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An ecological approach to the management of gulls, in particular
the Lesser Black-backed Gull *Larus fuscus* (L. 1758)

Mark John O'Connell

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18 MAY 1995

ABSTRACT

A study of gull management was made at a large colony of Lesser Black-backed Gulls *Larus fuscus* on Tarnbrook Fell, Lancashire. Approximately 18,000 gulls presently breed at the site, and the area utilised by the gulls extends over 6 km² on three private estates. The main studies were conducted on the Abbeystead Estate between 1992 and 1994. The reasons for increases in the numbers of several gull species in many parts of the world during the 20th century are presented, as well as the conflicts with humans caused by these increases. The practical and moral aspects of managing gulls are evaluated, as well as the conflicts likely to result from recent increases in the urbanisation of several Larid species. The need for management strategies to incorporate up-to-date knowledge of gull demography, density dependence, breeding biology and behaviour are discussed in the light of the limited success of past attempts at managing gulls.

Experiments to entirely clear specific areas of the Tarnbrook Fell Gullery by disturbing breeding gulls are described. The aim was to ameliorate local problems by reducing the extent of the colony using non-lethal management techniques. Disturbance was carried out in a series of 2.25ha experimental plots. Audio, visual and physical disturbance methods, presented singly or in combination, were used to investigate their ability to exclude gulls and prevent breeding. The number of gulls using the plots and the number of nests built were compared with numbers on control plots. Gulls showed habituation to all disturbance methods, although the number of gulls using a plot was reduced during disturbance and a proportion of the original number of gulls were totally excluded. Only where two disturbance methods were utilised on the same plot was breeding completely prevented. It was demonstrated that disturbance was more effective when initiated prior to the start of nest building and when conducted at the edge of the colony, and that disturbance by human presence is an effective method of preventing breeding. In the year following disturbance, only a very few gulls attempted to utilise the disturbed areas, and the need to establish a 'sink' area for birds displaced by disturbance is discussed. In two seasons, a total of 75ha were cleared of breeding gulls. This was 23% of the Abbeystead Estate and 11% of the total gullery area. This was the first time in over thirty years of management efforts at the colony, that the extent of the gullery was successfully reduced. Models are presented to show the effects of the 1978-1988 culls on adult survivorship and recruitment into the breeding group at Tarnbrook Fell. The relative effects of management strategies aimed at survivorship and productivity are discussed. A study was made to quantify the percentage of nests built by gulls at the colony that are not subsequently laid in. Behavioural differences between pairs that failed to lay eggs and pairs that successfully bred are presented. In the past, calculations of the number of breeding gulls at the colony assumed that one nest represented one pair. This was shown not to be true and a correction factor (multiplier) of 0.61 was calculated to allow counts of nests at the colony to be converted to the number of breeding pairs.

This thesis is dedicated to Sarah.

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CHAPTER 1.

INTRODUCTION: The 'Gull Problem'.

1.1. Introduction

Ecology has a variety of practical applications. Information on the abundance and distribution of plants and animals can be beneficial when attempts are made to conserve an endangered species by increasing its numbers. Likewise a detailed knowledge of a species' ecology and the processes that dictate its life history are essential when natural resources are to be harvested in a renewable and sustainable way. A third application of ecological principles can be made when certain plant or animal species come into conflict with human activities and a reduction in their numbers is deemed desirable and necessary. The plants and animals involved in these conflicts with humans are drawn from a wide diversity of taxonomic groups and are given status of 'pests'. The definitions of what constitutes a pest species are as varied as the problems they can cause. In general, a pest species is one that, at certain levels of abundance, is considered undesirable because it competes with humans for food, or transmits disease, or otherwise threatens human health, comfort or welfare (Flint and van den Bosch 1981).

Many bird species have gained pest status through their ability to destroy economically and agriculturally important crops. For instance, the Red-billed Quelea *Quelea quelea* of Africa annually causes millions of pounds worth of crop damage, despite extensive control programmes. In the 1950's and 60's, millions of these birds were destroyed but the control measures were generally employed in a completely *ad hoc* fashion. By the 1970's, it was realised these control measures were not having a large effect on the overall population of Quelea, and that the methods themselves were becoming part of the total economic loss caused by the birds. New management policies were then



initiated that were closely referenced to knowledge of the species' demography and breeding biology, and that could be scientifically evaluated at several points in the process. It was this approach that achieved the first major downward trends in Quelea numbers (Ward 1979). In addition to economic and agricultural problems, birds come into conflict with humans in a variety of other ways. This thesis describes the nature and causes of some of the conflicts between humans and a 'problem' group of gulls, and evaluates how the application of scientific and ecological principles can be used in the management of pest species.

