.* 1996). However, some preliminary work regarding bird pests at mussel farms has been carried out in Canada (Parsons *et al.* 1990; Lidster *et al.* 1994; Lien and Pittman 1996; Lien and Hennebury 1997). There are a number of anti-predator devices currently on the market and being used by mussel farmers in Scotland, but their respective efficacies have not been researched.

The aims of this study are to investigate the efficacy of a novel deterrent, laser light, upon both eiders and goldeneyes on two levels. Primarily, its efficacy in reducing the feeding pressure of groups of ducks on mussel farms will be investigated. The effect of laser light upon individuals will then be assessed and comparisons made between individuals from different populations.

**Materials and Methods**

The laser rifle used in these experiments was a DESMAN laser model FLR 005. It is a class IIIB He-Ne 520nm red beam laser with adjustable telescopic sights. Power was provided from a portable 12-volt motorcycle battery. The DESMAN laser model FLR 005 is specifically marketed as a bird scaring device, the manufacturers claiming that it can be used from distances up to 2000m, and that birds are startled by the strong contrast between the laser light and ambient light.

Observations were made using telescopes from tents set up at least 200m from respective farms. Tents were erected prior to the onset of any deterrent trial to allow the birds to get used to their presence. Data were collected every five or ten minutes (depending on the site and weather conditions) from dawn until dusk. The number of males, females and immature birds in each flock (one flock being defined as a group of birds with no individual more than ten metres from any other) was recorded as was their position in relation to the farm. Individuals inside, or within 10m, of the farm were recorded as feeding, whereas individuals between 10-200m from the boundary of the farm were recorded as not feeding.

The mean number of birds feeding every five or ten minutes was calculated for each hour of observations. A running mean was calculated of the hourly means for each day to reduce the characteristic variations of time-series data. Mean hourly values were then calculated for each section of each trial to describe trends in feeding pressure at different stages of each experiment (see below). Presence or absence of workers, scare-boat activity or other disturbances was also recorded. Where possible, the number of dives made during a feeding bout was counted.

There were two separate experimental designs with regard to testing of the laser rifle. The first trial design was used to investigate the general efficacy of using laser light to reduce diving-duck damage, and was employed when the respective farm was the only one in the immediate area. A five-day observation period prior to using the laser rifle was followed by five days using the laser, then a further five-day post-stimulus observation period (an additional 5-day period after post-stimulus was also recorded in the L. Creran trial).

The two sites used in this design were in Loch Striven and Loch Creran, Argyll. The Loch Striven site is a long-line installation situated approximately 8km from the mouth of the loch in the Clyde Sea. There are no other mussel farms currently in use within the loch or in the immediate area around it. The loch Creran site is raft based and again is the only mussel farm within that particular sea-loch. The closest mussel farms to this site are situated in Loch Etive, over 24km distant by sea.

Whenever birds arrived at the farm, the laser was used. To be certain that there was no risk of damage to the eye from laser light, the laser was only directed at birds that were over 150m away, based on safety criteria presented by McKay *et* *al.* (1999). The time and ambient light intensity were recorded using a hand-held lux-meter prior to each application of the laser. Once the laser was fired, the response of the focal bird was recorded. The maximum duration for which the laser was aimed at a bird was 20 seconds. Responses recorded fell into two distinct categories; no response, and fly/scoot. To give an idea of how lux levels are related to the time of the day on the West Coast, half-hourly readings of light intensity were also made using the lux-meter during the winter, on 2 sunny days and 3 overcast days.

The second design-type was employed when there were two farms in close proximity to each other, and was used to allow for, and investigate the effects of displacement of one set of birds to neighbouring farms when a deterrent is employed on one of them.

The site used in these trials was situated in the upper basin of Loch Etive, Argyll on two adjacent (1km distant) long-line mussel farms with similar stock densities and very similar disturbance regimes (as the same mussel farmer owns both sites). One trial was carried out during November 1997 during a period of high goldeneye attendance, and the other in March 1998 during high eider attendance.

The trial recorded activity at both sites concurrently, beginning with a preliminary observation period at both sites. This was followed by a set of four 3-day periods alternating between laser use and no laser, with one site receiving laser use whilst the other did not (see table 1). Results were collected as described in design 1.

**Table 1.** Laser trial design 2.

| | Day Number | | | | | |
|---|---|---|---|---|---|---|
| Site | 1-5 | 6-8 | 9-11 | 12-14 | 15-17 | 18-22 |
| A | Obs. | Laser | Obs. | Laser | Obs. | Obs. |
| B | Obs. | Obs. | Laser | Obs. | Laser | Obs. |

**Results**

Site: Loch Striven

Pest Species: Eider

Use of the laser rifle significantly reduced the number of birds feeding at the Loch Striven mussel farm ($p$ = 0.05, $df$ = 6, $t$ = 2.345). Numbers of feeding eiders were reduced by 78.5%, from an average of 79.5 ducks feeding per observation before the laser was used to 17.1 after use of the laser (figure 1).

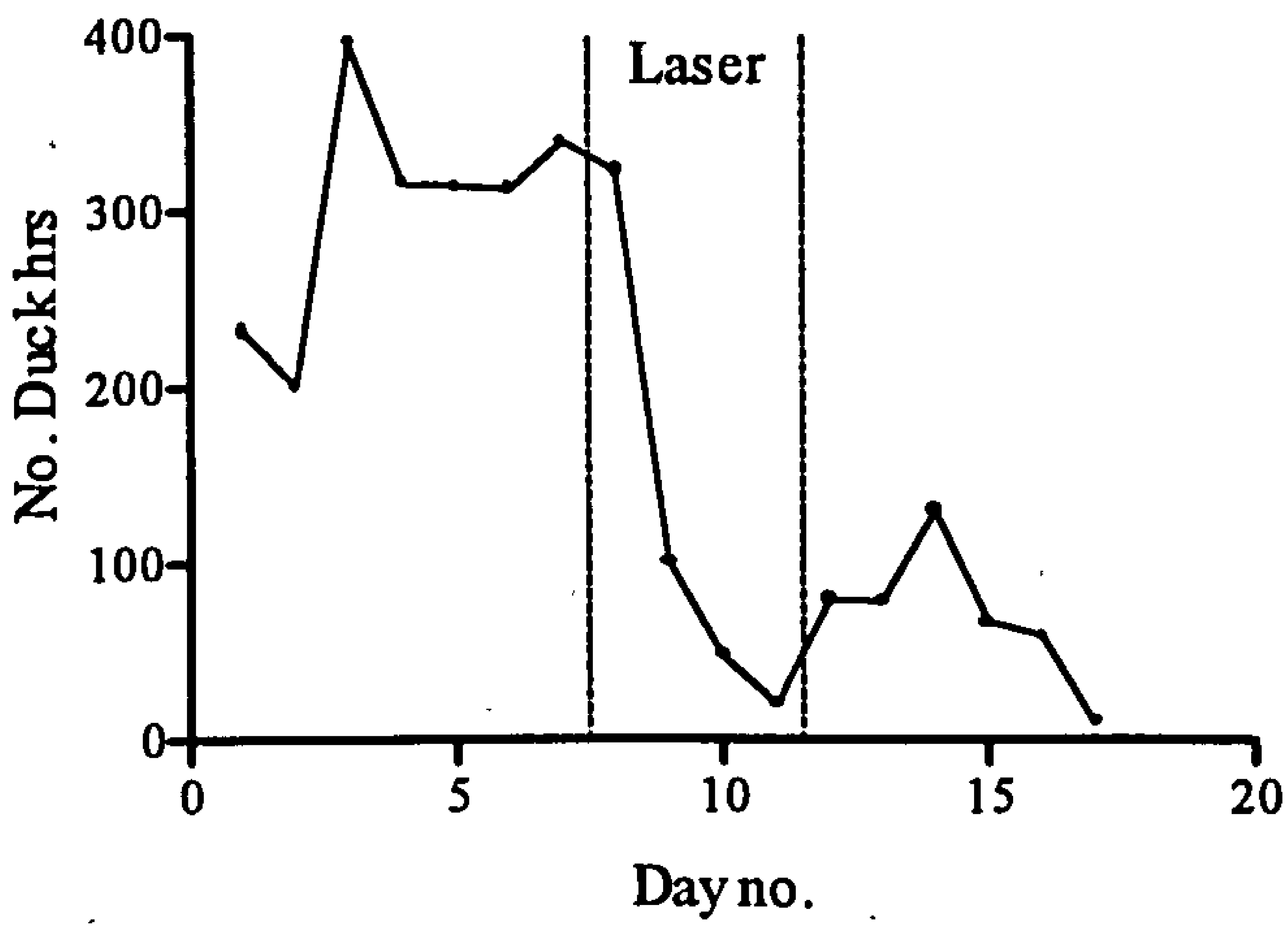


**Figure 1.** Effectiveness of Laser rifle in reducing number of eiders feeding per observation at mussel farm, L. Striven (Day 1 = 21 February 1997)

Site: Loch Creran

Pest Species: Eider

As with the L. Striven trial, use of the laser on the L. Creran mussel farm significantly reduced the numbers of eiders feeding there up to 15 days after it was first used ($p = 0.0112$, df = 3, $F = 5.139$ ), despite there being a significant increase in the total number of birds in the study area post-rifle use (See Fig. 2i,ii).

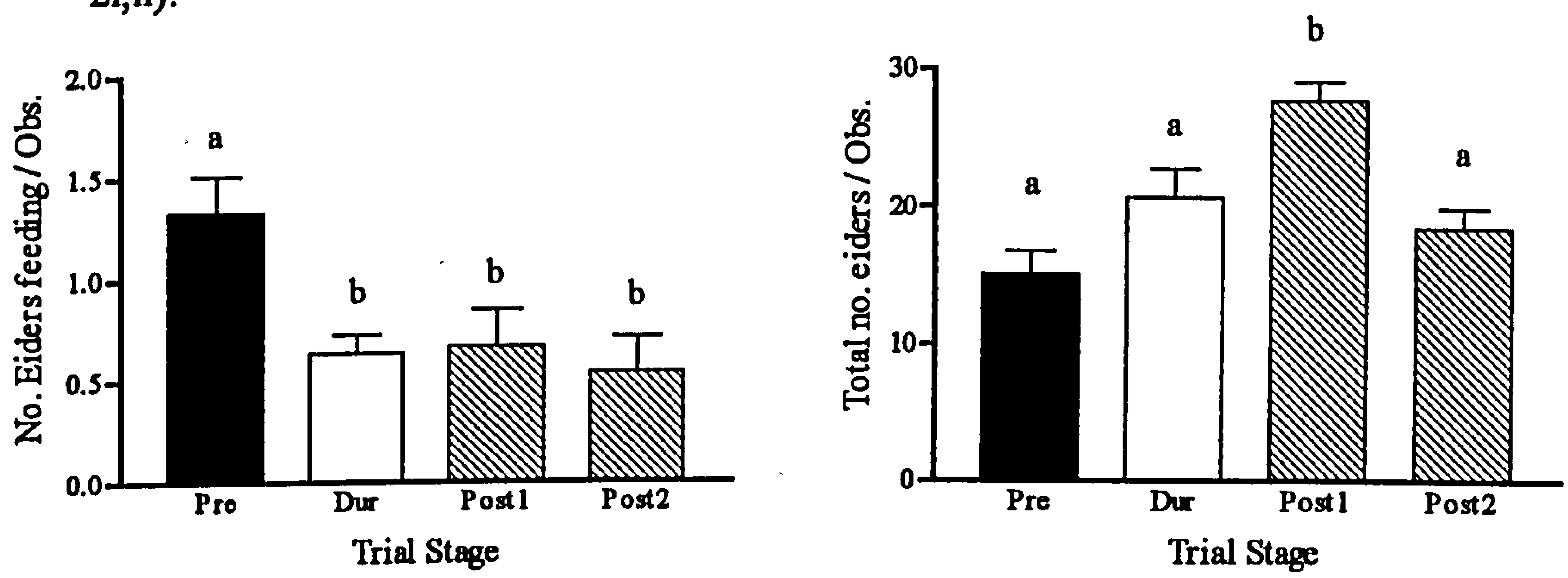


**Figure 2**. Changes in numbers of eiders counted in each observation period for i, feeding birds, showing an average decrease of 50% between pre and post-laser use, and ii, total numbers of birds in the study area, showing an average increase of 83% between pre and post-laser use. Bars with the same letter (on each graph) are not significantly different, $p > 0.05$.

Site: Loch Etive

Pest Species: Eider

The total number of birds feeding on the two adjacent sites fell significantly between the start of the trial and the end (Mann-Whitney U test, $p < 0.004$, d.f. = 6, $U = 0.000$), from 48.4 to 0.7 eiders feeding per hour, a reduction of 98.5%. The major reduction in numbers came after the first application of the laser, a 92.2 and 100 percent reduction in numbers for site 1 and site 2 respectively, followed by reductions of 88.5 and 96.3 percent for the second period. The presentation of laser stimulus on one site tended to result in a shift in numbers of birds from this site to the next (see fig 2.5, Pre-Laser 2), although this effect was virtually lost as the trial progressed (Figure 3).

Eiders tended to approach the mussel lines in groups, and dive with some synchronicity before moving back out into open water (see Table 2). There were no significant differences in the number of dives made per diving bout between males and females either before or during laser use ($U = 277$, df=48, $p = 0.283$ and $t = 0.442$, df = 70, $p = 0.660$ respectively).

**Table 2.** Numbers of dives per feeding bout made by eiders pre-trial on Loch Etive mussel farm, March 1998.

| | | No. dives per bout | | |
|---|---|---|---|---|
| Sex | Min. | Max. | Mean | SD |
| Male | 1 | 5 | 2.332 | ±0.890 |
| Female | 1 | 6 | 2.425 | ±0.954 |

Site: Loch Etive

Pest Species: Goldeneye

The total number of birds feeding on the two adjacent sites fell significantly between the start of the trial and the end ($p < 0.001$, d.f. = 6, $t = 11.86$), from an average of 48.1 goldeneye feeding per hour to 10.5, a reduction of 78.2%. A period of three days after the first laser treatment on both sites there were no data collected, allowing the numbers of birds to build up once more, perhaps accounting for the lower reduction seen overall. During the first application of the laser, a 28.9 and 93.5 percent reduction in numbers was observed for site 1 and site 2 respectively, followed by reductions of 94.9 and 85.7 percent for the second period. As with the above trial, the presentation of the laser stimulus on one site tended to result in a shift in numbers of birds from this site to the next.

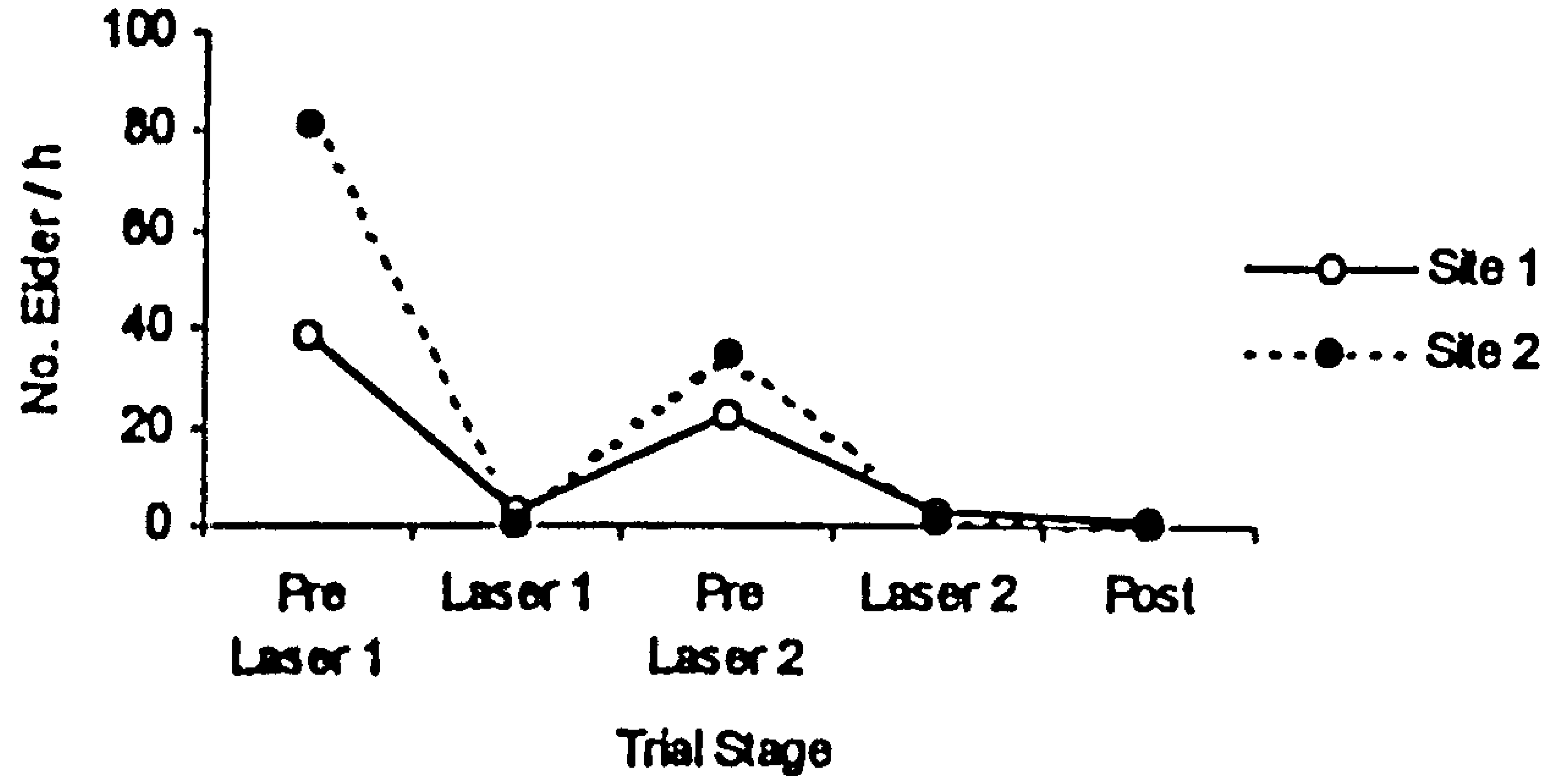


**Figure 3.** Effect of Laser rifle on numbers of eiders feeding on two adjacent long-line sites. The trial carried out was a type 2 design (see methods). Results presented are staggered to align data points for comparison.

Logistic regressions were carried out to investigate the relationship between probability of a flight response (PFR) and ambient light levels. Because responses were binomial, the range of ambient light intensities (log-transformed) for each population was split into equal sized groups, and the mean PFR ($P$) calculated for each. For the purposes of the logistic regressions, the midpoint of each range of light intensities ($x$ values) was plotted against the following $y$ value as a measure of likelihood of response:

$$Y = \frac{P}{1-P}$$

When the responses of different populations of target species to laser light were compared (ANCOVA), there was a highly significant negative effect of ambient light intensity on probability of response across all groups ($F = 48.446$, df. = 1, $p < 0.0001$).

There was a significant difference between slopes of the four regression lines ($F = 4.581$, df. = 3, $p<0.01$). Because slopes differed, elevations of the regression lines were compared at two different points – at low light intensity (1 Lux) and at high light intensity (10 000 Lux). Differences in responsiveness to the laser between groups were found at both high and low light intensities (one-way ANOVA, $F = 22.506$ df $= 3$ $p<0.0001$, and $F = 50.273$ df. $= 3$ $p<0.0001$ respectively).

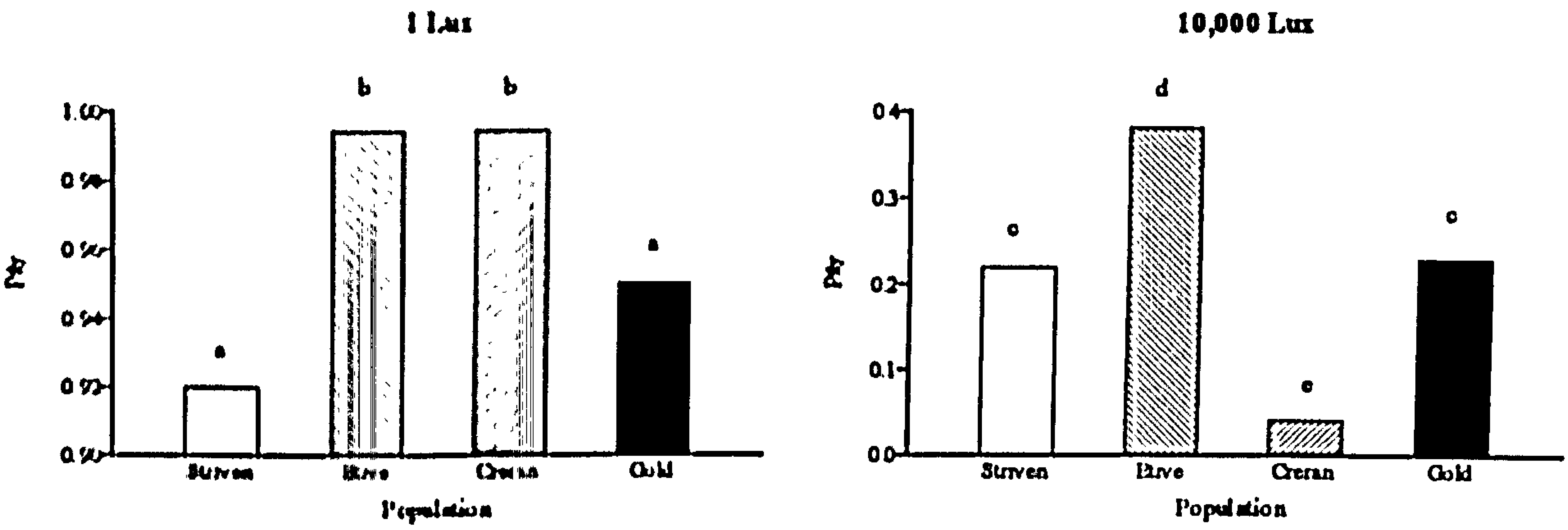


**Figure 4.** Probability of flight response of eider populations (Loch Striven, L. Etive, L. Creran) and goldeneye (Gold) to laser light at A, low (1 Lux) and B, high (10000 Lux) ambient light intensity. Bars with the same letter (on each graph) are not significantly different, $p>0.05$.