1.2. Changes in the status of some gull species during the 20th century

Gulls are medium sized, colonial nesting seabirds found in most geographical areas of the world except for the central Pacific Ocean and the Antarctic pack-ice. There are 45 species of gulls within the family *Laridae*, most of which breed in coastal areas. They are agile fliers and have a broad dietary range. They obtain food from a variety of marine and terrestrial sources by predation, scavenging and piracy. During the 20th century, many gull species have shown large scale population increases in Europe (Vauk and Pruter 1987; Isenmann 1991), North America (Blokpoel and Scharf 1991; Irons 1991) and Australia (Burbridge and Fuller 1989). The rate at which these increases have taken place and the time over which they have occurred has varied depending on the species or the particular colony involved. On the Pacific coast of North America for instance, colonies of Glaucous-winged Gull *Larus glaucescens* in British Columbia were increasing at an annual rate of about 2% between 1977 and 1986, while on the Aleutians, colonies of the same species were increasing at up to 8% *per annum* (Rodway 1988; US Fish and Wildlife Service 1988). In Europe during the 1960's and 70's the British population of the Herring Gull *L. argentatus*, was increasing at approximately 13% *per annum* (Chabrzyk and Coulson 1976). By about 1980, these increases had stopped and since then the number of Herring Gulls has almost halved in most of coastal

Britain (Lloyd 1991). However, colonies in western Scotland and north-west Ireland are still increasing in size (Spaans *et al.* 1991). The increases in Lesser Black-backed Gull *L. fuscus* populations are described in the next chapter.

Increases in numbers have not been the only feature of gull populations in the 20th century. Many of the increases in numbers have been accompanied by expansions in geographical distribution. The Herring Gull, for example, has colonised Iceland, Spitsbergen, Switzerland, Poland and Yugoslavia within the last fifty years or so. Indeed, of the six species of gulls that regularly breed in Britain, only the Common Gull *L. canus* has not increased its international range this century (Sharrock 1976; Lloyd 1991). In addition to increases in numbers and breeding range, gulls have managed to utilise new habitats for breeding, feeding and roosting, particularly in the urban landscape. The reasons why this may have contributed to their general success will be discussed in more detail later in the chapter.

1.3. Reasons for changes in gull numbers

The reasons for increases in the number of gulls during the twentieth century, have been discussed by several authors (Harris 1970; Bourne and Vauk 1988; Spaans *et al.* 1991). It is believed that the initial increases at the beginning of the century stemmed from legislative protection of seabirds and their colonies. Historically, large numbers of seabirds were killed in many areas as a food resource. Both eggs and adult birds were exploited and seabirds such as gulls were particularly vulnerable because of the more accessible nature of their colonies. In parts of the British Isles, seabirds were a vital part of many local economies and provided sustenance during periods of famine (Harris and Murray 1978). However, during the latter half of the last century, public opinion was slowly turning against the killing of wild birds and the first non-game bird legislation to come into force was the 'Protection of Seabirds Bill' of 1869 (Lloyd 1991). By the

1920's most British seabirds were protected by law, although large numbers were still being killed in adjacent parts of Europe.

The growth and expansion of human populations has also been a feature of the 20th century. As the human population grew, it produced ever increasing amounts of household and food waste. A large number of central disposal areas were created around centres of urbanisation, where waste material could be disposed. Morphological and behavioural characteristics of gulls enable them to exploit the food elements in material dumped at these waste disposal sites, and thus large amounts of food became available to them at a time when gulls were also benefiting from protective legislation. It should be noted however, that the habit of feeding on human waste did not develop until the gull population expansion was well underway (Bergman 1982) and it has thus been suggested, that protection allowed the gulls to begin increasing their numbers but it was their ability to exploit anthropogenic food sources that influenced the extent of the population growth (Monaghan 1983).

The amounts of waste available to gulls are enormous. In Britain c.30 million tonnes of domestic waste material are dumped annually and each person contributes approximately 350kg of putrecible organic waste to this refuse (this last figure includes wood and paper which are not available as food materials to gulls). The amount of household refuse being dumped in Britain is presently increasing by *5% per annum* (Kivell 1992).

Changes in pelagic fishing methods during the twentieth century have also provided gulls with a readily available source of food (Furness and Monaghan 1987). Limits on the size and species of fish brought ashore and the at-sea preparation of catches has meant that large amounts of fish and offal are now discarded from trawlers. Furness *et al.* (1988) calculated the annual calorific value of the total trawler discards in the early 1980's and estimated that the food requirements of 2.5 million seabirds could be supported by it.

Gulls have also benefited from modern agricultural methods particularly the large amounts of land put down for pasture and silage. These allow gulls to exploit many types of invertebrates, particularly earthworms. Indeed, at Britain's largest gullery on Walney Island, earthworms formed an appreciable part of the diets of the breeding Herring and Lesser Black-backed Gulls (Sibly and McCreery 1983).

1.4. Population regulation and superabundance

A large increase in numbers over long periods of time is only possible if the individuals within a breeding group are able to achieve one or more of the following:

- increased adult survivorship
- increased recruitment
- increased juvenile survivorship.