There was a close correlation (after ARCSINE transformation) between reduction in numbers of birds feeding on each site after laser use and PFR at high ambient light intensity ($r^2 = 0.980, p < 0.01$), although no relationship was found at low ambient light intensity ($r^2 = 0.009, p = 0.91$)(See table 3).

**Table 3.** Average reductions in numbers of eiders and goldeneyes feeding at mussel farms after use of the laser rifle and PFR for each population at low and high ambient light levels

| Population | L. Striven | L. Creran | L. Etive (eid) | L. Etive (gold) |
|---|---|---|---|---|
| Reduction | 78.5% | 50.0% | 98.5% | 78.2% |
| PFR 1 Lux | 0.920 | 0.994 | 0.994 | 0.950 |
| PFR 10000 Lux | 0.219 | 0.040 | 0.381 | 0.228 |

From the information shown in figure 4 we can see that at 10,000 Lux, there is a 5-40% chance that we shall elicit a flight response from an individual eider or goldeneye (depending upon the population it came from) when the laser is used. During an average overcast winters day on the West coast of Scotland, this light level is never reached (Figure 5). On a sunny day these probable response levels will only be reached from first light (around 7am) until around 9am in the morning, and from 3pm until last light in the afternoon (about 5:30pm). However, efficacy of the laser will increase rapidly below this light level.

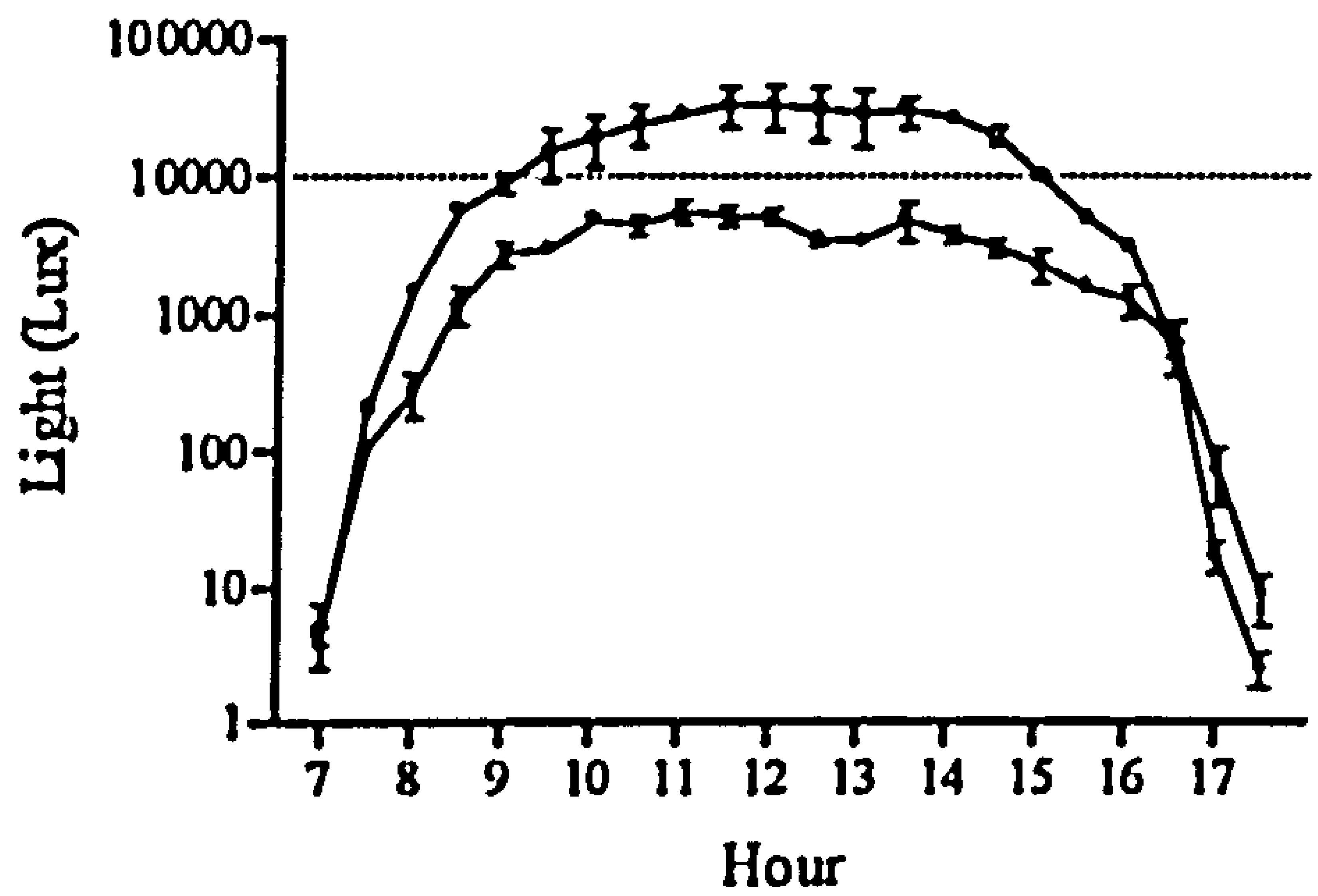


**Figure 5.** Mean (and SD) half-hourly winter daylight light levels for sunny (open circles) and overcast (closed circles) days on the West coast of Scotland.

### Discussion

In general, the laser rifle was very effective in reducing numbers of eiders and goldeneyes feeding on mussel farms, decreasing numbers of birds feeding by between 50 and 98 percent. Numbers tended to remain low after use of the laser rifle had ended, and in the Loch Creran trial numbers were still significantly lower fifteen days after first use of the laser. However, although effective in the short-term, longer term effects are harder to measure in experiments such as these, due to changes and movements in local populations of birds and the difficulty in locating independent and comparable control sites in the area (e.g. MacKay *et al.* 1999).

How successful a deterrent may prove to be can depend upon the availability of alternative resources in the area as discussed by Draulans (1987). To successfully prevent a pest species from establishing itself on an aqua/agri-cultural site, that site must be made to be less profitable than other food sources that the pest may naturally feed upon. If however, there are very similar sites in the vicinity that do not have the same degree of 'danger' associated with them, then deterrence should be made easier, as the differences in profitability between the two (or more) sites will initially be much lower. In terms of using such deterrents in industrial situations such as that in Loch Etive, where there are at least 14 sites actively growing mussels, initial deterrence may be easy as birds have a wealth of other potential feeding stations to exploit. In situations such as this however, as more and more farmers begin to use deterrents to move birds from their site, the relative differences in profitability of respective sites to the birds is likely to decrease. This decrease in heterogeneity between sites may then mean that deterrence may become progressively more difficult. This may explain why the mean reduction in type 1 trials was lower (64%) than for type 2 trials (88%), where there were other mussel farms in the loch to feed on.

The examination of relationships between PFR and reduction of feeding pressure suggests that the efficacy of the laser rifle on a particular site depends upon how well that particular population responds at higher light levels. This is perhaps unsurprising, because at 1 Lux, although there are significant differences between populations, the likelihood of making birds fly is very high (PFR is above 0.90) for all groups, whereas at 10000 Lux, the populations PFR values range is much greater (0.04-0.38). When there is a population with a high PFR at higher light levels, a longer period of each day can be spent in which the laser can be used to a reasonable level of efficacy.

However, the results do not explain why differences in PFR exist between populations. There are two possible reasons for these differences, both of which are hard to quantify. One possible reason is that birds that are habituated to 'disturbance' in general on a particular site may show less response to novel stimuli than birds that are less familiar with any deterrence regime. Testing this hypothesis however would be very difficult, as in quantifying disturbance, many factors would have to be taken into account, such as how frequently workers are present on site and in what ways, how frequently and how intensely birds are discouraged from feeding there.

Another possible reason is that PFR is linked to the 'motivational state' of the individual or population on that site. This hypothesis links with the differences in relative profitability of local alternatives as discussed above. Again, testing this idea in the field would present problems as not only disturbance will effect the relative profitability of a particular site, but other factors such as location (Stickley *et al.* 1995), condition and size-structure of the prey population (Ydenberg & Guillemette, 1991).

Eiders in particular in the UK have very few natural predators, and attempts made using trained falcons and model seals *Phoca spp.* have yielded inconclusive results in preventing eider damage at mussel farms (Galbraith 1987). Yokoyama and Nakamura (1993) found that a novel stimulus elicited greater response than did conspecific distress calls for tree sparrows *Passer montanus*, whereas Schmidt and Johnson (1983) review a number of examples where dispersal recordings have worked well. However, the use of alarm and distress calls for deterring eiders has also not been attempted as they do not seem to have such calls (Cramp & Simmons 1977).

Laser light as a deterrent is a novel stimulus for pest species, and whereas some novel deterrents with various visual and/or audio stimuli seem to have worked in some cases (e.g. Lidster *et al.* 1994), habituation is a major problem with many deterrents (Inglis 1980). Examination of the degree of habituation to laser light was beyond the scope of this study, as individual birds could not be recognised. It seems likely that habituation to laser light would occur, although this effect may be reduced by only using the laser when birds arrive on site to feed, as was carried out in this study. Another factor that may reduce habituation is that the flight response of one individual to the laser often elicited a panic flight in the rest of the feeding flock, thus only a fraction of the feeding flock is directly exposed to the stimulus at any one time.

Although it is clear that use of laser light could be a good deterrent, there are a number of potential problems associated with its application on a working farm. The first problem is that it is a reasonably expensive product and it is not yet widely available. However, the main problems associated with the use of the laser is that it is operated manually, and efficacy is dependent upon ambient light intensity. As a result of these constraints, the commercial use of a laser to reduce the impact of diving ducks on mussel farms could be labour intensive and involve work at unsociable hours i.e. at dawn and dusk. Despite these constraints however, laser light could prove to be an effective deterrent not only to diving ducks on mussel farms, but also to many other pest species especially during periods of high attendance.

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# Chapter 7

# The use of underwater playback to reduce the impact of eiders on mussel farms

## Abstract

One of the most commonly employed methods of reducing eider duck damage to mussel stocks on mussel farms in Atlantic Canada and in Scotland is chasing birds by boat. While effective in the short-term, the frequency of chases is often restricted by high costs, both in time and fuel. Work in Canada first examined the use of an underwater playback system (UPS) of recorded engine noise to scare ducks. In 1987 initial harassment by a chase boat was used in set transects around mussel leases twice daily. Harassment began when ducks first appeared in the area and before feeding patterns became established. Initially there were 200-500 eiders in the vicinity of leases. During this period, flush distances from the chase boat increased dramatically and latency of ducks returning to the area following boat activity also increased. Numbers of ducks declined erratically. Two leases fitted with underwater broadcast devices played recordings of the chase boat at 30-second intervals. Few ducks landed on these leases and when they did, dive times were very short. Tests in Scotland used underwater recordings of chase-boat engines replayed at regular intervals on continuous loop tapes through an underwater loudspeaker in an attempt to reduce predation pressure by eiders on mussel farms. Trials of the UPS in spring 1998 gave significant reductions in eider numbers of 50-80%, while a control trial with the playback of an unassociated noise gave no significant reduction. The mean return time of birds to the farm after chasing by boat also increased significantly during UPS trials. The long-term habituation of ducks to this system was negligible providing it is occasionally reinforced by boat chasing.

## Introduction

Common eiders, *Somateria mollissima* generally feed on the blue mussel, *Mytilus edulis*, by diving (Cramp & Simmons 1977, Ydenberg & Guillemette 1991, Guillemette *et al.* 1993). Eiders are an extremely common duck around the Scottish coastline, particularly in areas used for mussel farming, and populations seem to be increasing in size (Gibbons *et al.* 1993, Chapter 2). Goldeneyes, *Bucephala clangula* are another diving duck species which prey upon *Mytilus*, however, they take a much smaller size-class of mussel (Chapter 4), and are only found in coastal areas during the winter. The population size and distribution of goldeneyes is also expanding in Scotland (Dennis & Dow 1984).

Faster growth rates, thinner shells and higher relative flesh weights (Dunthorn, 1971; Galbraith, 1987, 1992), and the lack of tidal constraints to feeding regime (Chapter 3) make cultivated mussels more suitable as a prey item for eiders and goldeneyes. Large losses of stock from mussel farms as a result of diving duck predation have been documented in Scotland and also in Canada (Lidster *et al.* 1994, Chapter 4). Avian pests are well documented within both agriculture and aquaculture (e.g. Murton and Wright, 1968; Furness, 1996). Advances in farming often result in larger areas of monoculture and greater production and quality of the crop than would be found in 'natural' conditions. Such areas are likely to attract species that feed on the food in the wild (VanVuren and Smallwood, 1996). As a result of these interactions, in many areas of both agriculture and aquaculture there has been a need for the development of methods to reduce the amount of damage caused by pest species.

Deterrents generally fall into three categories: visual, acoustic and biological (Draulans 1987). Biological deterrents are usually concerned with playbacks of distress and alarm calls, and various studies have produced conflicting results (see Draulans, 1987). More importantly, literature searches have revealed no evidence of alarm or distress calls from eiders. Many low-cost visual deterrents such as scarecrows or flashing lights seem to result in rapid habituation (Inglis 1984). However a study of the use of Laser light as a deterrent to eiders showed promising results (Chapter 6).

Acoustic deterrents are often combined with visual scaring devices such as pyrotechnics or 'wailers' producing a number of different sounds through a loudspeaker, and again have produced ambiguous results (Lidster *et al.,* 1994; Moerbeek *et al.,* 1987). A problem with many deterrents seems to be that they are not usually associated with any other deterrent and therefore do not allow reinforcement as a means of lessening the effects of habituation.

One of the most commonly employed methods used to deter ducks from feeding on mussel farms in Atlantic Canada and Scotland is chasing by boat. Although effective in the short term, boat chasing is both labour intensive and expensive in terms of fuel. Preliminary studies in Canada have shown that the underwater playback of recordings of approaching chase boat engines could be used as a possible deterrent to diving ducks feeding on mussel leases (Lien and Pittman, 1996; Lien and Hennebury, 1997). These trials examined the problem with specific reference to problems caused by long-tailed ducks or oldsquaw, *Clangula hyemalis* and common scoters *Melanitta nigra,* and found that numbers of feeding birds in the area of the trials decreased with short-term use of the underwater playback system (UPS). The aims of this study were to measure the efficacy of the UPS system in deterring eiders from feeding on mussel farms in Scotland and to examine the likelihood of habituation to this device.

## Methods

Underwater recordings were made onto digital audio tape (DAT) using an Aiwa HD-S200 lightweight DAT recorder by means of a hydrophone (Brüel & Kjær, Type 8103) through a Nexus conditioning amplifier (Brüel & Kjær, Type 2692) at 31.6 mV/ms$^{-2}$.

The hydrophone was suspended 3m below the surface of the water from a floating platform, and recording commenced when the scare boat was 150-200m distant with the engine being started and the boat approaching the platform at full throttle. Recordings lasted approximately 2-3 minutes, ending when the boat had passed the recording point. Once a satisfactory recording was made, it was repeatedly transferred onto a 15 minute standard audio-cassette with an interval twice the length of the recording.

The playback system consisted of a car stereo cassette deck with auto-reverse, connected to an underwater loudspeaker (Lubell labs LL964) via a 120 watt booster amplifier. The system was powered by a 12v car battery replaced daily, and was contained in a watertight drum to protect the electronics.

Throughout the course of each trial, the UPS was secured either on the most central raft of the farm in question if on a raft based farm, or on a moored platform in the centre of a long-line farm. The loudspeaker was suspended in the water 3m below the surface.

Observations were made using telescopes from tents set up at least 100m from respective farms. Tents were erected prior to the onset of any deterrent trial to allow the birds to get used to their presence. Data were collected every five or ten minutes (depending on the site and weather conditions) from dawn until dusk. The number of males, females and immature birds in each flock (one flock being defined as a group of birds with no individual more than 10m from any other) was recorded as was their position in relation to the farm. Since eiders were never observed to have moved more than 10m between points of surfacing and diving, individuals inside, or within 10m of the farm were recorded as feeding on the farmed mussels, whereas individuals 10-200m from the boundary of the farm were recorded as not feeding.

The mean number of birds feeding every five or ten minutes was calculated for each hour of observations. A running mean was calculated of the hourly means for each day to reduce variations of the time-series data. Mean hourly values were then calculated for each section of each trial to describe trends in feeding pressure at different stages of each experiment (see below). Presence or absence of workers, scare-boat activity or other disturbances were also recorded.

For trials investigating the effects of hour along with UPS efficacy, each day was split into three parts; early morning, midday and afternoon. Early morning was based upon the mean number of eiders feeding per observation period each hour from 0800h until 1055h, midday from 1100h to 1355h, and afternoon from 1400h to 1655h. These values are presented in the results section as 0900h, 1200h and 1500h respectively.

For trials investigating the effect of worker presence / absence along with UPS efficacy, single hourly means were taken each day for one hour immediately prior to workers arriving on-site and for one hour after workers have arrived (for values for workers absent and workers present respectively).

The two sites used in this study were in Loch Striven and Loch Creran, Argyll. The Loch Striven site is a long-line installation situated approximately 8 kilometres from the mouth of the loch in the Clyde Sea. There are no other mussel leases currently in use within the loch or in the immediate area around it. The Loch Creran site is raft based and again is the only mussel farm within that particular sea-loch. The closest mussel farms to this site are situated in Loch Etive, over 24 kilometres distant by sea.

Trials generally consisted of a six or seven day observation period prior to switching on the UPS followed by a six day period with the UPS constantly on during daylight hours, followed by a similar length period with the UPS switched off again. However, the L. Creran trial in 1999 was of a longer duration (to investigate the longer-term effects of the UPS), consisting of similar length pre- and post-UPS periods, but a protracted period with the UPS switched on for 21 days. The UPS period of this trial was then split into three seven day blocks for analysis.

3 UPS trials were undertaken at the mussel farm in South Shian, Loch Creran in 1998. Two trials used playbacks of the scare-boat usually used to chase eiders and a third was used as a control producing an unassociated sound (white noise) at the same interval as the normal playbacks. The fourth L. Creran trial was carried out in spring 1999, and is detailed above. One trial was also carried out in L. Striven during autumn 1998, and was the same format as the first three L. Creran trials.

**Results**

Table 1 shows the results of two-way ANOVAs investigating the effects of the UPS trial stage and those of time or of worker presence or absence on numbers of eiders feeding at mussel farms for five different trials. Figure 1 shows the relative attendance for each of the first three Loch Creran trials during each stage of the trial (pre-UPS (pre), during UPS stimulus (dur) and post-UPS use (post)) at each hour. For all hours and when workers were absent, the UPS had a significant effect on eider attendance for every trial except the control, where there was only an effect of the UPS for 1500hrs, and the attendance was significantly *higher* (33%) during the UPS stimulus period (see Table 2). In the second L. Creran trial, there was no significant effect of hour on attendance across all treatments, after pooling the hour data for each trial stage, the effect of the UPS was even more significant than in the two-way ANOVA results ($p<0.0001$, d.f. = 3, $K\text{-}W$ = 17.88), and Dunn's multiple comparisons tests showed significant differences between the pre- and during UPS stages ($p<0.001$) and between pre- and post-UPS stages ($p<0.05$).

**Table 1.** Results of 2-way ANOVAs for each UPS trial, examining the effects of the UPS and time of day or worker presence/absence on numbers of eiders feeding on mussel farms. Levels of significance are indicated by asterisks ( * $p$<0.05, * * $p$<0.01, and * * * $p$<0.001).

| | | Between Factor effects | | | | |
|---|---|---|---|---|---|---|
| **Trial** | **Parameter** | **$F_{df1,df2}$ value** | | **MS** | **Significance** | **Figure** |
| L. Creran 1 | UPS effect | $F_{2,63}$ = | 19.930 | 4523.0 | 0.0001 * * * | Fig. 1 |
| | Hour effect | $F_{2,63}$ = | 4.018 | 911.5 | 0.0228 * | |
| | Interaction effect | $F_{4,63}$ = | 1.373 | 311.4 | 0.2535 n.s. | |
| L. Creran 2 | UPS effect | $F_{2,51}$ = | 8.367 | 275.1 | 0.0007 * * * | Fig. 1 |
| | Hour effect | $F_{2,51}$ = | 0.205 | 6.7 | 0.8157 n.s. | |
| | Interaction effect | $F_{4,51}$ = | 0.397 | 13.1 | 0.8097 n.s. | |
| L. Creran 3 (Control) | UPS effect | $F_{2,45}$ = | 5.839 | 238.6 | 0.0056 * * | Fig. 1 |
| | Hour effect | $F_{2,45}$ = | 4.953 | 202.4 | 0.0114 * | |
| | Interaction effect | $F_{4,45}$ = | 1.582 | 64.6 | 0.1956 n.s. | |
| L. Creran 4 (Long-term) | UPS effect | $F_{4,48}$ = | 4.255 | 1.5 | 0.0050 * * | Fig. 2,3 |
| | Worker effect | $F_{1,48}$ = | 30.360 | 10.8 | 0.0005 * * * | |
| | Interaction effect | $F_{4,48}$ = | 6.125 | 2.2 | 0.0001 * * * | |
| L. Striven | UPS effect | $F_{2,22}$ = | 13.540 | 13.5 | 0.0001 * * * | Fig. 2 |
| | Worker effect | $F_{1,22}$ = | 20.410 | 20.4 | 0.0002 * * * | |
| | Interaction effect | $F_{2,22}$ = | 8.139 | 8.1 | 0.0023 * * | |

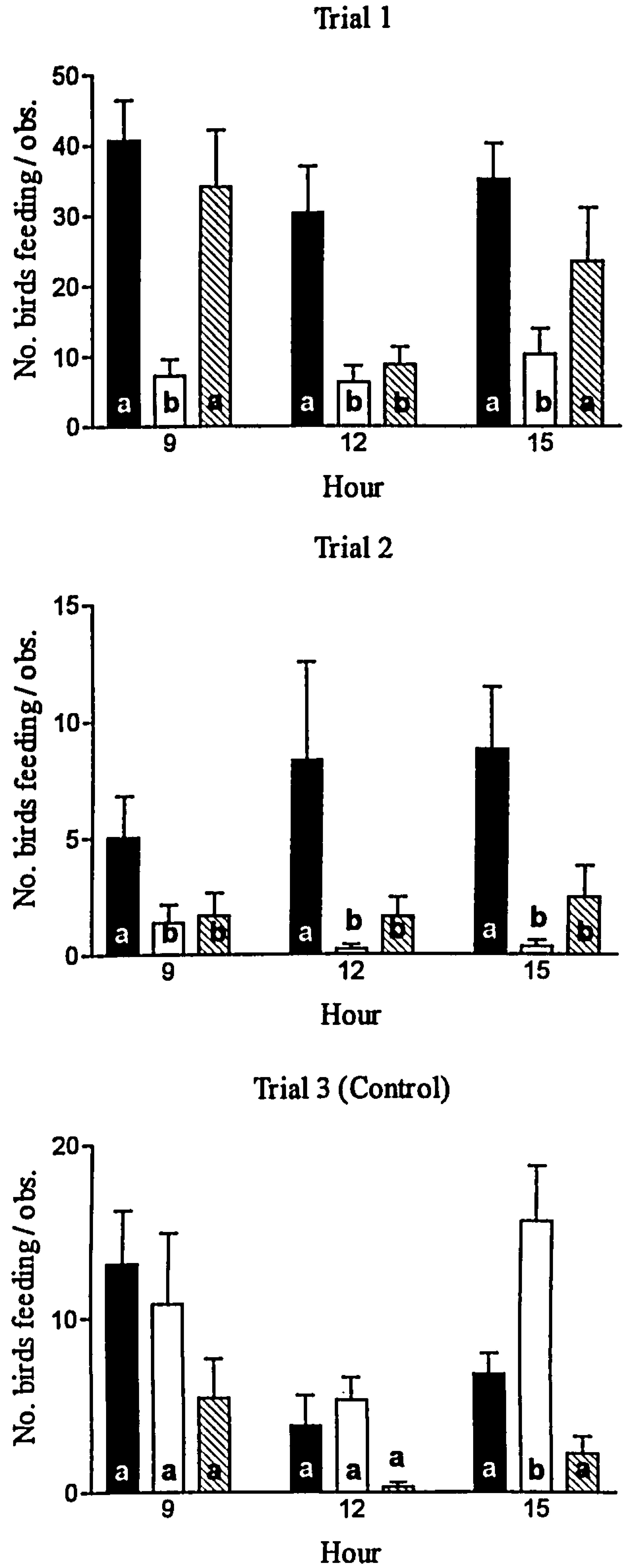


**Figure 1.** Loch Creran short-term UPS trial results. Charts show the average number of eiders feeding at the mussel farm per observation at three different times of day, and at each stage of the trial; for six days before the UPS was switched on (solid bars), for six days whilst the UPS is in operation (clear bars), and for six days once the UPS has been switched off (hatched bars). Bars labelled with the same letter (for each hour) on each graph are not significantly different from each-other ($p$>0.05)

**Table 2.** Mean numbers of ducks observed feeding at mussel farms each 5 minute period for four experimental UPS trials and the percentage change in numbers whilst the UPS is switched on (Pre to during), and that remaining once the UPS has been switched off (Pre to post). For the final two trials in the table, the figures given are for periods of worker absence only.

| | No. eiders feeding / obs. | | | % Change | |
|---|---|---|---|---|---|
| Trial | Pre-UPS | During UPS* | Post UPS | Pre during | to Pre to post |
| L. Creran 1 | 36.2 | 7.4 | 14.7 | -79.6% | -59.4% |
| L. Creran 2 | 6.7 | 1.8 | 2.8 | -73.1% | -58.2% |
| L. Creran 4 (L-term) | 2.4 | 0.7 | 0.7 | -70.8% | -72.4% |
| L. Striven | 36.5 | 19.3 | 1.2 | -47.1% | -96.7% |

Trials investigating the effect of the UPS and its association with the presence or absence of workers were carried out in Loch Striven and L. Creran, where a trial was carried out to evaluate the efficacy of the UPS over a longer time-scale (see Figure 2).

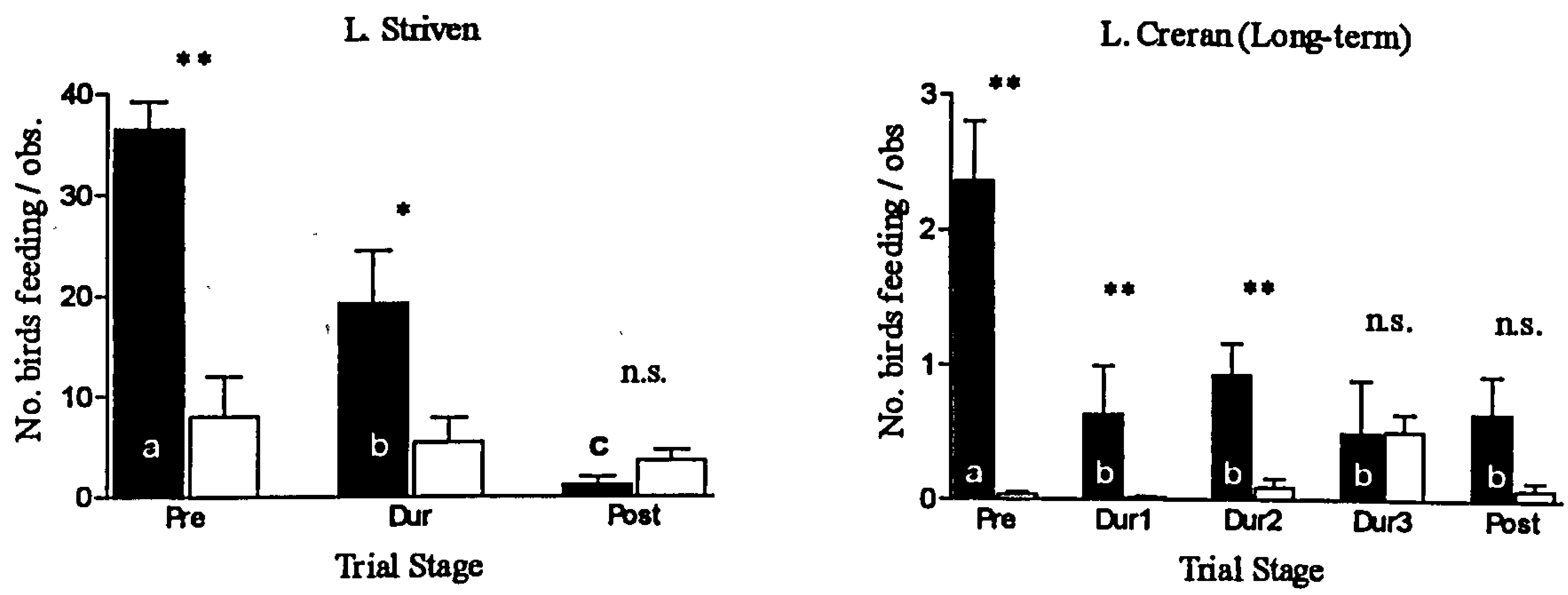


**Figure 2.** Results of UPS trials in Loch Striven and Loch Creran. Charts show the average number of eiders feeding at the mussel farm per observation when workers were absent (solid bars) and when workers were present (clear bars) at different stages of each trial. Significant differences in numbers as a result of worker presence/absence are shown by asterisks above each pair of bars. Differences between bars of the same colour throughout each trial are indicated by different letters at the base of each bar ($p<0.05$), bars with no letters are not significantly different from each-other. The L. Creran trial consists of a six-day period before the UPS is used (pre) followed by an extended period with the UPS in operation, with three six-day blocks (1-3) before a six-day observation period after the UPS is switched off (post).

When workers were absent from the site, for both trials there was a significant effect of the UPS, however, with the L. Striven trial there was also a significant reduction in numbers between the UPS being on and the post-UPS period. When workers were present on site, for both sites there were no significant differences in attendance at any stage of the trial. However, with the L. Creran trial, when daily means for attendance were examined with respect to day number since first switching on the apparatus, a strong positive relationship was found, although no such relationship was found when workers were absent (see Fig. 3).

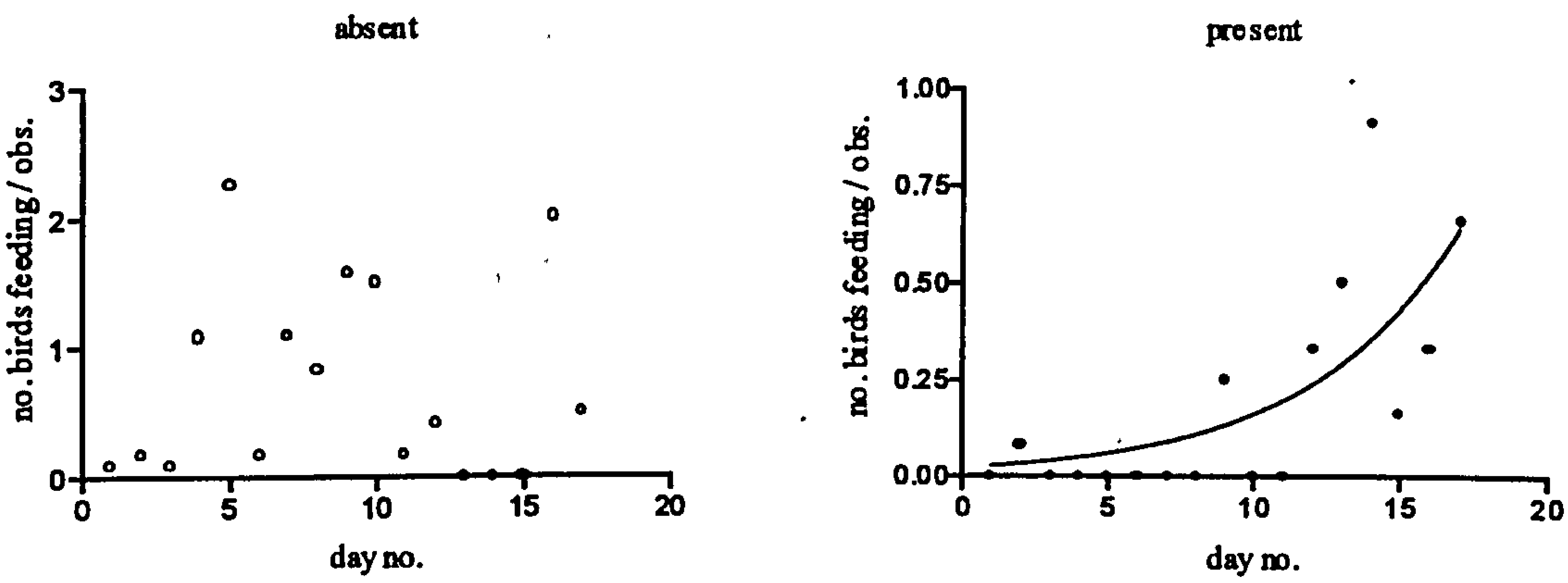


**Figure 3**. Relationship between day number after the UPS is switched on and the number of eiders feeding at the L. Creran mussel farm, showing no relationship with workers absent ($r^2$= 0.000, n = 17), but a strong exponential increase (best fitting line) when workers are present ($r^2$= 0.521, n = 17)

The presence of workers had a large effect upon numbers of birds feeding at any one time, particularly at the start of each trial (see Table 3). However, as shown in figure 3, the effect seems to be lessened when the UPS is switched on, and there was a reversal of this effect after the use of the UPS in L. Striven, hence the significant interaction effect observed for both trials.

**Table 3.** The effect of worker presence (+wrk) / absence (-wrk) on the numbers of eiders feeding per observation period during the long-term UPS trial on L. Creran and on L. Striven before, during and after implementation of the UPS system, and the percentage change in numbers attributed to the presence of workers.

| | Pre-UPS | | | During-UPS | | | Post-UPS | | |
|---|---|---|---|---|---|---|---|---|---|
| Trial | -wrk | +wrk | % change | -wrk | +wrk | % change | -wrk | +wrk | % change |
| L. Creran | 2.37 | 0.04 | -98.2% | 0.69 | 0.21 | -69.6% | 0.65 | 0.08 | -87.3% |
| L. Striven | 36.50 | 8.05 | -77.9% | 19.30 | 5.50 | -71.5% | 1.20 | 3.60 | +200.0% |

Figure 4 shows the effect of UPS treatment on the return times of birds to the mussel farm after being chased by the scare boat. For the first two L. Creran trials there are significant differences between groups ($p<0.0001$, d.f. = 2, $H$ = 21.75 and $p<0.01$, d.f. = 2, $F$ = 5.12 respectively). Multiple comparisons between treatments for each trial showed that return times prior to the onset of the UPS were significantly lower than when the UPS was in operation and after it has been switched off ($p<0.001$ and $p<0.01$ respectively). There was no effect on return time for the control treatment or for the L. Striven trial ($p>0.05$, d.f. = 2, $H = 0.001$ and $p>0.05$, d.f. = 2, $F = 0.894$).

A one-way ANOVA across all five treatment blocks for the long-term UPS study on L. Creran revealed a significant effect of the UPS on return-time of eiders ($p<0.05$, d.f. = 4, $F$ = 2.509), although tukey-tests revealed that there were no significant differences between groups. However, when all three treatment blocks were pooled, the effect of the UPS became more evident ($p<0.05$, d.f. = 2, $F$ = 4.381), and multiple comparisons showed that return-times were significantly lower pre-UPS than during the UPS trial or post-UPS ($p<0.05$). There was no relationship (Spearman's rank) between day number and average return-time whilst the UPS was switched on ($r^2$= 0.0060, n = 15).

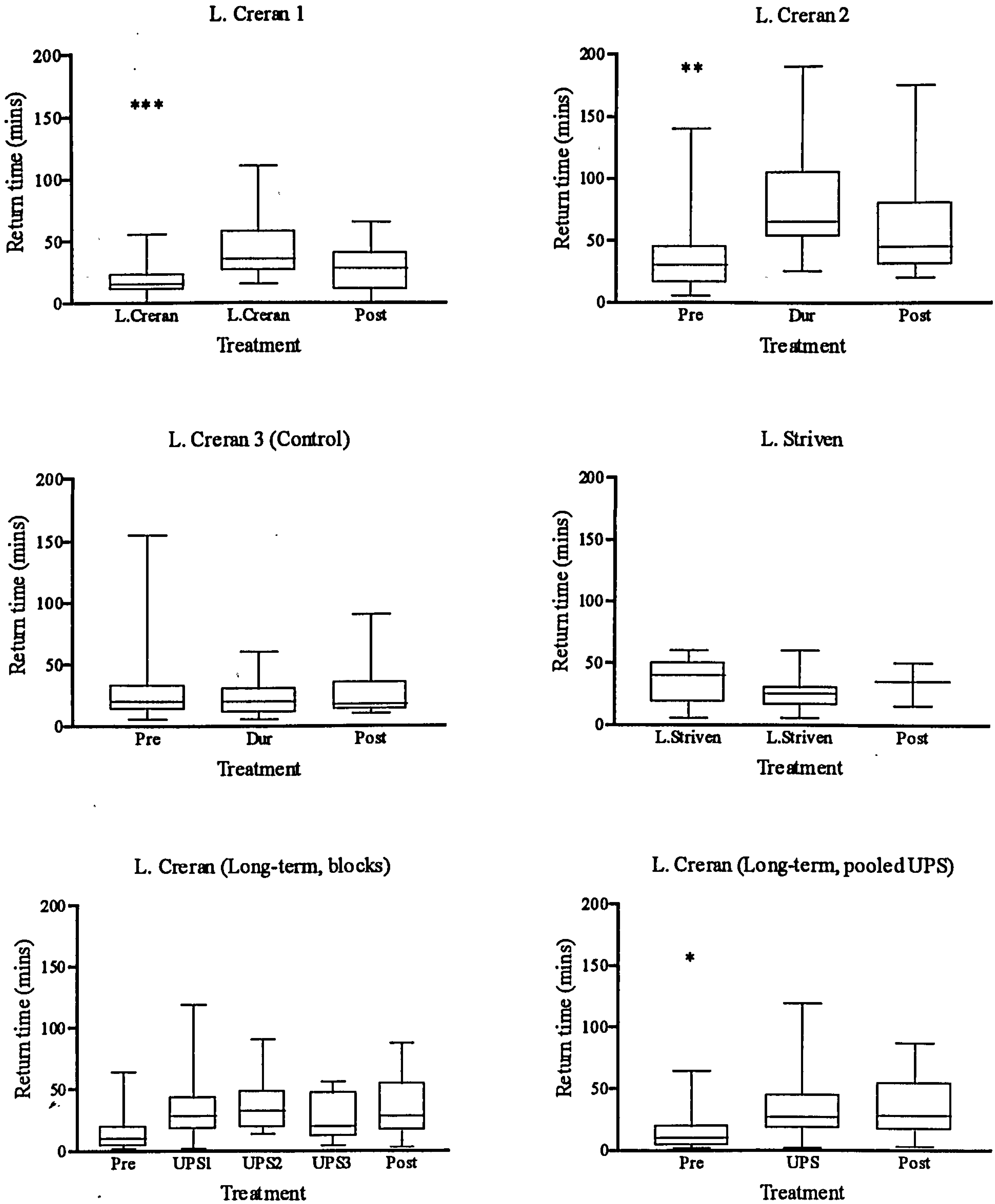


**Figure 4.** Box plots of the time taken for eiders to return to the mussel farm to feed after scare-boat runs at different stages of the UPS trial in question. Whiskers show the range of the data, boxes show interquartile ranges. Asterisks indicate mean values significantly different from other treatments within the same trial (*** $p<0.001$, ** $p<0.01$, * $p<0.05$).

## Discussion

In general, trials of the UPS worked well in alleviating predation pressure by eiders on mussel farms in Scotland, reducing then numbers of feeding birds by between 50 and 80% in all experimental trials. The control trial did not reduce feeding on the farm, and during this trial numbers of birds feeding actually increased.

In all the experimental trials in Loch Creran, use of the UPS caused a significant increase in the mean return time of birds to the mussel farm. When tried in Canada, it was noted that birds became much more wary of the chase boat when the UPS was in place, and that birds would tend to fly from the boat at a greater distance than when UPS was not present or switched off. Both these factors suggest that the deterrent stimulus of the scare boat is actually strengthened by the presence of the UPS.

The results of the Loch Striven trials are somewhat ambiguous, as although the number of birds feeding dropped when the UPS was switched on, the numbers also decreased significantly between the UPS being used and it being switched off. In all other experimental trials, the numbers of birds feeding post-UPS were either higher than during the UPS period or not significantly different. Coupled with this is the fact that the return times of birds on Loch Striven, as with the control, showed no changes throughout the UPS trial.

Although the Loch Striven trial may not clearly demonstrate any constraints with the UPS, some factors are likely to affect its efficacy:

1. Pre-exposure to original deterrent – If birds have previously been chased by boat only infrequently, then the UPS may provide a stimulus to them that has no association with a 'real-life' deterrent.

2. Frequency of reinforcement – Without reinforcement of the UPS with the scare-boat it is likely that habituation to the stimulus will be much more apparent.
3. Availability of alternative resources – A lack of alternative food sources (either cultivated or occurring in the wild) in the local area is likely to increase dependence of birds on a particular mussel farm, and therefore make it less easy to deter them (Draulans, 1987).
4. Numbers of birds – The ease of deterrence of a species can decrease if birds become established on a particular site, and thus begin to attract conspecifics (Lidster *et al.*, 1994). Guillemette *et al.* (1993) also showed that larger flocks of eiders facilitated feeding, which in turn would increase the relative profitability of the respective site.
5. Stage in breeding cycle – Energetic needs of eiders and other bird species will change throughout the year according to factors such as breeding, chick rearing and moulting (Gorman and Milne, 1972)
6. Mussel quality – Temporal variation in relative profitability of different size-classes of mussels between wild and cultivated sites may increase or decrease dependence of populations on respective sites.