Protective legislation and the supply of 'surplus' foods may have permitted gulls to increase all three factors. This has led to increases in breeding numbers by countering the effects of 'natural' population regulation mechanisms. Much has been written on the nature and relative influence of limiting mechanisms in seabird populations (Ashmole 1963, 1971; Lack 1954, 1966; Birkhead and Furness 1985; Croxall and Rothery 1991). Despite the diversity of theories, there seems to be general agreement that seabird numbers are regulated in a density dependent fashion and that food limitations plays a significant role. Gulls' ability to exploit new geographical areas and habitats for breeding, and the provision of large amounts of surplus food have therefore removed the two factors that would naturally significantly limit their numbers. The term 'superabundant' has been used to describe species where breeding numbers are thought to have been increased by human influences to levels higher than would be sustainable if natural regulation mechanisms were in operation (Blokpoel and Spaans 1991). Evidence of the role of food availability in population regulation is presented in the next

chapter. If human influences have helped to increase gull numbers, it is ironic that gulls are now perceived to be in direct conflict with human beings to the point where they are considered as pests.

1.5. The gull problem

The many and varied conflicts between humans and gulls have been placed under the umbrella term 'gull problem'. The perceived seriousness of any of these problems depend on the interests and tolerance of the affected parties and the abundance and tenacity of the species involved. Gull problems can be categorised into four major areas:

(a). Gulls and aviation problems. Grassy areas and airport runways, provide ideal loafing, feeding and roosting sites for gulls. Movements of gulls to and from these areas, have led to collisions with aircraft. Gulls account for just under 50% of all bird strikes at European airports and Civil Aviation Authority records show that 90% of bird strikes with civil planes in the United Kingdom, occur below 250m i.e. when the plane is taking off or landing (CAA report 1990). The large mass of gulls makes it more likely that gull-plane collisions result in serious accidents than strikes with smaller species such as Starlings *Sturnus vulgaris*, that also utilise airports.

(b.) Gulls and public health problems. Certain species of bacteria that are pathogenic to humans are known to be carried by gulls (Spaans *et al.* 1991). Predominant among these are *Campylobacter* and *Salmonella* which cause gastro-enteritis in both humans and livestock. Gulls pick up these bacteria by feeding at waste disposal sites and sewage outfalls (Monaghan *et al.* 1985). Cross-contamination between humans and gulls can occur when large numbers of gulls roost on reservoirs of potable water supplies (Benton *et al.* 1983). The relevant authorities usually deal with high levels of bacteriological contaminants by increasing chlorination of the water supply, but this is neither desirable or popular with the public (D. Taylor, North West Water Co., personal communication).

Many reservoirs in Britain, particularly in the English midland area, are now utilised as roost sites during the winter, by thousands of gulls of several different species. This behaviour has become more widespread and frequent over the past few decades and appears to still be on the increase. A million and a half gulls were counted in England and Wales during a recent survey of gulls on inland sites during January (Waters 1994). It is likely that as gulls increase their use of the urban environment and reservoirs as roost sites, contamination of water supplies will become an increasingly significant part of the gull problem.

Gulls have also been implicated in health problems with farm animals. Bacteria such as *Mycobacterium avium*, which are transmitted to livestock by gulls, do not cause actual direct harm to the animals. A problem arises however, because animals infected by this bacterium show a positive result when tested for bovine tuberculosis (Spaans 1991). This disqualifies them from export and hence reduces their economic value. Coulson *et al.* (1983) demonstrated that Herring Gulls were vectors of *Salmonella montivideo* which can cause spontaneous abortion in sheep and cattle. It is unknown how common or widespread this problem is.

(c). Gull problems in urban areas. The utilisation of urban areas for breeding, feeding and loafing did not become established in Britain and Ireland until the 1940's (Parslow 1967; Hutchinson 1989). Since then, the behaviour has become widespread and common and the numbers of birds involved continues to increase (Cramp 1971; Monaghan and Coulson 1977; Raven 1994). A similar pattern of urbanisation has occurred in North America (Vermeer 1988).

The present roof-nesting gull population in the UK probably exceeds 13,000 pairs (S. Raven, personal communication). The roof-nesting habit has spread to all coastal areas of Britain except between the Clyde and north Sutherland on the west coast and between the Humber and the Thames on the east coast. Roof-nesting gulls can now be found in several inland cities e.g. Birmingham. As the urbanisation of gulls has progressed, the

number of complaints against urban gulls has risen too. The commonest complaints made against gulls are: fouling of people, building or cars, noise, damage to building fabrics, blockage of drainage systems, spread of pathogenic bacteria and physical attacks on humans (Monaghan 1983; S. Raven, personal communication).

(d). Effects of gulls on other bird species. Gulls are able to utilise a wide range of food items. During the breeding season these include the eggs, chicks and adults of other species of birds breeding in close association with gulls. Because of these predatory habits, the presence of gulls on many nature reserves and at the breeding sites of more 'sensitive' species has been unwelcome. Terns and auks seem to be the most universally affected taxa (Thomas 1972 and Vauk and Pruter 1987) with gulls adversely affecting their breeding success and competing for breeding sites. Several tern species in Britain are internationally threatened (van Vesseem 1993) and have been the focus of much of the research on the effects of gulls on other species. However, the actual level of impact on the population of the species being predated has been questioned by some authors (Vauk and Pruter 1987). Swennen (1989) for instance, demonstrated that Eider *Somateria mollissima* ducklings predated by Herring gulls were weak birds that would naturally die of starvation had they not been predated first i.e. they were natural 'surplus'. It should also be remembered, that even if gull numbers were at 'natural' levels they would normally be expected to predate many of these species and had probably reached a dynamic equilibrium with their prey in the past.

1.6. Attempts to find solutions to the gull problem

The first large scale attempt to reduce numbers of gulls over a wide geographical area occurred between 1944 and 1951 along the coast of Maine in North America (Gross 1951). The aim was to reduce the Herring Gull population by spraying eggs with oil and formaldehyde. The programme was abandoned in 1952 because the results were not considered "spectacular" enough to justify the high costs involved (Graham and Ayers

1975). Smaller scale control programmes had been initiated in Europe (Netherlands) as early as 1939 with similar inconclusive results (Morzer Bruyns 1958).

During the past 50 years of attempts to control gull numbers, an enormous variety of methods have been used. Table 1 summarises the range of methods used in gull control programmes. The methods employed depend on whether the aim is to:

- move gulls away from a particular site
- reduce gull numbers
- control small or large groups over small or large areas
- control groups at breeding, feeding or roosting sites

Non-lethal methods have generally been employed to move gulls, while number reductions have often involved large scale lethal control methods. These will be evaluated in greater detail in a later chapter of this thesis.

1.7. Responsibility for gull control

Many control methods can involve high costs, are labour intensive and have inconclusive or short-term results. This has led to problems in identifying who should shoulder the financial burden for control. A local site owner may view the presence of gulls as a serious problem and will expect action to be taken by the appropriate national or local government agency. But these bodies have very limited resources and are equally mandated to protect gulls at a national level through the Wildlife and Countryside Act 1981. Government agencies are also compelled to take into account the general public's views on lethal control, and have very strict guidelines as to when control measures can be applied. In the absence of examples of control programmes that have met all the intended aims, it is easy to see why government agencies are now unwilling to

Table 1. Methods used for controlling gulls at breeding, feeding and loafing sites in Britain.

CONTROL METHOD	DESCRIPTION	RESTRICTIONS	SITE
Narcotics	The most frequently used narcotic is α -chloralose. Kills the gull by affecting temperature control mechanisms. Spread onto bread baits and put next to nests or spread over general area.	Requires licence and use is strictly controlled. Legally limited to certain species or times of year.	Breeding Feeding Loafing
Poisons	Poisons such as strychnine or phosphorus were once used but narcotics have now widely replaced them. Same method used as for narcotics.	"	"
Shooting	Generally used to remove small numbers of tenacious birds not removed by narcotic baiting. Shooting from hide most effective method.	"	"
Egg manipulation	Eggs can be destroyed, sprayed with oil, injected with formalin or punctured with a small hole to prevent hatching.	"	Breeding
Scaring	Uses a broad range of either acoustic or visual devices. Must be used in scientifically evaluated regime as gulls will rapidly habituate to many methods. Human presence at site can be used as well.	Certain gulls cannot be disturbed at the nest site without licence.	Breeding Feeding Loafing
Exclusion	At reservoirs, gulls can be excluded by series of parallel wires over water. At waste disposal sites and on buildings, gulls can be excluded using netting.	None	"
Habitat modification	Planting or cutting certain types of vegetation or larger scale re-landscaping of site. For urban gulls new roofing material or angle can affect birds.	"	"

readily licence or finance solutions to gull problems. In Britain there has been no 'national' attempt to reduce gull numbers and given the high costs involved and that the present climate of public opinion is predominantly against large scale lethal culls, 'site-by-site' local solutions are likely to continue to have to be the answer to gull problems. The financial burden for such control will, in many cases, undoubtedly fall on site owners rather than county or city councils. These local culls will not, however, reduce the overall numbers of gulls on a national and long-term scale, even if they do significantly affect numbers of individuals in local areas. As long as the root causes of superabundance exist, there will be problems associated with high levels of gull numbers that will have to be dealt with at a local level. In other words until superabundant food supplies from human waste and fisheries are no longer nationally available, gulls and humans will continue to come into conflict. The role of government agencies in these conflicts is likely to be an indirect one, and they will probably do no more than licence control measures. In certain cases they may also want to set specific aims for gull control and monitor the humane execution of management programmes.

1.8. Demographic processes and gull control

Evidence that a change in waste disposal practices can significantly reduce gull numbers and ameliorate local gull problems, comes from studies of gull colonies where local disposal methods have changed from open tipping to incineration (Anderson and Keith 1980; Pons 1992). Other studies have shown that declines in numbers of the nominate race of the Lesser Black-backed Gull *L. fuscus fuscus* in north Norway are linked to changes in fishery practice and catch sizes (Straank and Vader 1992). In Britain, there are unlikely to be any radical changes in either waste disposal or fishery practices in the short-term. The costs of implementing such changes are prohibitively high compared to the perceived environmental gains. Site-by site control methods are therefore likely to remain the general solution to gull problems. In the past, lack of

success in ameliorating the gull problem, can be attributed, at least in part, to the use of *ad-hoc* methods that have not been scientifically evaluated. Most, if not all, of these methods have taken no account of the under-lying demographic processes within gull populations. Without prior knowledge of, and reference to these processes, control measures are unlikely to be successful in the long-term (this will be discussed in Chapter 2 and past attempts to control the numbers of gulls evaluated in Chapter 5). Control measures must also take into account the processes involved in colony formation and growth. Gulls are generally highly colonial and find it difficult to establish themselves in new areas without stimulation by the presence of other gulls. Successful clearance of sensitive areas will therefore only be successful if complete clearance is achieved. As long as there are a few tenacious individuals remaining, other birds will be attracted to the site and stimulated to breed in that area. Many control programmes have failed in the long-term because culling achieved only a reduction in nest density rather than complete clearance.