Worker presence on site also seems to have a great effect on reducing predation pressure at mussel farms. However, with use of the UPS, the difference between the numbers of birds feeding when workers are absent and when they are present seems to diminish over time. It seems unlikely that this increase would ever rise above the number present when workers are absent when the UPS is switched on. This figure did not show any signs of increasing as the long-term trial progressed, suggesting that birds do not habituate to the UPS *per se*, but that the effect of worker presence whilst it is applied will become negligible over time. This effect again suggests that that the UPS is (or can be) a stronger deterrent stimulus than the scare boat itself.

The UPS, with reinforcement, may be a stronger deterrent stimulus than the scare boat itself because, in theory, it is only presented to the birds whilst they are feeding (i.e. when they are underwater). The UPS is purely an acoustic deterrent whereas the chase boat itself combines both acoustic and visual cues. However, of these two components, the acoustic cue may be the more important, as it is present when the bird is at the surface and when it is underwater, whereas when diving the visual cue is lost. It is conceivable that birds may be more easily startled when underwater, as the whereabouts of the chase boat will be unknown. The presentation of deterrent stimuli only when the birds are feeding also means that they are not continually exposed to the stimulus even when they are some distance from the farm and not feeding, as is the case with most above-water acoustic deterrents such as propane canons or wailers. Such continual presentation of a stimulus, particularly when the target species is not actively causing damage is also likely to favour more rapid habituation.

We can indicate the savings that could arise from use of the UPS. For a site with 100 eiders regularly feeding on the farm (a not uncommon situation), UPS may reduce numbers by about 65 birds. Since eiders may remove about 2.5kg per bird each day from mussel lines (Milne and Galbraith, 1986), this represents a saving of 162kg per day. For a typical situation in west Scotland, with eiders feeding on a farm for around 100 days of the year, this represents a saving of over 16 tonnes of mussels per year, which in turn represents a financial saving of around £16 000 to the mussel farmer (based upon 1999 prices).

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# Chapter 8

# General discussion

Global production from aquaculture is growing annually. Price and Nickum (1995) predicted that the figure for the year 2000 would be somewhere between 20 and 25 million tonnes. Despite recent setbacks in Scotland (e.g. the discovery of Infectious Salmon Anaemia, in farmed Scottish salmon, (Stagg 1998)), the aquaculture industry is still developing, with *Mytilus* production rising annually (Fraser 1999). The presence of such monoculture is likely to attract species that are able to exploit them. Such species can then become pests, and excess losses of stock may require that they have to be controlled in some way.

After the problem of eiders feeding on mussel farms in Scotland was first documented by Dunthorn (1971), Colin Galbraith (1987) then demonstrated that the problem had intensified. The results of the questionnaire (chapter 4) in this thesis show that it is a problem that is now facing the majority of Scottish mussel farmers. The presence of large flocks of goldeneyes feeding on some mussel farms also raises concern, as it is a relatively new problem species in Scotland. It's small breeding population and range in Scotland may still be expanding (MacMillan 1970, Dennis and Dow 1974, Gibbons *et al.* 1993).

Although it seems likely that eider populations were increasing in size prior to the development of the aquaculture industry in Scotland, the effect that this may be having now is uncertain. During winter and early spring, eider attendance is highest, with adult birds feeding on the high quality cultivated mussels (Galbraith 1987, Galbraith and Milne 1992) at a lower energetic cost of foraging (chapter 3). Mussel farms receive little attention from adult eiders during the summer months, but may be more important to juvenile birds, thus increasing their survival, as seen in Cormorants, *Phalocrocorax carbo* in freshwater fisheries in England and Wales (Russell *et al.* 1996). The eider is a long-lived duck, and if individuals learn that mussel (or salmon) farms are a profitable feeding ground, they may develop some dependence on these sites. The potential consequences of such dependence can be devastating if the resource is suddenly lost. This was demonstrated in the Dutch Wadensee following a near total reduction in bivalve stocks in 1990, resulting in massive mortality of the local wintering eider population (Nehls & Ruth 1994, Beukema & Cadee 1996). In this respect it is important that eiders, or goldeneyes, should not become reliant on cultivated stocks of mussels before the development of wholly effective deterrent measures.

Not only might aquaculture have an impact on population growth, it may also effect distribution of birds. Both mussel and salmon farms had a marked effect on wintering distributions of eiders on the west coast in this study (chapter 2). Changes in agricultural or aquacultural practices in an area can have a large effect on the populations normally utilising that habitat, either beneficial or detrimental. For instance, in Western France, changes in farming practices resulted in long-term declines in wintering duck species in the area, and corresponding increases in other areas in France (Duncan *et al.* 1999). Conversely, in the southern United States, expansion of the wintering ranges of wader species and double-crested cormorants, *Phalacrocorax auritus* is attributed to growth of the catfish farming industry in the area (Fleury & Sherry 1995, Glahn & Stickley 1995). The distribution of aquaculture sites is generally sympatric with that of eiders on the west coast of Scotland, so on a grand scale we would not expect to see any changes in the distribution of eiders as a result of aquaculture development. However, on a smaller scale we have seen there is a local effect on birds, and further studies of population movements may find that a growing number of birds will choose to winter in the north and west of Argyll at aquaculture sites.

To successfully reduce the predation pressure put on a mussel farm by diving ducks it is necessary to make that site less profitable than those feeding grounds occurring in the wild locally. In order to be successful, a deterrent must alter the feeding behaviour of the birds in such a way to decrease the intake rate of birds on these high quality prey items until 'normal' feeding behaviour on wild mussel beds becomes more profitable.

Both eiders and goldeneyes are wary of humans, and the presence of workers on farms generally serves to prevent them from feeding (chapter 5). However, because workers cannot be present all day long or every day, birds are able to exploit these periods and cause substantial amounts of damage. In this respect, deterrents need to be either automatic, or strong enough that limited applications will substantially reduce numbers of birds for long periods.

One of the major problems generally encountered with deterrents is that birds often rapidly habituate to them. Inglis (1980) suggested that the reason for this was that deterrents generally tended to lack some 'scaring' component, which would cause some permanent distress to the birds. The knowledge that chasing birds away from farms by boat is an effective deterrent (chapter 5), even though it only has a limited duration of effect, meant that this 'real' deterrent could be used to develop the UPS (chapter 7). As with the Laser trials (chapter 6), the UPS relied upon an association being made between the particular deterrent and the act of feeding at the mussel farm.

**Conclusions**

The interactions between seabirds and fisheries are well documented (e.g.Garthe *et al.* 1996, Phillips *et al.* 1999). However, the effect that expansion of the aquaculture industry is having on bird populations and their ecology is not fully understood. Decreases in Scottish cormorant populations have been attributed to persecution by fish farmers (Furness 1996, Russell *et al.* 1996), but thankfully no such trend has been observed in eiders as of yet. Detailed studies of population changes of diving ducks with particular reference to aquaculture facilities are needed to assess their importance. There is also a need for the development of non-lethal deterrent methods for reducing the damage that eiders and goldeneyes cause to mussel farms. If such aims can be achieved, co-existence of both mussel farmers and diving ducks may be possible with no detrimental effects to either.

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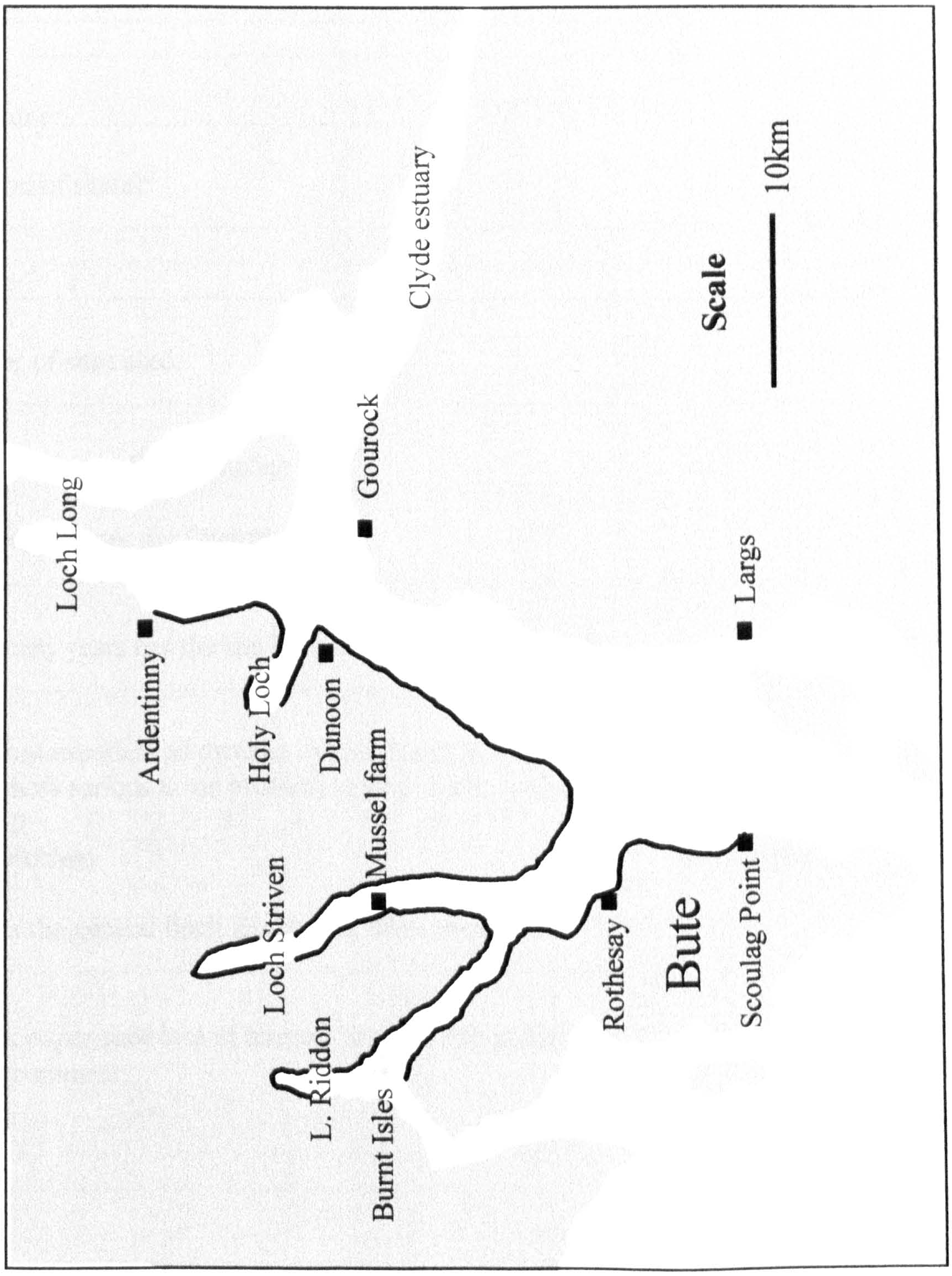
**Map of Clyde Sea, showing survey area (bold coastline)**



**QUESTIONNAIRE** (* Delete as appropriate)

Name:
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Address:
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....................................................................................................................
....................................................................................................................

Telephone: ............................................

Location of site(s):
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....................................................................................................................
....................................................................................................................

Number of sites used:
....................................................................................................................

Type of farm: Raft/Longline *

No. droppers per site (approx.):
....................................................................................................................

How many years has the site been used as a mussel farm?
....................................................................................................................

Have you experienced damage to your stock from Eiders? Yes/No *
If yes, how serious is the problem to you? Rank on the following scale:

0 1 2 3 4 5 6 7 8 9 10
no problem very serious

What is the general flock size during these times?
....................................................................................................................

Do you experience loss of mussels to any other predators? Yes/No *
If yes, comment:
....................................................................................................................
....................................................................................................................
....................................................................................................................

The following questions are all with specific reference to damage caused by eiders:

Does damage vary between sites? Yes/No *
If yes, comment:
.....................................................................................................................
.....................................................................................................................
.....................................................................................................................
.....................................................................................................................

Circle the size-classes of mussels that are generally lost to eiders:

<1cm 1-2cm 2-3cm 3-4cm 4-5cm 5-6cm >6cm

Has the extent of damage varied between years? Yes/No *
If yes, comment:
.....................................................................................................................
.....................................................................................................................
.....................................................................................................................
.....................................................................................................................

Could you estimate % loss of stock due to eiders over the last 5 years:
1992: ........... 1993: ........... 1994: ........... 1995: ........... 1996: ...........

Could you estimate the financial loss due to eiders over the last 5 years:
1992: £.......... 1993: £.......... 1994: £.......... 1995: £.......... 1996: £..........

Circle the months of the year in which eiders cause the most damage to your site:

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

Any additional comments:
.....................................................................................................................
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.....................................................................................................................
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Is there an obvious daily pattern of attendance of eiders at the sites; e.g. what time do they arrive/leave the site and do they all arrive/leave at roughly the same time?
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.....................................................................................................................
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What control measures have you tried?

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How well have they worked?

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What is the extra financial cost of these measures?

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What additional control measures have/would you consider using?

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.....................................................................................................................
.....................................................................................................................

Have you ever had/applied for a license to shoot eiders at your site? If yes give details:

.....................................................................................................................
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.....................................................................................................................
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What kind of action would be most helpful to you?

.....................................................................................................................
.....................................................................................................................
.....................................................................................................................

Do you have any additional comments?

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# Minimising the impact of eider ducks on mussel farming

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# Contents

# Preface

An excellent booklet on 'mussel farms, their management alongside eider ducks' was written by Dr Colin Galbraith in 1992. Much of that remains highly relevant today, and we have made considerable use of the content in preparing this new booklet. However, this new booklet, written by Dr Ben Ross and Professor Bob Furness, is largely based on research conducted between 1996 and 1999 by the University of Glasgow under the LINK Aquaculture Programme, funded by the Natural Environment Research Council (NERC) and members of the shellfish industry. This includes both experimental and observational work in Scotland, and a review of the mitigation measures tested and practised in other parts of the world where ducks impact upon mussel farming. We suggest ways in which mussel farmers can act to reduce the risk that eider duck numbers will build up to levels that cause serious reductions in the profitability of mussel farming. Mussel farming can exist alongside conservation interests, but the numbers of eiders are increasing in Scotland, and in some areas eiders already represent a major problem. We hope that a better understanding of the behaviour of the eider duck, and mitigation measures that can be taken to reduce or prevent damage, will be of practical help to mussel farmers. This booklet is intended to be informative to mussel farmers and the general public and so scientific terminology, detailed descriptions of scientific methods used and statistical testing are avoided. Anyone wishing to see the scientific basis for results described in this booklet is referred to the Ph.D. thesis of Ben Ross (Ross, B.P. 2000. *Manipulation of feeding behaviour of diving ducks at mussel farms. Ph.D. thesis, University of Glasgow*).

Contents of this booklet have been endorsed by the Association of Scottish Shellfish Growers and Scottish Natural Heritage/SERAD.

# Summary


- Eider numbers are increasing in most of Scotland (but decreasing in Shetland). Their consumption of cultivated mussels is a major and increasing problem in many areas as ducks learn to consume mussels from cultivation lines.

- Eider damage at farms is mostly in spring and autumn but timing can vary between sites. Eiders can strip mussels off lines at rates that quickly deplete stock and can put farms out of business.

- Eiders may change their local movement patterns as a result of learning to use mussel farms as places to feed.

- Eiders are long-lived birds, capable of learning the best places to feed, and capable of distinguishing between real hazards and ineffective 'deterrents'. They are also social, and can pass on such behaviour to inexperienced birds.

- Many deterrents have been tried against eider damage. None is entirely effective, and in most cases a combination of deterrents should be used to minimize the habituation of ducks to harmless threats.

- Eider ducks are protected by law, and licences to shoot eiders are only issued where it can be demonstrated that reasonable efforts to prevent losses have failed.

- Rafts are easier to protect than long lines, and compact sites are easier to protect than dispersed ones.

- Anti-predator panels provide the most effective protection

against ducks, and can be used even on long line farms. Netting should be installed only for periods when eider numbers tend to be high, and in most cases should be removed during summer and winter to reduce fouling of nets. Use of vertically set anti-predator netting is preferable to use of floating netting.

- Human activity on the farm is a very effective deterrent, reducing numbers of eiders feeding in the farm by 80-99% compared to periods with no human activity on site. However, eiders will feed from dawn and may take much stock during early hours before workers arrive on site.

- Chasing ducks by boat is the most commonly practised method of reducing impact, but is expensive in time and fuel. Eiders will learn the sound of the chase boat engine and often begin to leave the farm as soon as the engine is started up. However, in most cases ducks quickly return after a period of chasing and resume feeding.

- Underwater playback of recorded chase boat noise reduces numbers of eiders feeding on a farm even when no human activity is present. We suggest that underwater playback is a useful way of protecting the farm during the hours between dawn and the arrival of workers on site. Playback systems are moderately inexpensive. They can be set to switch on and off automatically according to time of day or light intensity. To remain effective, birds must be chased by the same boat moderately regularly.

- Laser light can reduce eider activity at farms, but is expensive and labour intensive, and needs to be used around dawn in order to be effective. However, it can be effective where eider numbers are

high and feeding habits are well established and other deterrents have failed.

- A wide range of stimuli can be successful in scaring eiders, including mannequins, inflatable scary men, plastic streamers, flashing lights, gas cannons, firecrackers, starter pistol or blank cartridges. Not only are these likely to be anti-social to any nearby neighbours, but all of these stimuli result in rapid habituation (eiders learn to ignore them) if they are presented frequently and without any association with real hazards. They can be made more effective by coupling them with shooting live ammunition (to scare, or, if licensed, to kill), or chasing by boat.

- Where eiders represent little problem, a mixture of these simple deterrents may be adequate, but numbers of eiders should be monitored on a regular basis. If numbers show an increasing trend, deterrent use should be strengthened before eider damage increases to become a major problem.

- We provide a list of recommendations for practical steps to be taken by mussel farmers to minimize problems of duck damage.

# Recommendations

1. Numbers of eiders and other sea ducks at your mussel farm site should be counted regularly, to determine whether they show an increasing trend over years, and at which times of year numbers are high. Counts should be made at a consistent time of day, preferably early in the morning when human activity on the farm has not started in order to obtain counts that reflect eider numbers before disturbance.

2. Steps should be taken to discourage eiders from feeding on the farm before numbers of eiders have increased to 'problem' proportions, as it is easier to deter small numbers than to change the established habits of a large flock. A variety of deterrents should be used, each being presented as infrequently as possible to reduce habituation. Reinforce deterrents by chasing ducks by boat or if necessary by shooting (blanks or under licence). A licence to shoot eiders will only usually be granted if all non-lethal alternatives have been tried and shown to fail, since this is a requirement of the EU Birds Directive.

3. When a new mussel farm is being planned, anti-predator measures should be incorporated into the design of the farm and should be costed into the development. Anti-predator netting is the most effective approach and should be carefully considered for any new mussel farm development, whether raft or long-line, so that farm design can make incorporation of anti-predator netting as straightforward as possible.

4. Anti-predator netting is the best means of reducing damage by ducks. Raft designs are much easier to net than long-line farms, but panels around long-lines greatly reduce loss of stock to eiders.

Investment in netting is not cost-effective unless the amount of eider damage is substantial. Where eiders are taking large amounts of stock, anti-predator netting panels should be fitted. Obtaining old salmon farm anti-predator netting can be a much less expensive alternative to buying new anti-predator netting panels. Setting anti predator netting vertically is preferable to use of horizontally laid (floating) anti-predator netting. Floating nets are much more likely to tangle and drown birds, and impede work on the farm. Details of methods used successfully to set nets around long-line farms that had been subject to serious damage by eiders are provided later in this booklet.

5. Farms should be designed to be as compact as possible. If possible they should be sited where eiders are scarce throughout the year (especially in spring and autumn) and preferably where there is as much human activity as possible, rather than in quiet bays.

6. Deterrents should be used to complement anti-predator netting. Human activity is one of the most effective deterrents. Others that work well are chasing by power boat, laser light, and shooting (blanks or under licence).

7. Chasing ducks by power boat reduces their feeding activity in the short term. However, ducks often return to feed on farms within an hour of being chased away. Use of underwater playback of recorded chase boat engine noise can reduce the need to chase, and is especially useful to reduce feeding in early hours of the morning. Where losses to ducks are a problem but cannot be prevented by netting, consideration should be given to establishing an underwater playback, reinforced by frequent chasing of ducks

by one particular boat and engine so that ducks learn to avoid that engine noise. It is essential that the same boat and engine is used routinely to chase ducks away, and in the underwater playback, in order to convince the ducks that the playback noise represents a threat. Ducks do not respond simply to underwater noise or to recordings of boats that are not used to chase them.

8. Laser light equipment is expensive, requires safety training before being used, and requires considerable input of time at unsocial hours, but it can be effective in clearing eiders from a site that has become heavily used by ducks. It may be considered as a last resort where other measures have failed or are impractical. We recommend that you contact Professor Furness or the ASSG for specific advice on laser use before investing in this facility.