1.9. Rational strategies for gull control

Many gull problems are not perceived as such on a 'national' scale, but are the focus of concern for the individuals and communities directly affected. Within each group there will be a different perception and tolerance to the particular problem. Even within the scientific literature there is some doubt that a gull 'problem' actually exists (Southwood 1987). This is perhaps too dismissive, but in finding solutions to gull problems, anecdotal speculation should be replaced by scientific evaluation of the precise nature and level of the problem. Furthermore, attempting to make past control methods work by merely increasing the control effort will not solve gull problems. Future control programmes require rational strategies i.e. ones that incorporate scientifically evaluated methods and allow further research into gull demography and breeding biology. They must also operate within a strict framework of short and long-term aims and be licensed

by appropriate government agencies. These agencies should be mandated to ensure that any control measures taken are appropriate to the particular problem and are not merely designed to satisfy the need for "some sort of action" to be taken indiscriminately against the gulls by those most affected by a particular problem. Given that the root causes of superabundance in gulls are not likely to be removed in the near future, new methods of controlling gulls at a local level are required. Experiments into finding novel ways of completely and humanely clearing gulls from specific areas, that can be incorporated in a rational control strategy, are described and evaluated in Chapter 3.

CHAPTER 2.

THE GULL PROBLEM AT THE TARNBROOK FELL GULLERY: Problems, causes and past attempts at control.

2.1 Introduction

In Chapter 1, the nature, causes and solutions to the 'gull problem' were discussed from a national and international perspective. The role of scientific evaluation in future gull control measures was also highlighted. In this chapter, a specific example of a gull problem is described in a local context. The work was carried out over three breeding seasons between 1992-1994, at a gull colony where extensive culling of adults between 1978 and 1988 significantly reduced the number of breeding gulls but failed to reduce the physical extent of the colony boundaries or ameliorate the problems associated with this group. When the licence to cull gulls on a large scale at the colony was withdrawn in 1989, one of the three shooting estates on which the gulls breed, approached Dr. J.C. Coulson (Durham University) to establish a research programme designed to develop novel methods of controlling the gulls. In this chapter, the problems caused by gulls at the study site are described, and suggestions made as to the probable causes of these problems. Past attempts at controlling the gulls at the colony are then evaluated in the light of present knowledge of the biological and demographic effects of large scale culling.

2.2. Study species: the Lesser Black-backed Gull *Larus fuscus*

2.2.1. Distribution

The species *Larus fuscus* (Linnaeus 1758) is polytypic, with five sub-species¹ world-wide. Figure 1 shows the world distribution of the species, Figure 2 shows the European distribution. The breeding group in Britain and Ireland is made up entirely of the sub-species *L. f. graellsii* which also breeds in Denmark, France, Holland, Iceland and Spain. Lesser Black-backed Gulls generally move southwards during the winter, with birds in the west of the breeding range wintering off Portugal, south-west Spain, Senegal and Mauritania, and birds of eastern part of the breeding range wintering in the Mediterranean, Red Sea, east Africa and the north and east coasts of the Indian Ocean (Cramp and Simmons 1983). Prior to the 1950's, British Lesser Black-backed Gulls followed this migration pattern and wintered between Spain and Senegal. Since then, a marked change in wintering areas has occurred and a large proportion of British Lesser Black-backed Gulls now over-winter in the English Midlands (Baker 1980). In common with several other gull species, the Lesser Black-backed Gull has colonised new geographical areas during the 20th century (Table 2).

2.2.2. Changes in status of the Lesser Black-backed Gull

The spread in the geographical breeding range of the Lesser Black-backed Gull during the twentieth century has been accompanied by an increase in numbers in most countries (although nothing is known of the status of birds breeding in Russia).

¹*L.f. graellsii* (Brehm 1857): Britain, Denmark, France, Holland, Ireland, Iceland, Spain; *L.f. intermedius* (Schiöler 1922): Denmark, Holland, south Norway; *L.f. fuscus* (Linnaeus 1758): north Norway, Sweden, Kola peninsular; *L.f. heuglini* (Bree 1876): north Russia; *L.f. taimrensis* (Buterlin 1911): north Russia and Tamyr.

Figure 1. World distribution of the Lesser Black-backed Gull (Lloyd et al. 1991)

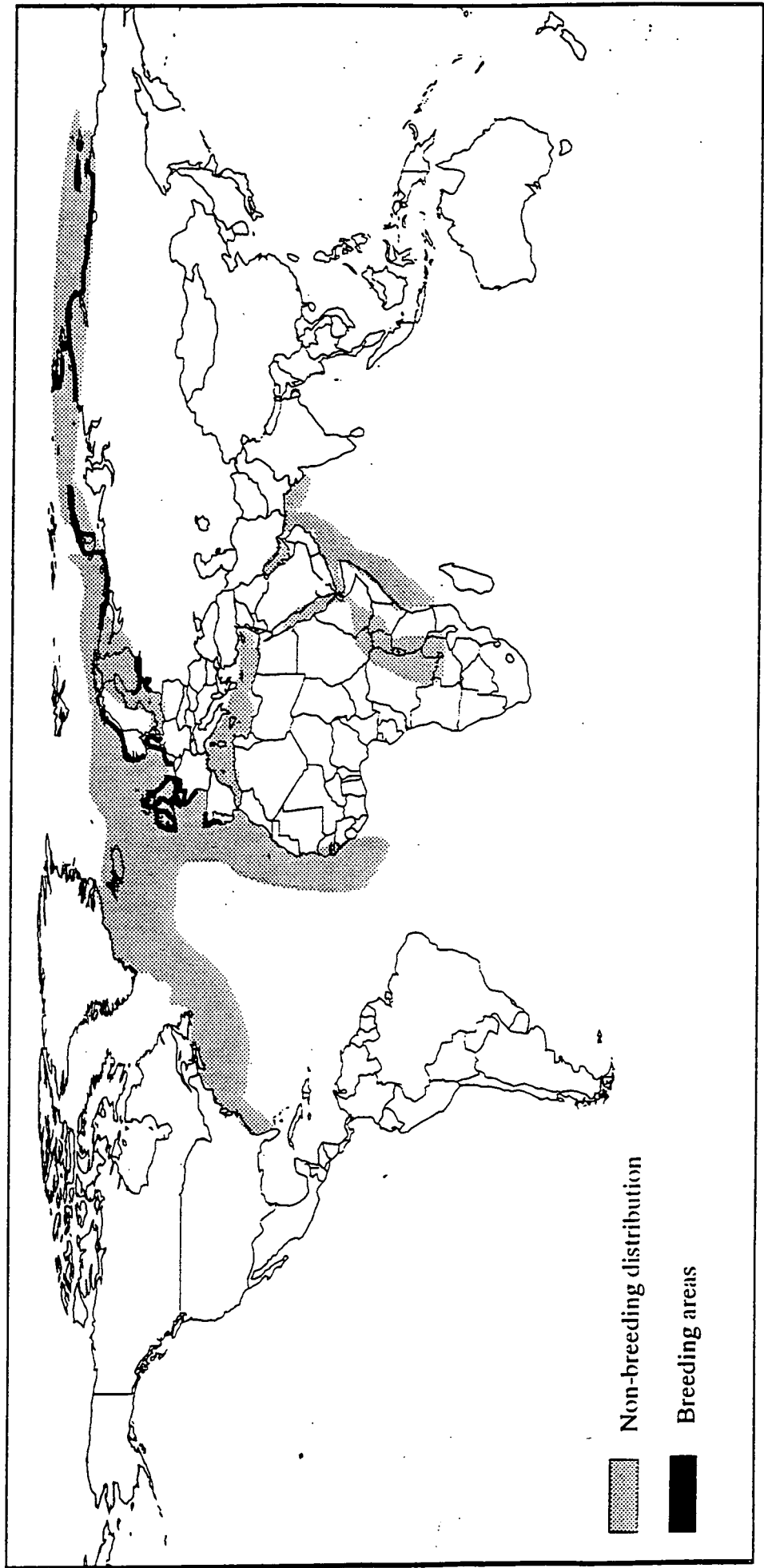


Figure 2. European distribution of the Lesser Black-backed Gull (Lloyd et al. 1991).