*Female eider*

# Predators on farmed mussels

Mussel farming is widespread in Europe and North America, with benthic cultivation in a few areas such as the Wadden Sea, but culture on suspended rope lines being predominant. In Scotland, about half of the mussel farms are based on raft culture and half on long-lines, the latter tending to be larger farms and increasingly the type being set up. The mussel grown in Scotland is the blue mussel *Mytilus edulis*. Mussel farming in Scotland is almost exclusively on the west coast sea lochs of mainland or the islands, or in the sheltered voes and sounds of the northern isles. Increases in mussel farming are especially evident at present in Shetland. Established mussel farms in Scotland have been affected by several predator problems, with loss of stock to eider ducks *Somateria mollissima*, goldeneyes *Bucephala clangula*, and starfish being the main problems. Starfish can be removed by hand or by immersion of lines in freshwater, or particular solutions. Ducks are protected by law and are of high conservation and public interest. They are also less easy to deal with than starfish as sea-ducks such as eiders and goldeneyes are long-lived, are quick to learn, and are mobile and adaptable. Goldeneyes seem at present to be little problem in Scotland except locally in Loch Etive. Eiders on the other hand are a big problem in most places where mussels are farmed, though so far not in Shetland. In Atlantic Canada, especially Nova Scotia, eiders are a major problem to mussel farmers, but scoters *Melanitta* spp. and long-tailed ducks *Clangula hyemalis* are also responsible for significant losses of newly settled spat. In British Columbia and Washington State, scoters and

*Male goldeneye*

long with eiders, and also mollusc-eating fish. Loss of cultivated mussel stock to fish is also a problem in some Mediterranean mussel farms. Thus the problems faced in Scotland are not unique, and solutions may be indicated from the experiences of workers in other countries.

*Male eider*

*Male long-tailed duck*

# Eider duck biology

The common eider *Somateria mollissima* is the largest European sea duck, the male weighing around 2.3 kg and the female about 1.9 kg. Except during June-August when males have a blackish brown 'eclipse' plumage, the male is a handsome white and black bird with a green patch on the side and back of the neck. Females are brown, while immature males (which usually form only a few percent of the population) are blackish with white markings on the back, breast and sides. Compared with the smaller ducks that may also occur on the sea, eiders are not only larger but also more heavily built, with large heads on short necks. Eiders tend to be sociable, occurring in flocks up to several hundred strong, and are often noisy. As fully grown birds at sea they have few natural predators, and they are exceptionally long-lived compared to most other ducks. Many adult eiders live to be 20 years old. However, their breeding productivity is low. Few ducklings survive. Adult females have a higher mortality rate than adult males because they are at risk of predation by foxes, mink, otters and skuas while incubating. Thus in most eider populations there are about 1.3 adult males for every adult female.

Because they live many years, adult eiders have the opportunity to learn about feeding sites in their home area, and because they live in flocks, such information can be passed on to other birds. They can also learn to visit floats in the water because these tend to have food attached to the mooring lines, and learn to avoid humans where humans represent a threat.

**Learning to feed at mussel farms or learning that visiting mussel farms is hazardous represents an important attribute regarding control of eider impact.**

Eider ducklings feed on small marine crustacea such as amphipods, which are relatively easy to digest. However, adult eiders feed mostly on the blue mussel *Mytilus edulis*. They prefer to take mussels of

10-50 mm length, from water depths of about 2-10 m, although they can dive to, and feed at, depths of 40 m or more.

Eider females need to build up large stores of energy and nutrients in spring because they not only lay several eggs, but they incubate these without help from the male, and do not feed throughout the 28 days of incubation. This means that they have especially high food requirements during March-April. This high requirement for food is likely to make them more determined to feed, regardless of any deterrent measures employed, so that eider damage to mussel stock is particularly likely, and more difficult to control, during spring.

*Flock of eiders*

# Distribution and numbers of Eiders

The common eider has a circumpolar breeding distribution, with large numbers on the coasts of many high latitude countries. There are large populations in Canada, Alaska and Russia. About 850,000 pairs nest in Europe, the largest numbers being in Iceland (240,000 pairs), Sweden (240,000 pairs), Finland (150,000 pairs) and Norway (130,000 pairs). The UK lies at the southern edge of the eider's breeding range, and holds about 40,000 pairs. Numbers of eiders are increasing in most parts of Europe, with a persistent rate of increase in the UK of about 2.5% per annum (so that the population size doubles about every 30 years). Contrary to the trend elsewhere, eider numbers in Shetland have been decreasing at about 4% p.a. for the last 20 years, although the reason for this is obscure. Durham, the Solway, and the north coast of Ireland represent the southern breeding limits of the species (Figure 1), although this limit has been very slowly moving south as numbers have increased. Numbers in Scotland are somewhat higher on the east than on the west coast (Table 1).

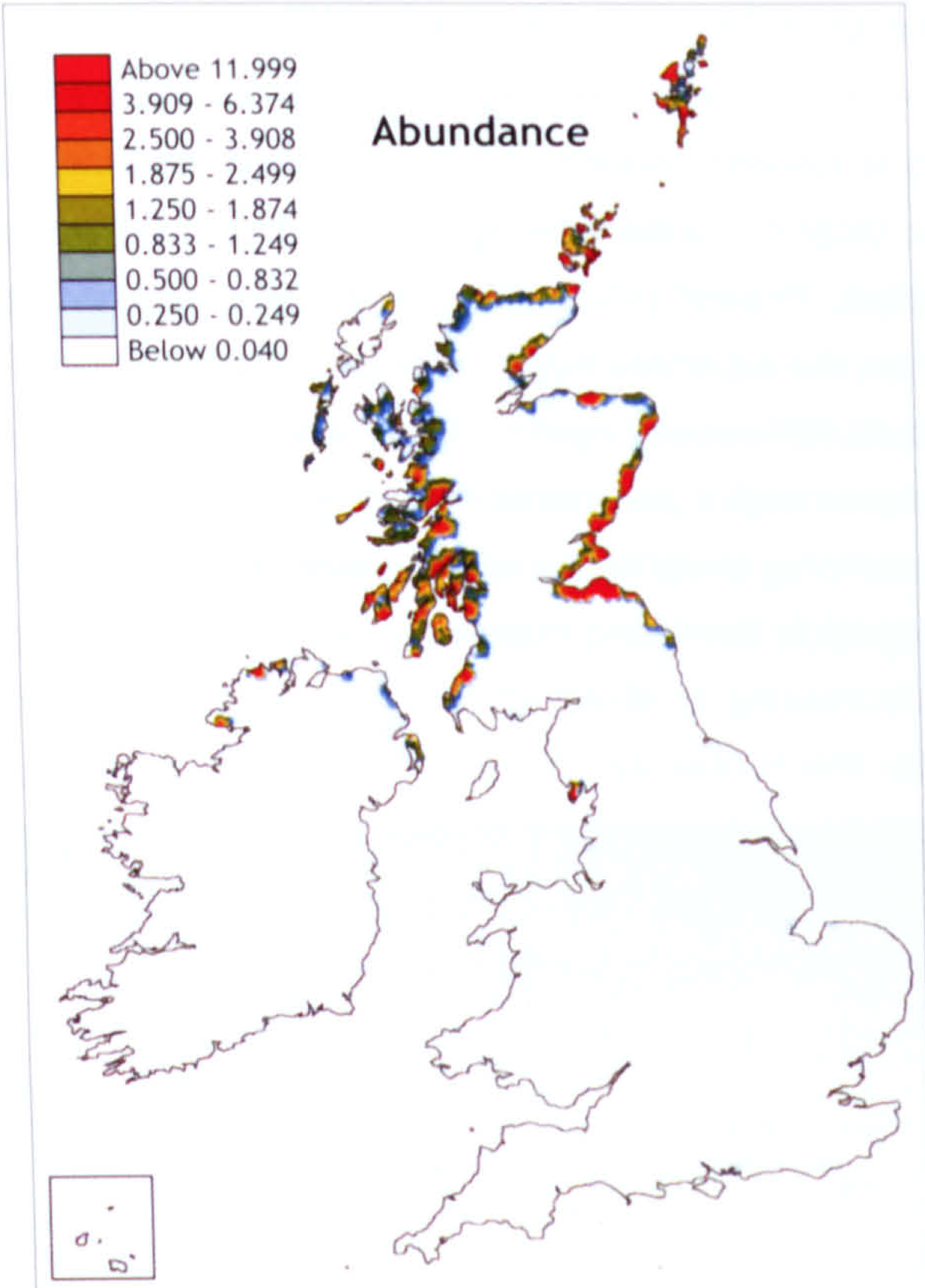



**Figure 1**. *Map of the breeding distribution and abundance of eider ducks in Britain and Ireland. From Gibbons et al. 1993. Permission to reproduce the figure granted by T. & A.D. Poyser. Note that eiders in Britain and Ireland do not undertake large seasonal migrations, and so the winter distribution is very similar to that shown in this map. The numerical abundance scale on this figure is a scale of relative abundances in different areas; major concentrations of eiders are found in areas marked red, orange or yellow, minor numbers where the map is green or blue, and very few or none where the map is white.*

# Distribution and numbers of Eiders

**Table 1.** *Numbers of breeding pairs of eiders in different areas of the UK, as counted in the most recent surveys during the 1990s or late 1980s.*

| REGION | PAIRS OF EIDERS |
|---|---|
| Shetland | 6000 |
| Orkney | 3500 |
| east Scotland | 16000 |
| Northumberland | 1000 |
| Western Isles | 3000 |
| north-west Scotland | 2000 |
| Argyll west of Kintyre | 2500 |
| Clyde | 6000 |

In the UK, eiders do not migrate far. Most remain near their nesting area all year, but they may move to more sheltered locations during winter, or to moulting grounds in late summer. In August eiders tend to gather into flocks, with larger flocks in places with more food. They remain in flocks until spring. Then pairs or small groups tend to split off from flocks and become more widely distributed along coasts. Females nest in loose colonies, incubate alone, then tend chicks in small groups while males move into moulting flocks in undisturbed areas. The small groups then coalesce back into larger flocks towards the end of summer.

A very few eiders from Scandinavia come as far as the UK to winter, but the winter population in the UK is virtually the same in number and general distribution as the breeding population. There is evidence that some eiders breeding in Orkney may move to winter in Shetland, and that some birds breeding in the Argyll islands and sea lochs move to winter in the Clyde. Movements also occur between breeding areas on east Scotland such as the Ythan sand dunes, and major wintering concentrations in the Tay and Forth estuaries.

Within a season, eiders may move around within a range of some tens of km in search of patches with high densities of food. Depletion of such patches can then lead to further movements, so that numbers within a defined small area such as a particular bay or sea loch may vary considerably from week to week. Local movements may also be made in response to wind direction to avoid rough seas on exposed coasts, as eiders prefer to feed in moderately sheltered water.

Recent surveys of eider distribution in Argyll and the Clyde, west Scotland (Furness and Waltho 1999, Ross 2000) show strong associations between local concentrations of eiders and mariculture. These surveys suggest that mariculture may now be encouraging further eider population growth. Mariculture is certainly influencing the local geographical distribution of eiders in the west of Scotland at certain times of year. For example, in a survey in September 1998, of 528 eiders in Mull, Argyll, 380 were on a large mussel farm in Loch Scridian, 105 were around salmon cages in Loch Spelve, 25 were on other fish and mussel farms, and only 18 were to be found around the remaining coastline of the island away from aquaculture establishments, despite the fact that most of the coastline of this island is free from aquaculture. Few eiders were found in Loch Scridian before the mussel farm was established there. Proportions of eiders at farms were less in other areas, but aquaculture sites still held large numbers. Similarly, in September 1999, high numbers of eiders were found feeding on mussel farms, and even more on salmon farms in some parts of Argyll (Table 2). The decrease in numbers of eiders on Mull between the 1998 and 1999 counts is interesting, as it coincides with the closure of one salmon site that had been attended by large numbers of eiders in 1998, but also reflects the fact that mussel farmers that lost 90% of their stock to eiders in 1998 established boat chasing, gas cannons, shooting and some anti-predator netting to reduce losses in 1999. Their efforts greatly reduced eider numbers on their site in 1999, but also apparently halved the numbers of eiders staying on Mull.

**Table 2.** *Numbers of eiders counted in September 1998 and 1999 that were at mussel farms, fish farms or on other habitats in certain areas of the west of Scotland.*

| AREA | EIDERS AT MUSSEL FARMS | EIDERS AT FISH FARMS | EIDERS ON OTHER HABITATS | TOTAL NUMBER OF EIDERS |
|---|---|---|---|---|
| Mull (1998) | 395 | 115 | 18 | 528 |
| Loch Striven (1998) | 380 | 0 | 416 | 796 |
| Loch Fyne (1998) | 120 | 180 | 1258 | 1558 |
| Mull (1999) | 159 | 9 | 80 | 248 |
| Loch Eill to Connel (1999) | 16 | 423 | 206 | 645 |
| Morven Coast (1999) | 0 | 141 | 7 | 148 |
| Kerrera (1999) | 22 | 0 | 0 | 22 |

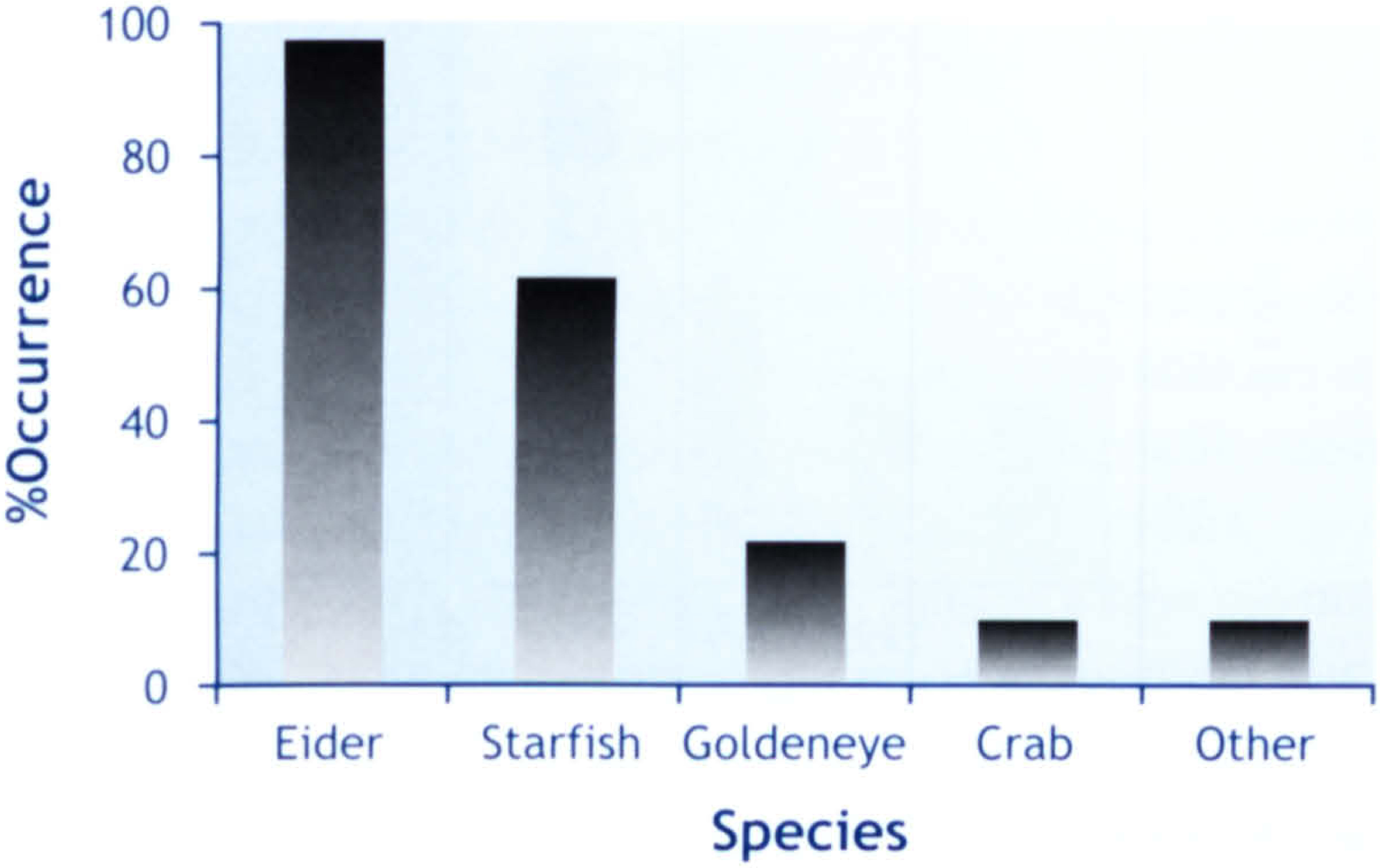
# Feeding behaviour of Eiders

Eiders feed by diving to pull mussels off their substrate, swallowing them whole. They tend to feed socially, in flocks. After filling their flexible fore-stomach (proventriculus) with mussels they may retire to a quiet place to grind up the mussels in their muscular stomach (gizzard), and then digest the meal. As a result, feeding tends to be in bouts interspersed with periods of rest. Eiders do not feed at night, but they may feed at any time between dawn and dusk, regardless of the state of the tide. Mussel cultivation produces mussels with thinner shells and higher meat content than found in wild intertidal mussels. These differences are favoured by both humans and eiders (Galbraith 1992). For eiders, cultivated mussels are easier to crush, and provide more nutrition per stomachful. Also, eiders can feed on cultivated mussels at favoured shallow depths which reduces the effort of foraging compared to having to dive to the seabed in areas of deep water. Thus it is not surprising that eiders will feed at mussel farms, since these provide a high density of high quality food at low foraging effort. Eider ducklings need easily digested food such as small marine shrimps, so females with ducklings rarely feed at mussel farms, though they may visit rafts for shelter. Similarly, males moult and become flightless during July-August and tend to move to secluded areas away from human activity during this period. Females store energy and protein for egg production and to live on throughout incubation, so that during February-April they must feed especially intensively. How much they can store determines their breeding productivity. Studies of eiders feeding on wild mussel beds suggest that in some areas eiders severely deplete their food stocks over the winter and have difficulty finding food in spring, but in Scotland the prolonged increase in eider numbers over recent decades suggests that the Scottish population is not food limited at present.

The fact that eiders are long-lived means that they have ample opportunity to learn over the years where there are profitable, and safe, feeding opportunities. Mussel farms are likely to see increasing numbers of eiders exploiting their stock unless steps are taken early to prevent eiders from developing a feeding habit on a particular farm. Where farms are not protected, eiders are likely to aggregate, in increasing numbers over the years, risking putting the farm out of business.

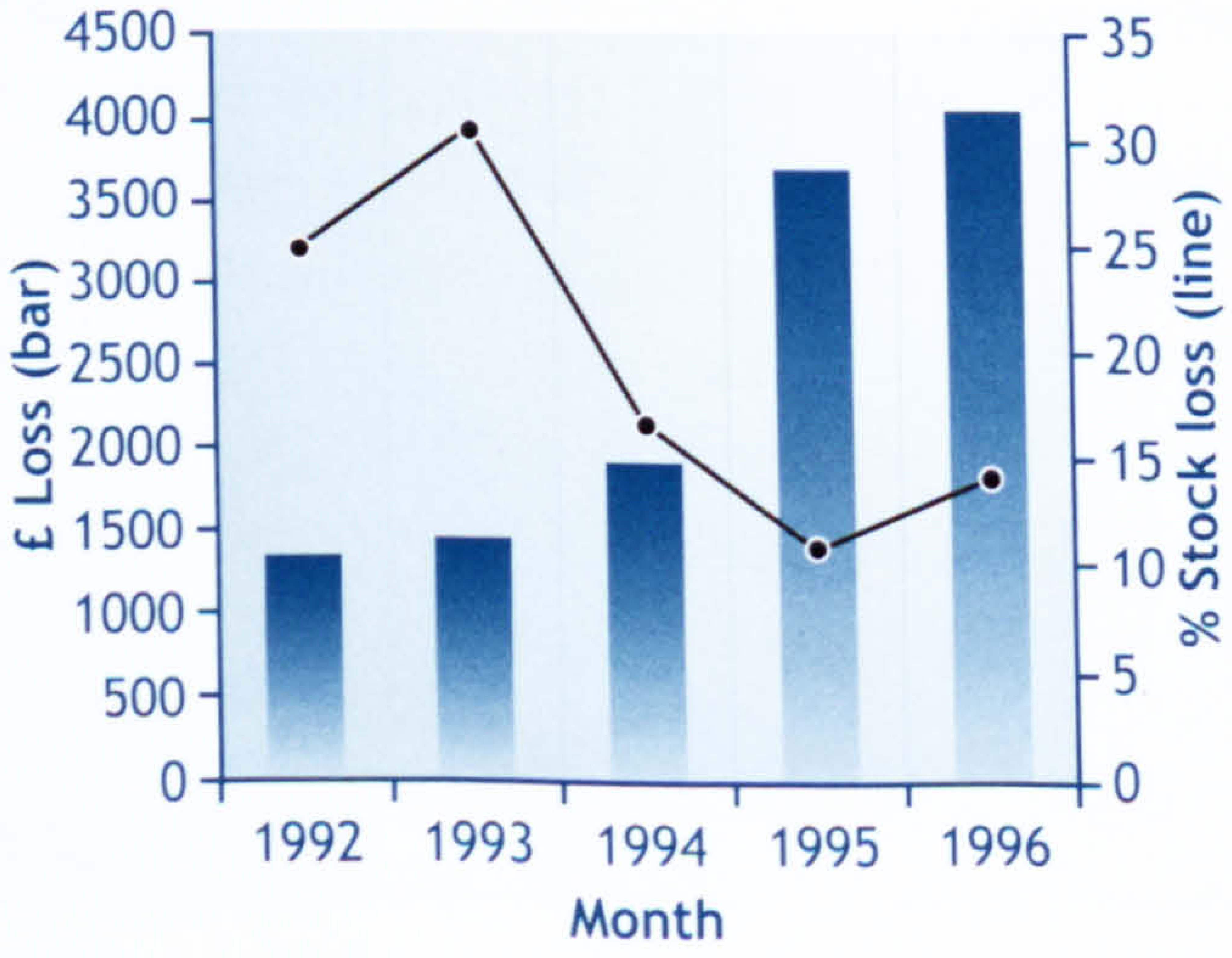
In a questionnaire survey sent to all owners of shellfish leases in Scotland, 97% of mussel farmers who replied (and most did reply) reported eiders as a problem. Loss of stock to goldeneyes was reported in 21% of replies (Figure 2).