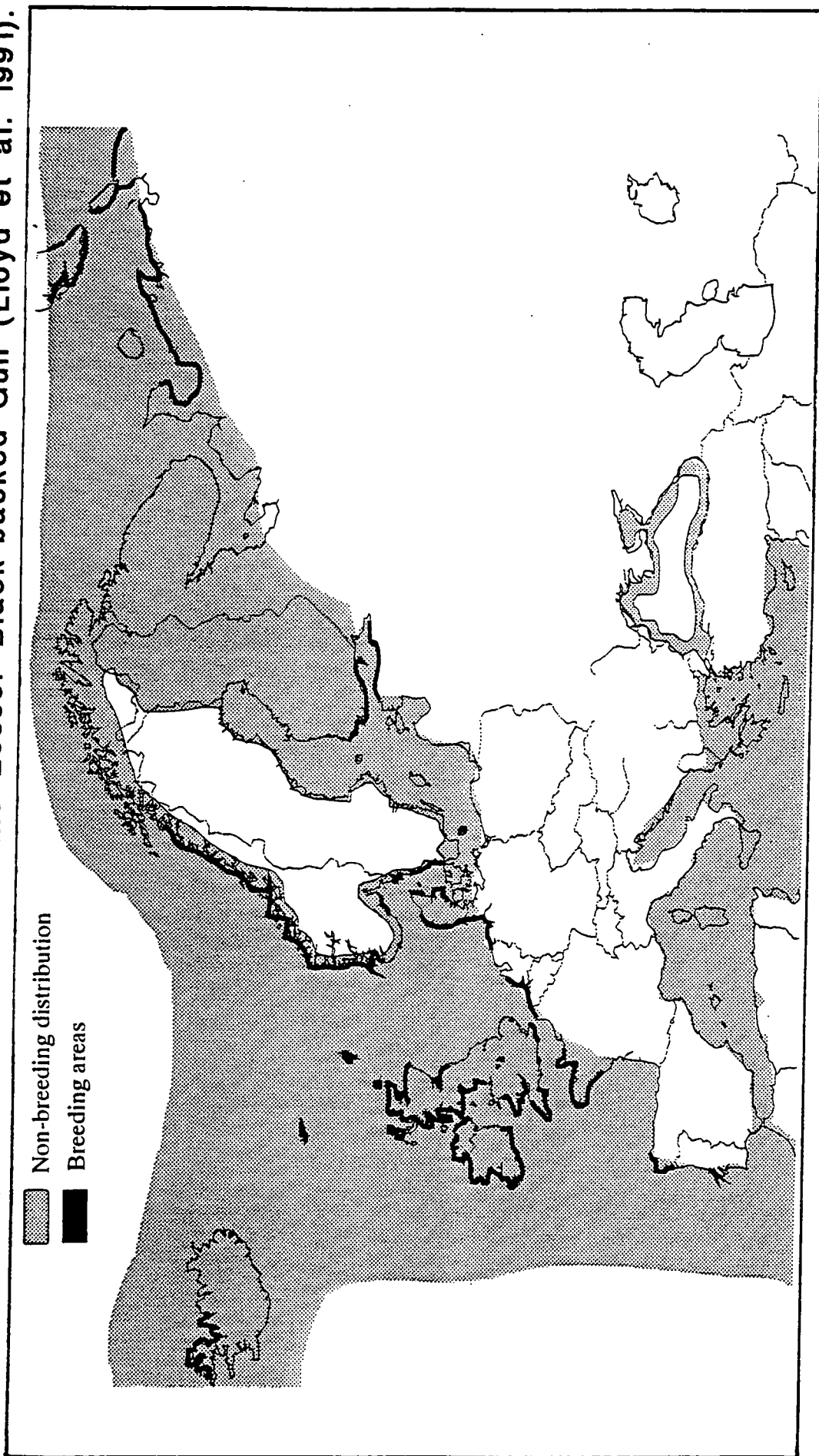


Table 2. Changes in the geographical breeding range of Lesser Black-backed Gulls during the twentieth century.

Geographical area	Year of colonisation	Reference
Iceland	1920	Cramp 1983; Lloyd 1991.
France	1925 (re-colonised)	"
Holland	1926	"
West Germany	1927	"
Spain	1971	"
Portugal	1978	"

In Britain as a whole, numbers increased by approximately 25% between 1969 and 1987, although some colonies were in decline during this period (Lloyd *et al.* 1991). The scale of increases varied from region to region, with the largest increases occurring in some Scottish and Welsh colonies (up to +55% and +65% respectively).