**Figure 2.** *Problem species at mussel farms and the frequency with which these problems were identified by mussel farmers responding to the questionnaire.*



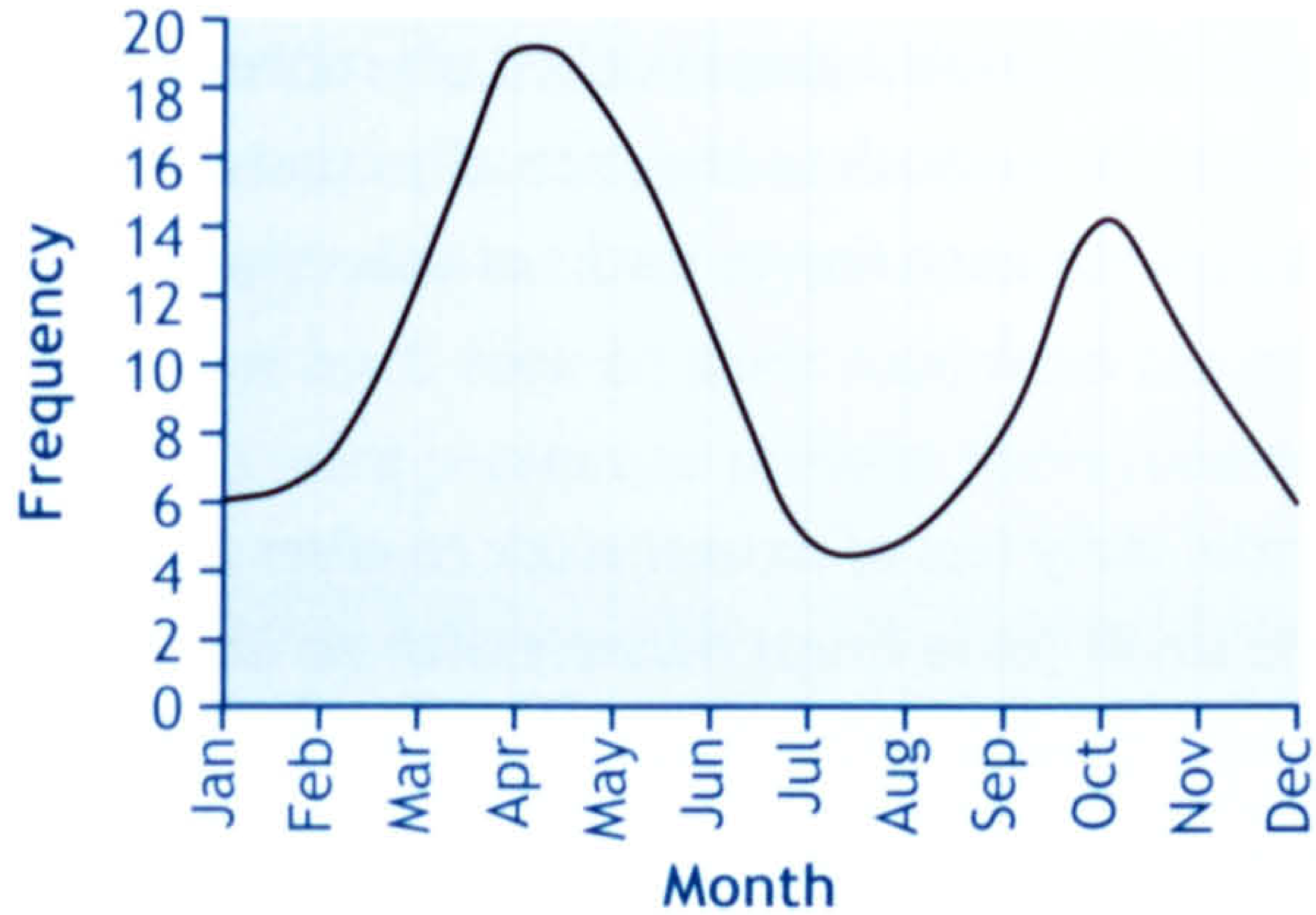
The average value of stock loss to eiders per farm per annum increased every year from 1992 to 1996, when the average stock loss was £4000. This tendency for eider damage to escalate as farms become an established feature in the environment was first noted by Galbraith (1992) and is likely to be due to birds learning over the years that farms provide good feeding opportunities. However, the amount of mussels lost from each farm, expressed as a percentage of the total amount of stock per farm, tended to decrease over this period (Figure 3), probably because farm size tended to increase even faster than eider numbers.

**Figure 3.** *Average percentage loss of stock (red line) and financial cost of stock loss per farmer (blue bars) as a result of eider predation (1992-1996)*




When the frequencies of what farmers determined to be 'high-damage months' was plotted, a bimodal distribution was observed. A large peak in reported duck numbers at mussel farms occurs in the spring, followed by a fall in numbers through the summer and a smaller peak in the autumn (Figure 4).

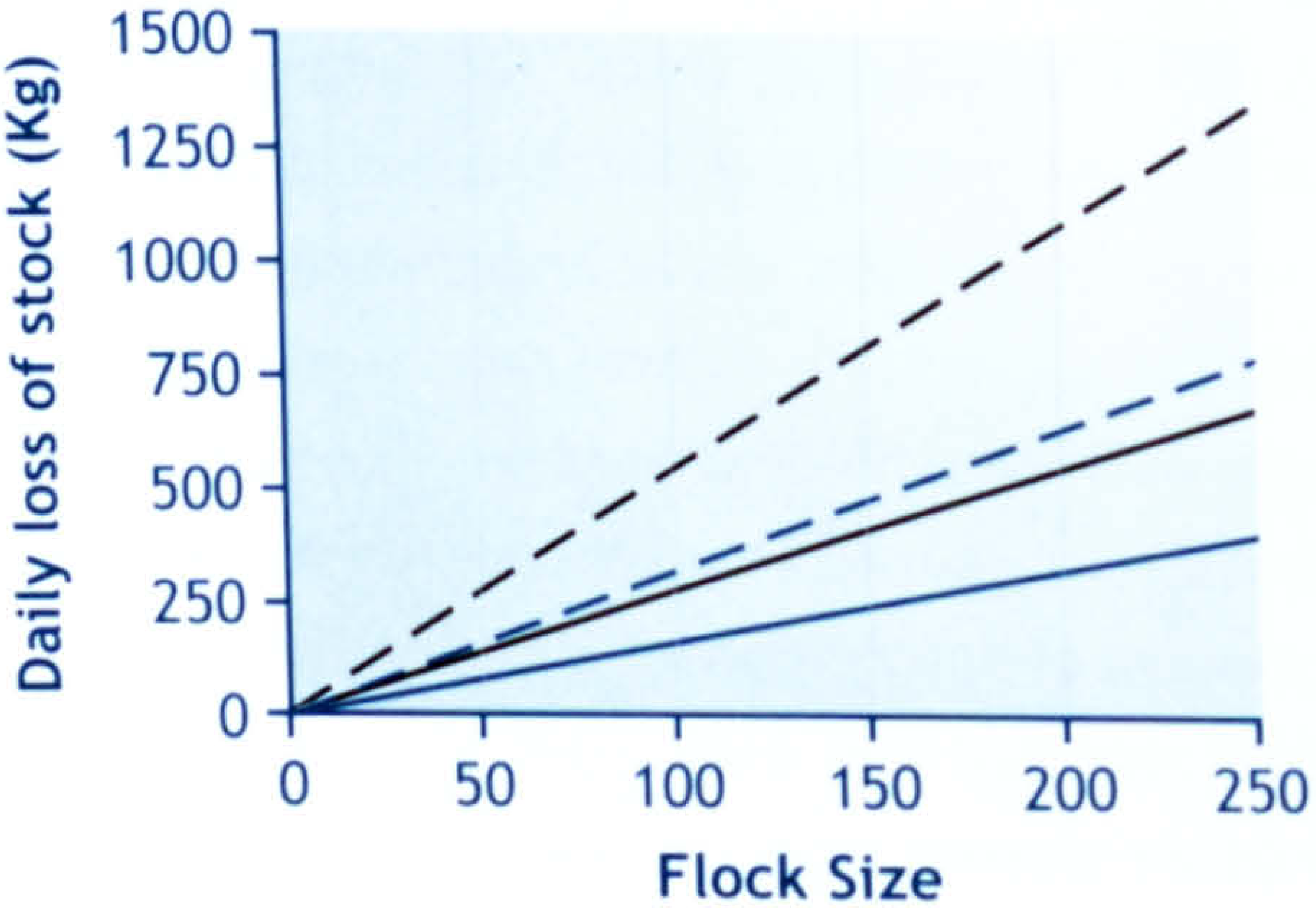
**Figure 4.** *Seasonality of attendance of eiders at mussel farms.*




The spring peak corresponds to an increase in feeding in preparation for the breeding season, and the smaller, autumnal peak as birds move from moulting grounds to wintering areas. The understanding of such seasonal fluctuations in numbers and distributions of birds is vital for mussel farmers to predict periods where high damage can potentially occur, and implement appropriate control measures before damage becomes too great. Galbraith (1992) pointed out that numbers of eiders visiting farms varied from year to year, apparently as a consequence of variation in amounts of natural food in different years.

Galbraith (1992) reported that each eider at a farm can dislodge up to 2.5 kg of mature mussels from cultivation ropes per day. He quantified impact at one farm at 125 kg per day from 50 eiders that only visited the farm for short periods each day. Estimations of the losses of stock incurred as a result of eider damage were also made using data from Galbraith (1987) and Bustnes and Erikstad (1990), combined with 10 months of weekly observations of birds feeding on a mussel farm in Loch Striven, Argyll. Depending on the size of mussels being eaten, eiders need between 1.5 (small mussels) and 2.7 kg (large) of mussels per day to obtain their daily energy requirements. However, depending upon how well mussels are attached to the rope or to each other, the amount of mussels being knocked off ropes or dropped by feeding eiders could be as much as they actually consume. As a result, potential losses of stock each day to flocks of eiders can be very large (Figure 5).

**Figure 5.** *Potential daily loss of mussel stock to eider flocks, for large (black lines) and small (blue lines) mussels with no uneaten drop-off (continuous lines) and with 100% uneaten drop-off (dashed lines). Based upon data from Clarke (pers. comm.) and Bustnes and Erikstad (1990). Eiders eat larger masses of larger mussels because these have greater shell content.*




Observations of eiders feeding at mussel farms in Loch Striven showed that eider numbers could be in excess of 250 birds per day during periods of peak attendance.

Using the information described above, combined with the attendance data gathered for the L. Striven farm over 10 months in 1997, we can estimate potential losses over this period depending on the size of mussels taken (Table 3).

**Table 3.** *Estimation of potential losses (weekly and over the 10 month observation period) at L. Striven mussel farm in 1997 for two size classes of mussels, with no drop-off of mussels. Figures are based on assumptions that birds took all their food from the mussel farm and that no workers were present to prevent them feeding.*

| | | Weekly loss (Kg) | |
|---|---|---|---|
| PERIOD | MEAN No. BIRDS/DAY | SMALL MUSSELS | LARGE MUSSELS |
| Jan - Feb | 224 | 2505 | 4227 |
| Mar - Apr | 114 | 1277 | 2155 |
| May - Jun | 45 | 499 | 843 |
| Jul - Aug | 75 | 844 | 1424 |
| Sep - Oct | 126 | 1406 | 2372 |
| 10 month total loss | | 52 244 Kg | 88 162 Kg |

A loss of 88 tonnes of large mussels would be equivalent to nearly £80,000 at 1999 prices. Eider numbers tend to be highest at farms in the first few hours immediately after dawn, as they do not feed during darkness. Later in the day, some birds may be resting to digest their meal away from the farm, while others are feeding. There is therefore a particular need to try to keep eiders off farms in the early hours before workers are on site. The total financial cost to farmers of eiders is, of course, much more than the estimated cost of the direct loss of stock, since it includes also the cost of farmers attempting to reduce impacts of eiders. If the damage was to be reduced by having a person on the site at all times, then this would add to labour costs according to the amount of time work was being done on the farm. If, for example, it was necessary to add 26 weekends at £50 per day this would amount to £2600. Extra cover during hours from sunrise to 9 a.m. during vulnerable periods of spring and autumn might add 90 days x 4 hours at £5 per hour, totalling a further £1800. The most frequently practiced deterrent, of chasing ducks by boat, can be estimated to cost several hundred pounds per year in fuel, depreciation and labour. Thus a typical mussel farm may experience costs of between £4500 and £10,000 per year at 1999 prices as a consequence of the presence of eiders. Where eider numbers indicate a need to invest in equipment for scaring or in anti-predator netting, costs of these measures need to be weighed against the likely losses caused by the ducks. Losses from farms with severe damage from eiders can be very much higher. One long line farm that anticipated production of ca 200 tonnes in 1999 lost about 90% of its production to eiders; equivalent to a loss of £160,000.

Firstly, it is essential to develop a strategy to minimize damage by eiders. This requires knowledge of eider numbers using the farm and how these numbers vary. There will be strong seasonal variation, there is likely to be an increase in numbers over years as birds develop a habit of exploiting a new mussel farm as a feeding site, and there will be diurnal variation and irregular fluctuations. Brief counts of eider numbers at the farm should be made regularly, perhaps once or twice per week. **The best time to count numbers of ducks at a farm is immediately before the start of a working day, so that you can record the numbers present before they are disturbed.** If numbers remain below 5 birds then it may appear that there is no need to spend time on deterrents since this would be a waste of money and effort. However, eiders are social birds, and many more may join a small group that has established a feeding habit on a farm. Deterrent use should be introduced ***before*** numbers build up to high levels, and preferably before ***any*** birds have established a firm habit of feeding on a farm. Established habits are much more difficult to change than to prevent. **Many deterrents are moderately effective in stopping small numbers of birds (say 10 to 50) from developing a habit of feeding at a farm, but most fail to be effective when large numbers (over 50) have already become established. Remember that most adult eiders are likely to live for 10 or 20 years. They have plenty of time to learn where there are concentrations of high quality food, and to learn if deterrent measures are sham threats and not real hazards to their survival.**

Relative profitability, feeding behaviour and choice of feeding area is not only dependant upon prey availability, quality and distribution, but can vary with the degree of 'danger' (generally in terms of predation risk) associated with that site. Deterrents should work by increasing the degree of danger, or risk, associated with the respective feeding area so that alternative feeding areas become relatively more profitable. Deterrents generally fall into three categories: visual, acoustic and biological. Biological deterrents are usually concerned with playbacks of distress and alarm calls, and various studies have produced conflicting results. More importantly, literature searches have revealed no evidence of alarm or distress calls from eiders. Many low-cost visual deterrents such as scarecrows or flashing lights seem to result in rapid habituation. If deterrent use seems necessary, a basic aim should be to use a variety of deterrents, so that the eiders are never sure what the next threat will be. Eiders quickly learn to ignore deterrents that are not reinforced by real threats, and so it is also important to mix use of deterrents with either chasing ducks by boat or shooting (whether shooting to kill under licence or shooting over the birds to scare them). ***The aim is to make the ducks feel insecure at the farm site, to encourage them to choose to feed elsewhere at less disturbed sites.***

Questionnaires completed by mussel farmers indicated ten different deterrent methods currently and regularly employed by experienced Scottish mussel farmers to reduce the damage caused by diving ducks (Table 4). Chasing birds by boat was the most commonly employed method, and had a limited effect in that birds would fly off the respective lease when approached by a boat, but return after one or two hours. The approach that yielded the best results seemed to be the complete netting of farms, but there are associated logistical problems. Despite the initial costs of deterrents and large fuel costs, 69% of farmers contacted said that in deterring eiders, time or labour was also a major cost affecting their decision about use of deterrents.

**Table 4.** *Deterrents employed by farmers and their perceived efficacy.*

| DETERRENT | No. FARMS | Perceived Efficacy: VERY EFFECTIVE | LIMITED EFFECT | POOR EFFECT | NOT INDICATED |
|---|---|---|---|---|---|
| Nets | 7 | 5 | 1 | 0 | 1 |
| Boat Chasing | 12 | 1 | 6 | 2 | 3 |
| Shoot to Kill as a deterrent | 4 | 1 | 1 | 1 | 1 |
| Shoot to Scare | 5 | 0 | 3 | 2 | 0 |
| Mannequin/Scary Man | 5 | 0 | 0 | 3 | 2 |
| Gas Cannon | 5 | 0 | 3 | 2 | 0 |
| Pyrotechnics | 3 | 0 | 0 | 2 | 1 |
| Siren/Noises | 3 | 0 | 1 | 2 | 0 |
| Scary Eye | 1 | 0 | 0 | 0 | 1 |
| Ultrasonic Sound Generator | 1 | 0 | 0 | 1 | 0 |

The eider duck is a protected species under the Wildlife and Countryside Act 1981. Shooting of eiders is an offence, unless carried out under licence issued by The Scottish Executive Rural Affairs Department for the purposes of preventing serious damage to fisheries. Normally, a farmer will be required to provide justification that the farm is suffering serious damage, and that scaring methods have been employed and shown to fail, before a licence will be granted. Licences granted in recent years have been for small numbers of ducks to be shot as a way of reinforcing deterrents. Shooting to kill can be a very effective deterrent if it is coupled with other deterrents that can be used between bouts of shooting. As with most deterrents, shooting to kill tends to be less effective in reducing eider feeding on a farm where large numbers of birds have an established habit, whereas small numbers of ducks that have just moved into an area can be much more easily deterred by limited shooting. A licence is unlikely to be issued to permit significant reductions to be made to local numbers by culling.

*Mussel farm*

The range of deterrents tried by farmers was large, and showed varying degrees of success. Many deterrents have no association with any real danger to feeding birds and therefore habituation to these devices can be rapid. Boat chasing can be effective, but needs to be carried out frequently, and can be expensive, although an underwater playback system (see Section 15 'Underwater Playback Systems' below) may be an effective addition to any farm where this is usually undertaken.

# Mussel farm location

Eider abundances vary between areas of Scotland, as does the extent of the eider duck problem at established mussel farms. Eiders represent little problem at present in Shetland, where eider numbers are declining. However, it is difficult to predict whether the many long-line farms recently established there will remain free from eider damage. Experience elsewhere indicates that farms established in areas with relatively few eiders can quickly attract large flocks. For example, on Mull wintering numbers of eiders were low during the 1980s before mussel farming was well established there, but the large farms attracted hundreds of eiders to winter there by 1998. Eider density is high and increasing in the Clyde, and mussel farms there tend to be severely affected by large numbers of eiders. Eiders prefer to feed in fairly sheltered water with large natural mussel beds in depths of 3-15 m.

A mussel farm located close to large natural feeding areas may be at risk of attracting attention from eiders that feed on the natural site. On the other hand, at a farm that is distant from natural mussel beds but has acquired a flock of eiders, it may be more difficult to persuade the ducks to move away to distant natural sites. Similarly, a farm close to other farms may be easier to protect from eiders because they can simply move to the adjacent farm. Scaring eiders away from an isolated mussel farm is more difficult than scaring them from one farm to another nearby (Ross 2000). This raises a possibility that has been suggested by several mussel farmers but has not yet been tested: establishing a 'sacrificial' mussel farm where lines could be set for mussel growth without any intention to harvest. Eiders may feed on such a site and thus leave the commercial farm untouched. In addition to the cost of setting up such a sacrificial site, the risk with such a strategy would be the possibility that the sacrificial site would accumulate even larger numbers of eiders, which would move to the commercial farm when the mussel crop on the sacrificial site was depleted.

Two basic designs of mussel farm exist in Scotland, ropes suspended at high density from rafts, or ropes suspended at lower density from horizontal long-lines supported by floats. Vertical lines carrying mussels tend to be about 6 m long. It is important to keep the lines off the seabed to prevent starfish from climbing up to feed on the mussels, but these depths of mussel culture are ideal for eiders to feed on at minimal diving costs.

According to Canadian mussel farmers, eiders and other sea ducks tend to recognise floats on the sea surface as indicating likely underwater lines and structures that will carry mussels, and they tend to investigate these because they expect to find food associated with floats. Canadian mussel farmers sink their long lines during winter to avoid damage from sea ice, and they also sink lines if duck damage becomes high, as ducks tend not to aggregate at sunken mussel farms. Deep lines would also be relatively unattractive to eiders since they prefer not to dive below 10 m. However, they can dive to at least 20 m so that putting mussels in deep water is unlikely to be a practical solution as a long-term measure since growth rates in such deep water would probably be much reduced.

Rafts are easier to protect from eiders due to their compact nature. Long lines grouped closely together are easier to protect than dispersed blocks of long lines. For example, one farm suffering intense exploitation by eiders found that ducks could be scared off the lines for short periods by chasing the ducks with an inflatable, but the birds tended simply to fly from one block of lines at one end of the lease to another block of lines at the other extreme, and back again when the boat followed them back, incurring considerable fuel costs and staff time slowly depleting numbers of eiders on site by continual chasing. Deploying lines in a single block reduced this problem substantially, but it was not resolved until anti-predator netting panels were also added.

# Anti-predator netting

Galbraith (1992) recommended use of vertical net panels as deep or deeper than the cultivation ropes, with a mesh size of 70-150 mm (4-6 inches). He suggested use of thick mesh since the more obvious the netting the less likely ducks are to try to pass it. More recent tests of netting suggest that 4 inch mesh is the largest that is suitable, as eiders can pass through 6 inch mesh fairly easily. Netting can be deployed during seasons of high eider activity but removed at other times to reduce fouling growth on the netting and to minimize inhibition of mussel growth due to reduced water flow through netting. In some parts of the world it is essential to fit anti-predator netting to mussel rafts. In Washington State and British Columbia it is normal to set anti-predator netting around mussel rafts with a closed bottom as well as net sides to prevent mollusc eating fish from attacking mussel cultures. Farmers there use second-hand salmon aquaculture anti-predator netting as anti-predator nets for mussel rafts since this can be acquired at low cost and even if it has some holes, these can be repaired so that it is satisfactory as a barrier to prevent ducks entering. For Scottish raft farms it is probably unnecessary to fit a bottom net, but having vertical panels hanging at least 8 m depth from the surface seems to be adequate to deter eiders from entering. Eiders certainly can dive much deeper than this, but they recognise netting as a hazard, and are extremely reluctant to swim under net panels and surface inside a netted area. Presumably the lack of open water for them to escape makes them unwilling to surface inside a rectangle of net panels, and so prevents them from being able to feed on the mussel lines. Eiders may eventually learn to enter under anti-predator panels, but if the ducks are also subjected to other deterrents, it seems unlikely that a netted raft farm will suffer losses of stock to ducks.

Fitting net panels around rafts is relatively simple, but fitting panels to protect long lines is much more difficult, depending on factors such as tidal flow, and particular features of the site. Use of anti-predator netting was tested in 1998-99 on the long line mussel farm on Loch Striven, where several hundred eiders had become accustomed to feeding on the farm and had severely depleted the production of the farm. The decision to use netting was based on the fact that 400 eiders can quickly deplete the mussel stock of the farm, full time human presence to deter eiders was impractical and unlikely to be cost-effective. The netting was found to be highly effective at excluding ducks and enhancing mussel production, and was a cost-effective solution on this site. The major disadvantages were the time requirements to set up and dismantle, and the need for an organised mooring system. The design used is illustrated in Figures 6-9. Moving lines close together to keep them within anti-predator nets (Figure 7) obviously increases the density of the mussel crop, and so may reduce their growth through competition for food. In the Loch Striven case, no evidence of reduced mussel growth was detected, but this loss is likely to be small by comparison with losses otherwise experienced to eider ducks. It was found that white netting is more effective than black as it is more obvious to ducks and causes them to avoid it. Use of 3 inch netting above water was better than using 4 inch mesh. About 10 kg weight was attached every 15 m along the netting to keep it hanging vertically. Storms can blow over the above water netting, and debris and seaweed can accumulate in the netting, so that occasional maintenance is required. Because eider damage is mainly a problem in autumn and spring on this site, the netting was deployed only from autumn to spring. Removing the netting in spring was more difficult than deploying it, as it had then become much heavier with fouling.

**Figure 6.** *Plan of the long line farm before netting.*

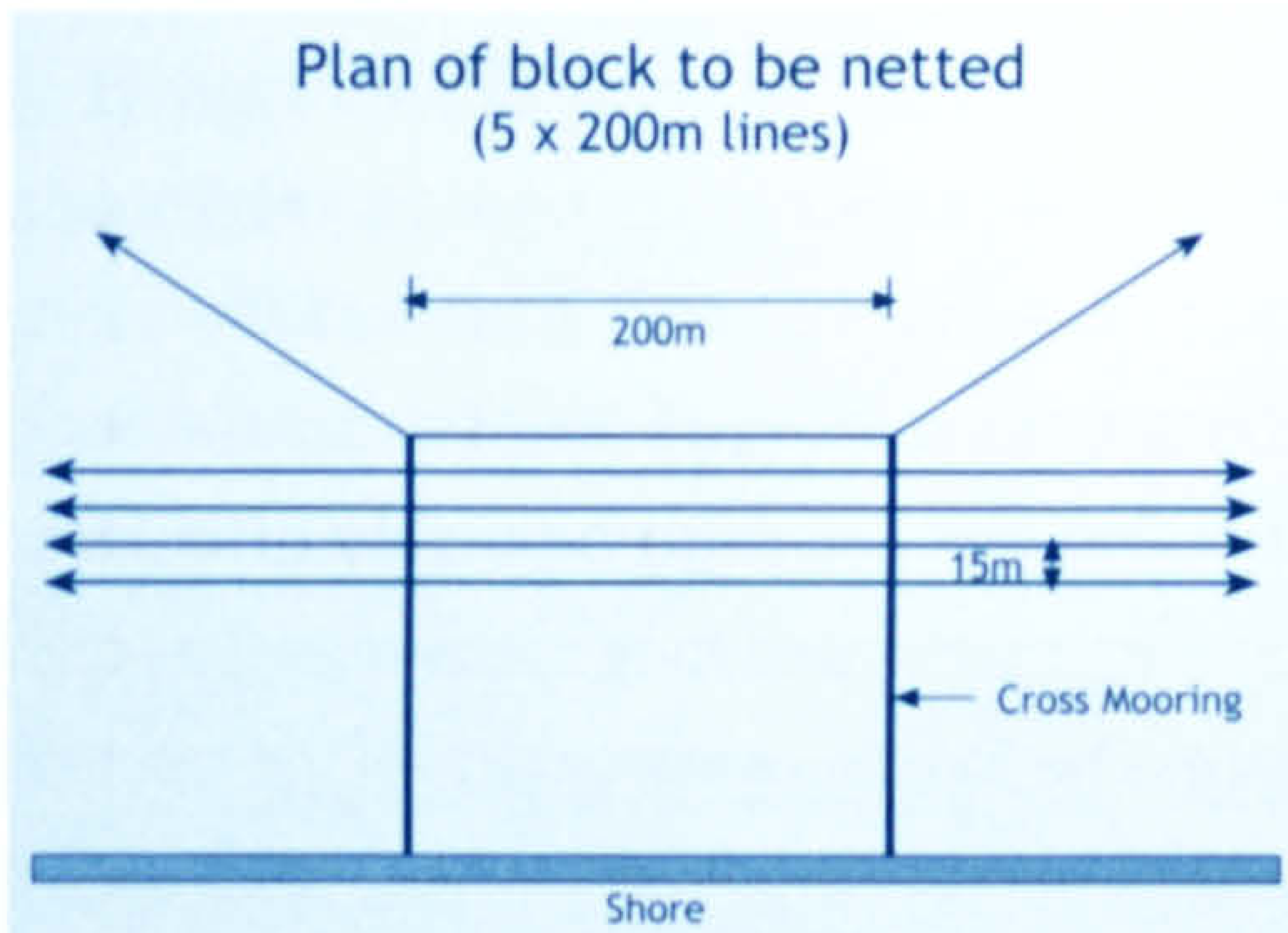



**Figure 7.** *Plan of long line farm after lines moved to prepare for netting.*

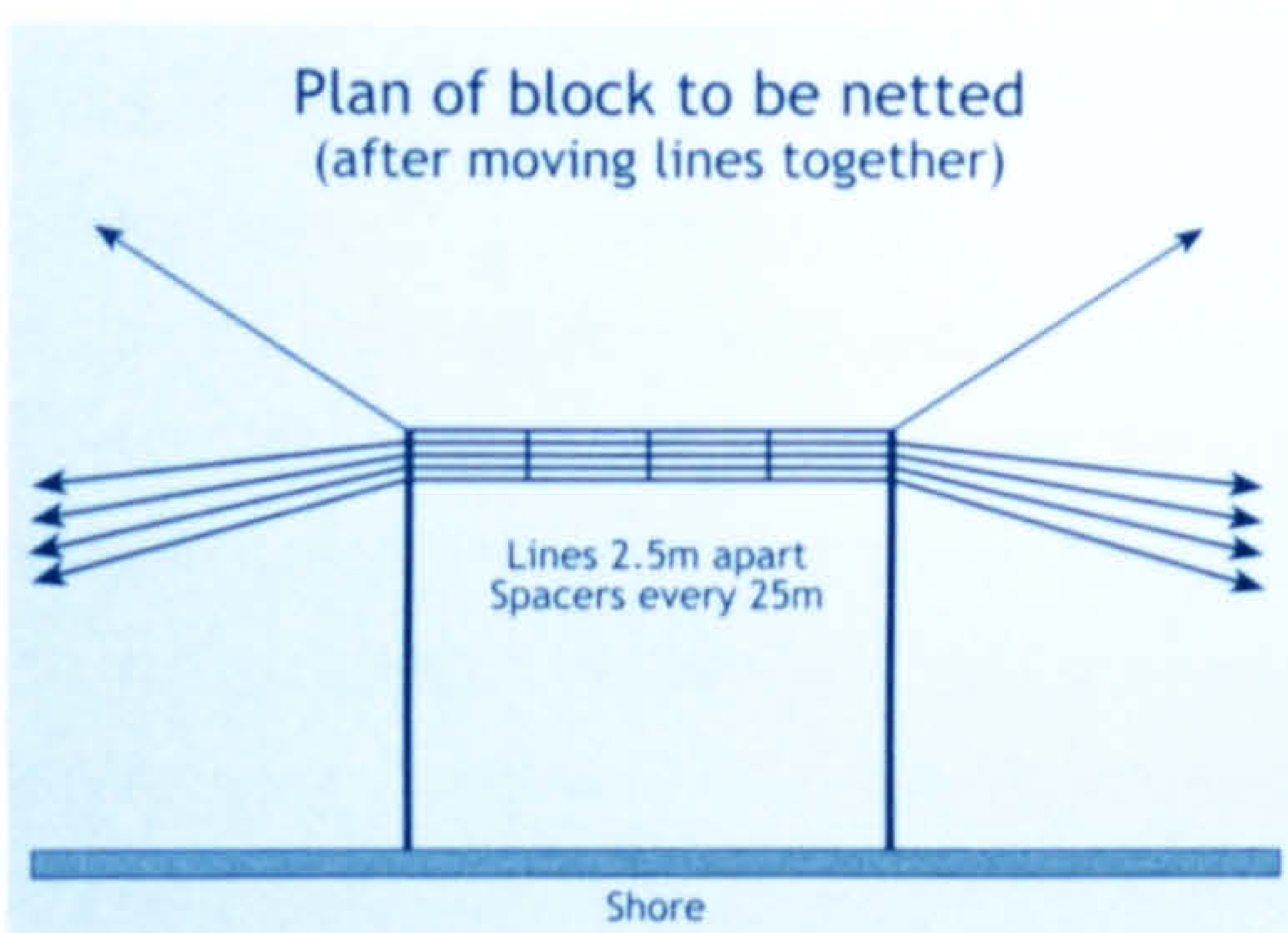


**Figure 8.** *Plan of outrigger design holding netting placed above water.*

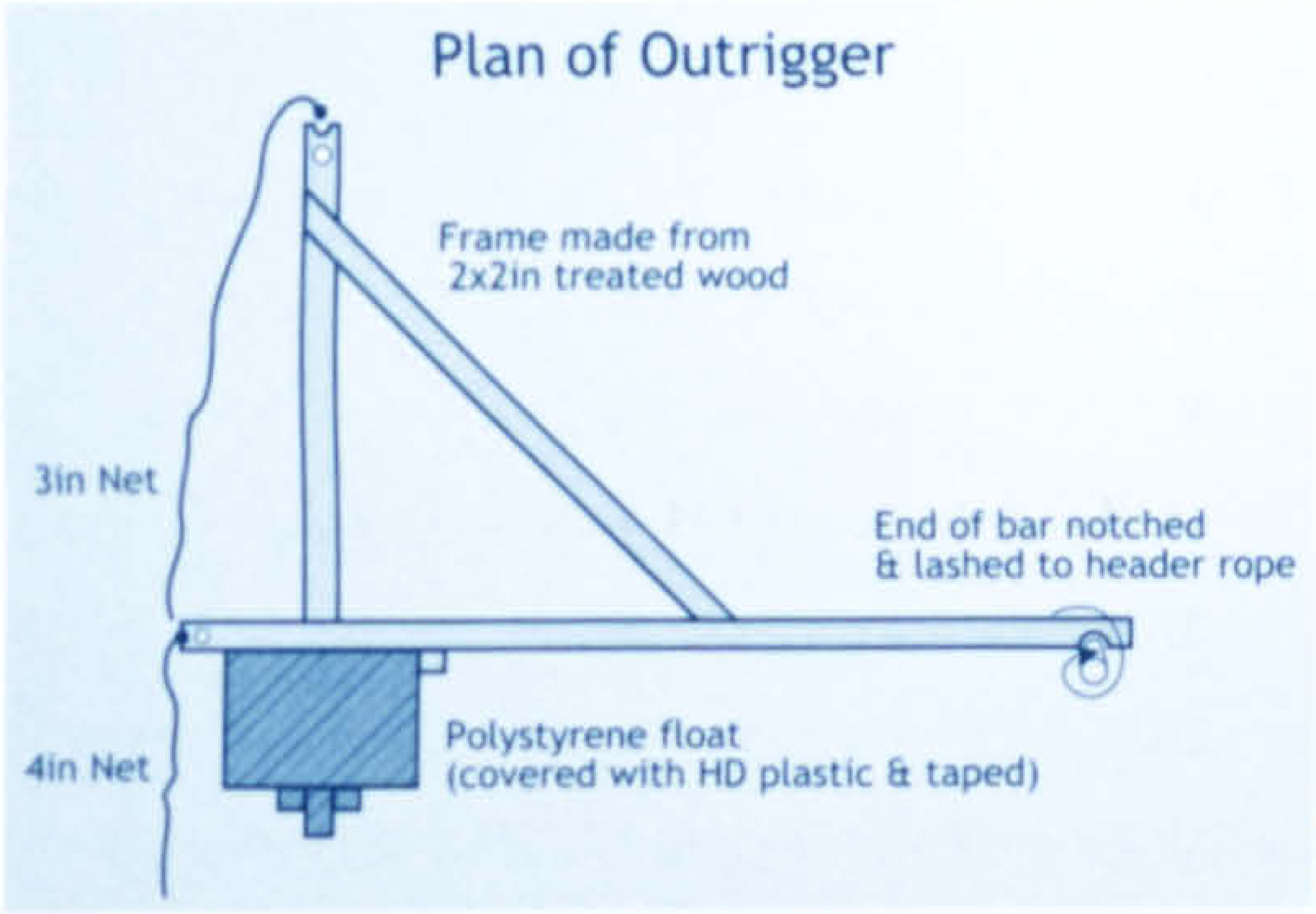
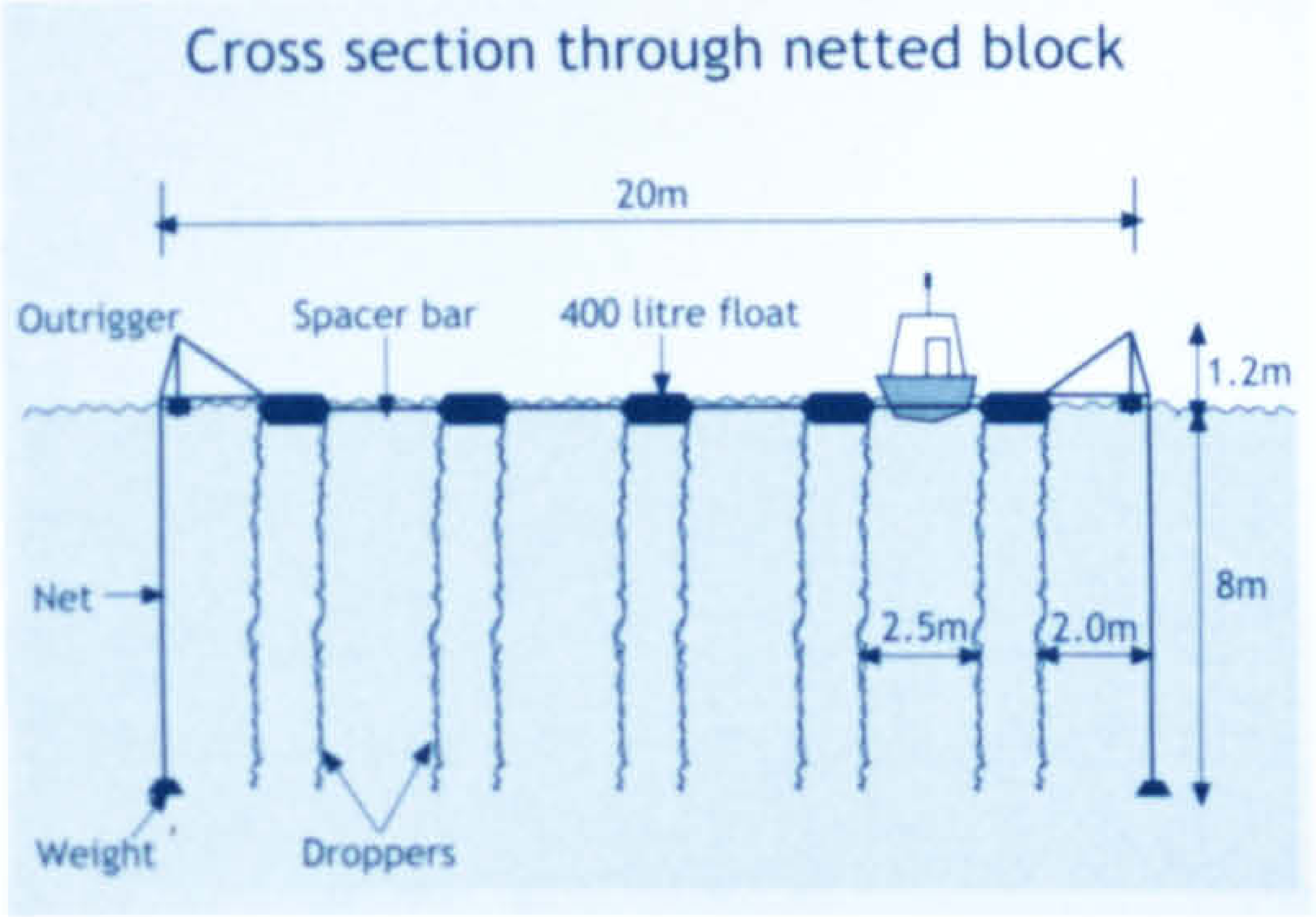



**Figure 9.** *Cross section through netted block of mussel lines, showing spacing of lines and netting.*



Costings (at 1996 prices) for this test site of 5 long lines (200 m long) were £1650 to purchase netting, £400 for outriggers and spacers, £1600 for the annual labour costs of setting and removal (12 man-days setting up the netting, 12 man-days dismantling it, and 12 man-days in maintenance and cleaning), and estimated £700 p.a. depreciation (assuming the nets will last for 3 years). In relation to the value of the crop, 5000 droppers producing 40 kg gives a total production of 200 tonnes, which at £900 per tonne is worth £180,000. Thus netting the farm cost less than 2% of the value of the crop. Eiders consumed more than 50% of the crop in the year before this site was netted, and consumed even higher proportions of production at another, similar, long line site where eider control had not been effected.

There is no doubt that netting sites can be very cost-effective where eider damage is high. However, there will be many situations where low numbers of ducks and little impact on production makes the use of netting undesirable. Both the cost of netting and the difficulties that netting presents in terms of working on a site and in possibly reducing water flow through a farm, make this solution undesirable where it is not necessary.

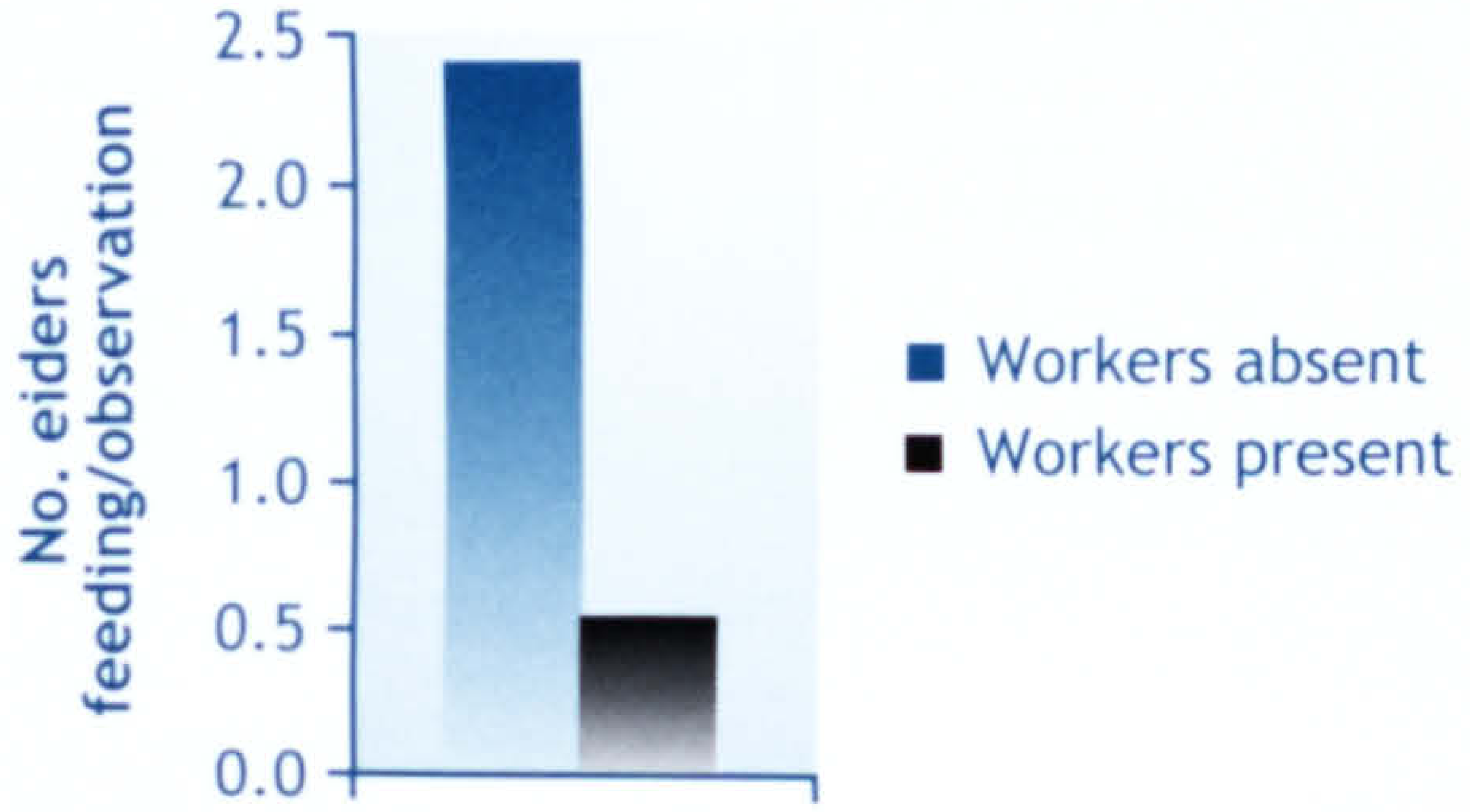
Rather than setting vertical panels of anti-predator netting, some farms have tried the use of horizontal (floating) netting around the farm perimeter as a means of deterring eiders. This may be effective, but floating netting is much more likely to tangle ducks and drown them or kill them through exposure. It seems unlikely that floating netting will be a better approach than the vertical net panels described here, and we do not advocate the use of floating netting.

Presence of workers on the farm is very effective in reducing numbers of birds feeding (Table 5, Figure 10). Small scale farms that are not attended daily by workers are likely to be extremely vulnerable to eiders. Even on large farms where workers may be present daily, ducks can congregate well before workers arrive on site and feed heavily during the period between dawn and the start of the working day.

**Table 5.** *The effect of worker presence on the numbers of eiders feeding at focal mussel farms on L. Creran and on L. Striven, and the percentage change in numbers resulting from the presence of workers.*

| TRIAL | AVERAGE NUMBER OF EIDERS FEEDING WHEN WORKERS ARE ABSENT | AVERAGE NUMBER OF EIDERS FEEDING WHEN WORKERS WERE PRESENT | CHANGE |
|---|---|---|---|
| L. Creran | 2.37 | 0.50 | -79% |
| L. Striven | 36.50 | 8.05 | -78% |

**Figure 10.** *The effect of worker presence/absence on numbers of eiders feeding at mussel farm, L. Creran.*



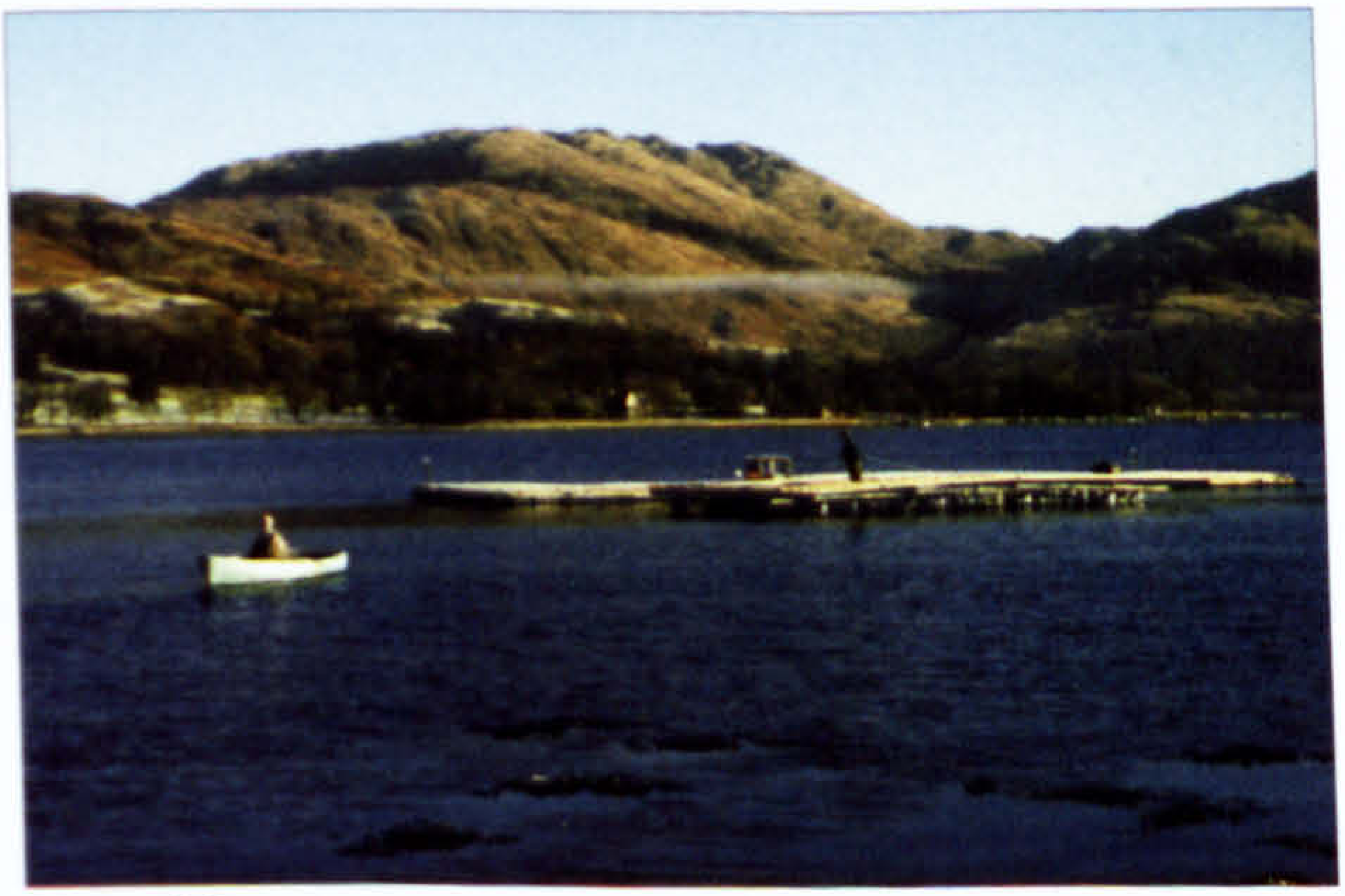
# Human activity on the farm

Having a person on the farm throughout daylight hours during times of year when eiders are attempting to feed on the farm would be an effective way to keep down the level of damage, but would be costly in terms of labour. Furthermore, there may be times when it is simply not practical to have a person on site, as during bad weather.

*Attending the mussel farm*

# Chasing ducks by boat

One of the most commonly employed methods of reducing eider duck damage to mussel stocks on mussel farms in Atlantic Canada and in Scotland is chasing birds by boat. While effective in the short-term, the frequency of chases is often restricted by high costs, both in time and fuel. Initial tests of the effectiveness of chasing by boat were carried out in Canada. Harassment began when ducks first appeared in the area and before feeding patterns became established. Initially there were 200-500 eiders in the vicinity of farms. During this period, distances from the chase boat at which ducks were frightened into flight increased dramatically and the interval of time before ducks returned to the area following boat activity also increased. Numbers of ducks declined erratically.

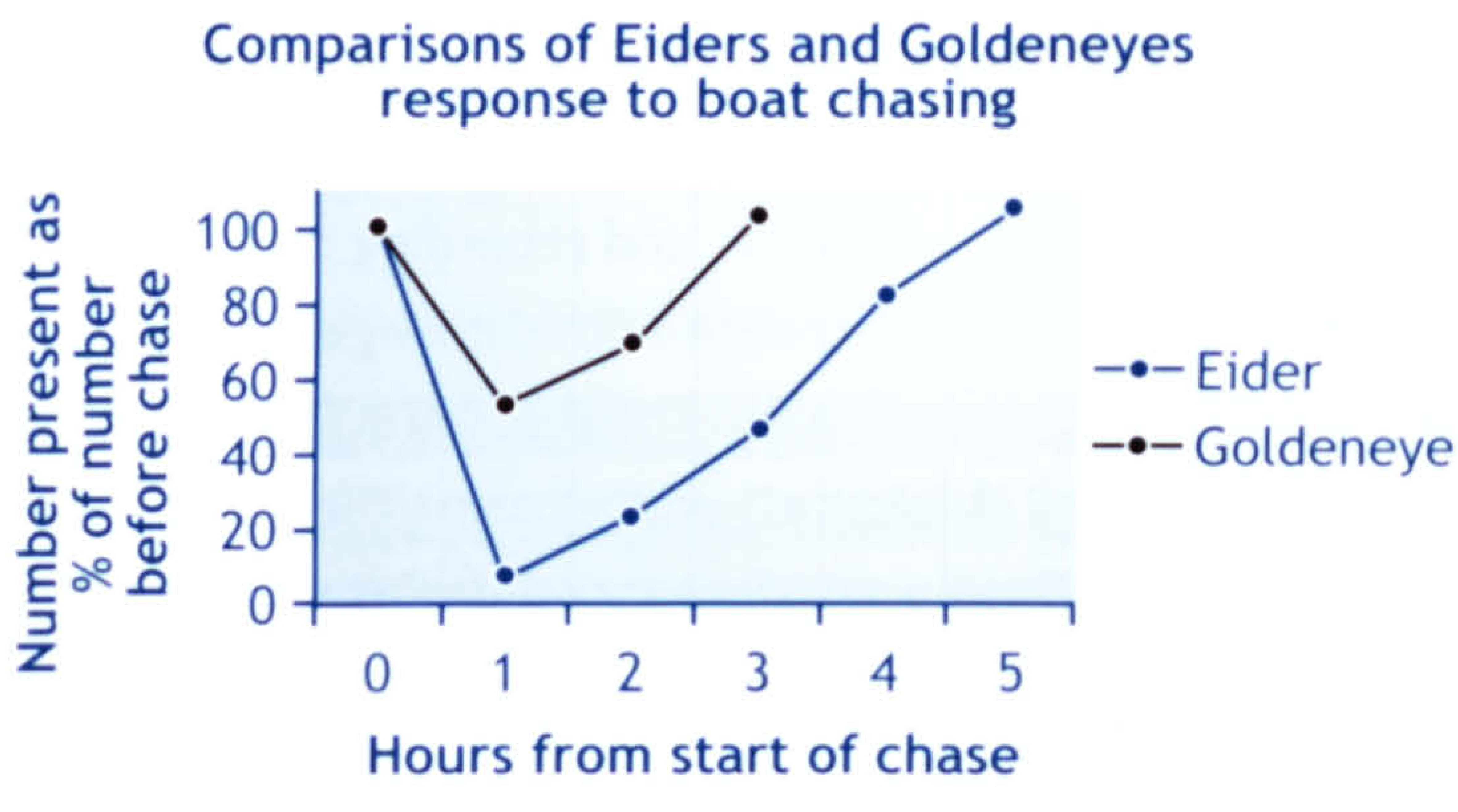


*Mussel farm*

Our studies in Scotland showed that chasing ducks by boat does effectively move eiders off farms, but that goldeneyes are less easily moved away by boat (Figure 11). Furthermore, both the numbers of goldeneyes and numbers of eiders returned to the levels present before the chase within a few hours. Chasing by boat keeps eiders off farms for longer than it keeps goldeneyes off, but as a sole deterrent method it would only be effective if practiced every few hours from dawn to dusk. In spring, eiders feed at a high rate to build up body reserves to fuel egg production and energy costs of incubation. Their breeding success is directly affected by their ability to build up reserves.

Therefore, it is undesirable to chase ducks during the spring fattening period because it is likely to affect their breeding success. It would be preferable to concentrate chasing earlier in the winter in order to get birds out of the habit of feeding on the farm before their critical spring fattening period.

**Figure 11.** *Effectiveness of chasing eiders and goldeneyes by boat as a means of reducing numbers of ducks on mussel farms in Scotland.*



# Underwater playback systems

Work in Canada first examined the use of an underwater playback system (UPS) of recorded engine noise to scare ducks. Two farms fitted with underwater broadcast devices played recordings of the chase boat at 30-second intervals. Few ducks landed on these farms and when they did, dive times were very short. Following up this apparent success, our tests in Scotland used underwater recordings of chase-boat engines replayed at regular intervals on continuous loop tapes through an underwater loudspeaker. Trials of the UPS in spring 1998 gave significant reductions in eider numbers of 50-80%, while a control trial with the playback of an unassociated noise gave no reduction. The average return time of birds to the farm after chasing by boat also increased significantly during UPS trials. The long-term habituation of ducks to this system was apparently negligible providing it is occasionally reinforced by boat chasing.

Underwater recordings were made onto audio tape by means of a hydrophone. The hydrophone was suspended 3m below the surface of the water from a floating platform, and recording commenced when the scare boat was 150-200m distant with the engine being started and the boat approaching the platform at full throttle. Recordings lasted approximately 2-3 minutes, ending when the boat had passed the recording point. Once a satisfactory recording was made, it was repeatedly transferred onto a 15 minute standard audio-cassette with an interval twice the length of the recording. The playback system consisted of a car stereo cassette deck with auto-reverse, connected to an underwater loudspeaker (Lubell labs LL964) via a 120 watt booster amplifier. The system was powered by a 12v car battery and was contained in a watertight drum to protect the electronics. Throughout the course of each trial, the UPS was secured either on the most central raft of the farm in question if on a raft based farm, or on a moored platform in the centre of a long-line farm. The loudspeaker was suspended in the water 3m below the surface.

In general, trials of the UPS worked well in alleviating predation pressure by eiders on mussel farms, reducing the numbers of feeding birds by between 50 and 80% in all experimental trials (Table 6). However, numbers feeding at the farm increased again fairly soon after use of the UPS ceased in one case, remained low in two cases and continued to fall in one (Table 6). Probably it would make sense to use a UPS throughout periods of high eider presence at a farm until the numbers were greatly reduced by the UPS or by seasonal changes, whereas our field trials deliberately ceased use of UPS to see whether eider numbers would return to high levels.

**Table 6.** *Average numbers of ducks observed feeding at mussel farms for four experimental UPS trials and the percentage change in numbers whilst the UPS is switched on (Pre to during), and that remaining once the UPS has been switched off (Pre to post). For the final two trials in the table, the figures given are for periods of worker absence only.*

| | Average number of eiders feeding | | | % Change | |
|---|---|---|---|---|---|
| SITE | Pre-UPS | During UPS | Post UPS | Pre to during | Pre to post |
| L. Creran | 36.2 | 7.4 | 14.7 | -79.6% | -59.4% |
| L. Creran | 6.7 | 1.8 | 2.8 | -73.1% | -58.2% |
| L. Creran | 2.4 | 0.7 | 0.7 | -70.8% | -72.4% |
| L. Striven | 36.5 | 19.3 | 1.2 | -47.1% | -96.7% |

A control trial, using a tape recording of random noise of similar volume did not reduce feeding on the farm, and during this trial numbers of birds feeding actually increased. In all the experimental trials in Loch Creran, use of the UPS also caused a significant increase in the mean return time of birds to the mussel farm after being chased away. Before the UPS was used, on average, the first eiders returned to feed on the farm about 30-40 minutes after the flock had being chased off by boat, whereas during periods of UPS use, birds remained away for 50-100 minutes after being chased off. When tried in Canada, it was noted that birds became much more wary of the chase boat when the UPS was in place, and that birds would tend to fly from the boat at a greater distance than when UPS was not present or was switched off. Both these factors suggest that the deterrent stimulus of the scare boat is strengthened by the presence of the UPS.

Several factors are likely to affect the efficacy of the UPS:

1. Pre-exposure to original deterrent - If birds have previously been chased by boat only infrequently, then the UPS may provide a stimulus to them that has no association with a 'real-life' deterrent. We observed that other species, such as divers (loons) did not respond to the UPS, presumably because they had not been chased by the boat.
2. Frequency of reinforcement - Without reinforcement of the UPS with the scare-boat it is likely that habituation to the stimulus will be much more apparent.
3. Availability of alternative resources - A lack of alternative food sources (either cultivated or occurring in the wild) in the local area is likely to increase dependence of birds on a particular mussel farm, and therefore make it less easy to deter them.
4. Numbers of birds - The ease of deterrence of a species can decrease if birds become established on a particular site, and thus attract conspecifics. Guillemette et al. (1993) also showed that larger flocks of eiders facilitated feeding, which in turn would increase the relative profitability of the respective site.

5. Stage in breeding cycle - Energetic needs of eiders and other bird species will change throughout the year according to factors such as breeding, chick rearing and moulting, and the birds may show higher motivation to feed despite deterrents at certain times of the year.
6. Mussel quality - Temporal variation in relative profitability of different size-classes of mussels between wild and cultivated sites may increase or decrease dependence of populations on respective sites (Ross 2000).

The UPS, with reinforcement, may be a stronger deterrent stimulus than the scare boat itself because, in theory, it is only presented to the birds whilst they are feeding (i.e. when they are underwater). The UPS is purely an acoustic deterrent whereas the chase boat itself combines both acoustic and visual signals. However, of these two components, the acoustic signal may be the more important, as it is present when the bird is at the surface and when it is underwater, whereas when birds are diving they cannot see an approaching boat unless it is extremely close to them. It is conceivable that birds may be more easily startled when underwater, as the whereabouts of the chase boat will be unknown. The presentation of deterrent stimuli only when the birds are feeding also means that they are not continually exposed to the stimulus even when they are some distance from the farm and not feeding, as is the case with most above-water acoustic deterrents such as propane canons or wailers. Such continual presentation of a stimulus, particularly when the target species is not actively causing damage is also likely to favour more rapid habituation.

It is important to point out that, although the UPS had a considerable effect in reducing feeding activity of eiders on farms, the response of the ducks to the UPS was not spectacular. Ducks did not fly away in panic as soon as the UPS was switched on, so that the initial response of farmers might be disappointment at the lack of an obvious result. However, we can indicate the savings that could arise from use of the UPS. For a site with 50 eiders regularly feeding on the farm (a not uncommon situation), UPS may reduce numbers by about 33 birds. Since eiders may remove about 2.5kg per bird each day from mussel lines, this represents a saving of 80kg per day. For a typical situation in west Scotland, with eiders feeding on a farm for around 100 days of the year, this represents a saving of over 8 tonnes of mussels per year.

# Laser light

Although there appears to be nothing published in the scientific literature to demonstrate the success of laser light as a bird scaring or deterrent device, a French commercial company markets a laser light constructed to look like a rifle, which it claims is highly effective for scaring birds from sensitive localities such as airfields. We therefore looked into the possibility that laser light might be effective for scaring eiders from mussel farms. The lasers used in this study included one of the ones made by the French manufacturer DESMAN, model FLR 005. It is an 'off-the-shelf' class IIIB He-Ne 520nm red wide-beam laser with adjustable telescopic sights, purchase price around £5000. However, we also constructed our own laser systems (at much lower cost) from a laser beam generator (cost under £2000) and rifle telescopic sight, mounted on a tripod. Power for either system was provided by a portable 12V motorcycle battery.

Initial trials of laser lights on eiders showed that eiders are much less sensitive to laser light than are many other birds; laser light that made gulls fly away immediately did not necessarily create any visible response when shone onto an eider. Only at low ambient light intensities did eiders show any response. Some birds swam away, while some flapped across the water with much splashing, and this response generally led to all other nearby eiders moving away too.

During formal tests of lasers at farms, numbers of birds feeding at the mussel farm were counted every 5 minutes throughout the day during each trial. Each trial was split into five-day experimental periods before use of the laser, during use of the laser, and after use of the laser. During the laser-use periods, the laser was directed at any bird feeding within the farm between dawn and dusk, and the ambient light level and reaction of each bird was recorded. One set of experiments examined the efficacy of laser light on isolated farms, another investigated the effects of displacement of one set of birds to adjacent