2.2.3. Changes in Lesser Black-backed Gull breeding habitats

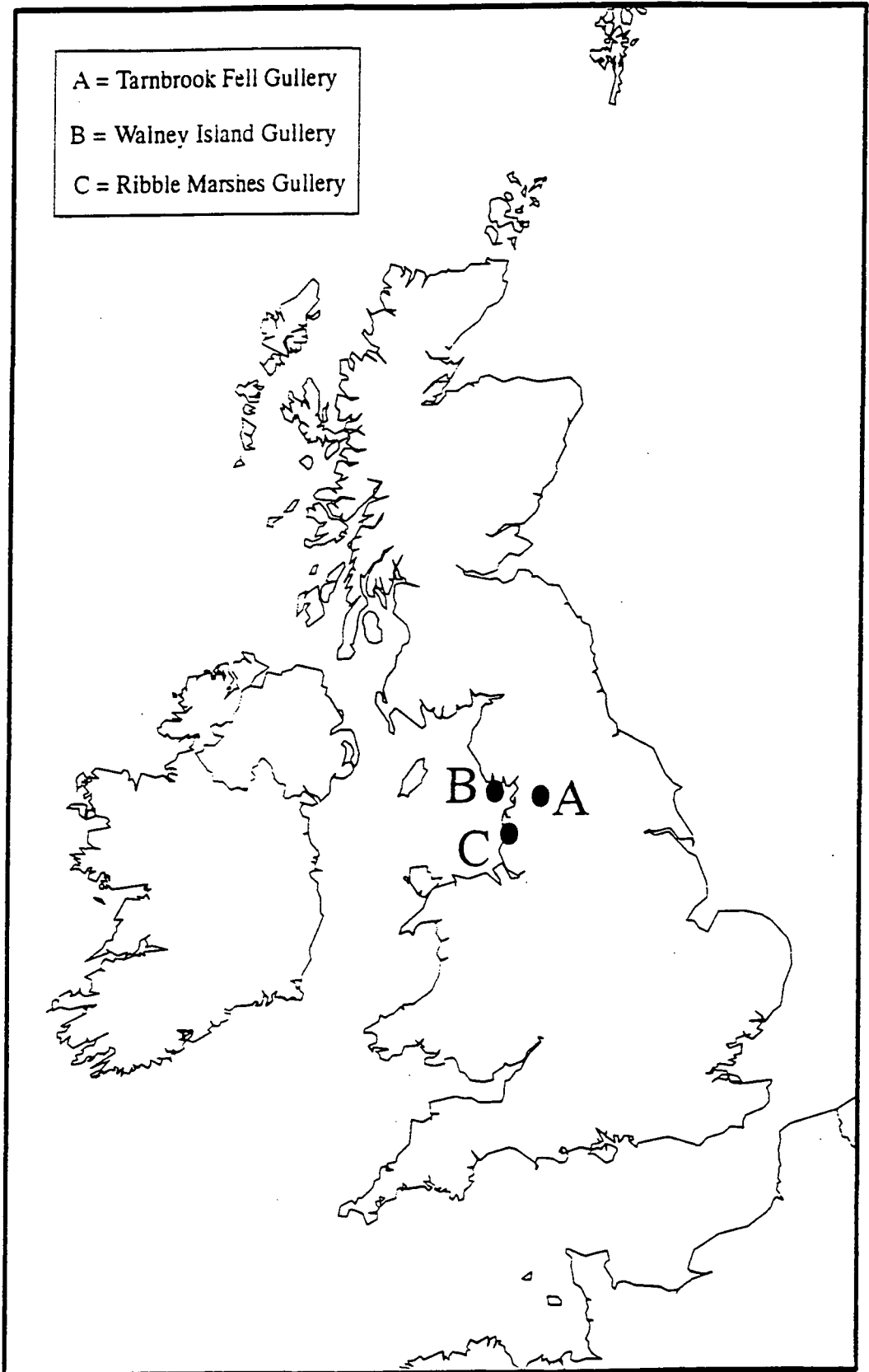
Historically, most Lesser Black-backed Gull colonies were on the coast in sand dune complexes, on grassy swards at the top of cliffs or on islets in brackish and tidal lagoons. During this century they have started to utilise other breeding habitats such as lake sides, urban roofs, and platforms on industrial sites. A large colony on heather moorland, was established in the 1930's (see below), and during the 1960's the first colony entirely on shingle/grass was established at Orfordness in Suffolk. In Ireland, many colonies established since the 1950's, have been sited by lake shores and these now outnumber coastal colonies (Lloyd *et al.* 1991).

Lesser Black-backed Gulls have also been able to utilise urban and industrial habitats for breeding. This behaviour was first noted during the 1940's (Parslow 1967; Hutchinson 1989) and has been on the increase ever since. In 1976, there were approximately 300 pairs of Lesser Black-backed Gulls nesting in urban areas (Monaghan and Coulson 1977). The numbers in 1994 are probably in excess of 3,000 pairs (S. Raven, personal communication).

2.3. Description of study site

The Tarnbrook Fell Gullery (grid reference: SD614595) lies on the western slopes of the Pennines, in an area known as the Forest of Bowland (Figure 3). The colony

Figure 3. Position of Tarnbrook Fell, Walney Island and Ribble Marshes gulleries.



presently occupies approximately 6 km² of typical west Pennine blanket bog lying between 450m and 515m above sea level. Plants such as Cotton Grass *Eriophorum angustifolium* and Heather *Calluna vulgaris* predominate, with Bilberry *Vaccinium myrtillus* common on the steeper and rockier slopes. *Juncus* sp. are found in the in the wetter areas and other grasses such as Mat Grass *Nardus stricta*, Wavy Hair Grass *Deschampsia flexuosa* and Purple Moor Grass *Molinia caerulea* are present, occasionally as close-grazed swards.

Peat depths vary within the colony from 0.1m to 4m and many steep sided peat 'hags' intersect the vegetated areas. The rock underlying the peat is mainly Millstone Grit which outcrops on the higher slopes and in Mallowdale.

In a typical year, mean rainfall within the gullery area is higher than the mean for other areas in Lancashire and probably exceeds 1500mm *per annum* (J. Wrigley, personal communication). Dense mists can blanket the gullery area at any time during the breeding season (March-August) and frequently occur at dawn and dusk. Snow is not permanently present during the winter months but can lie on the area for several days up to the end of April, by which time many of the gulls have established territories and some have built nests.

2.4. History of Tarnbrook Fell Gullery

The first pair of Lesser Black-backed Gulls were recorded breeding on Tarnbrook Fell in 1938 (Greenhalgh 1973). The area in which these first gulls bred was owned by the late Lord Sefton and acclaimed as one of the finest Grouse moors in Britain (Hudson 1986). It is therefore surprising that there seems to have been no attempt to remove the gulls during the early period of colony growth. The spread in area and the increase in the numbers of breeding birds is not well documented for the first twenty years of its existence. The population dynamics and calculations of the rates of increase of breeding

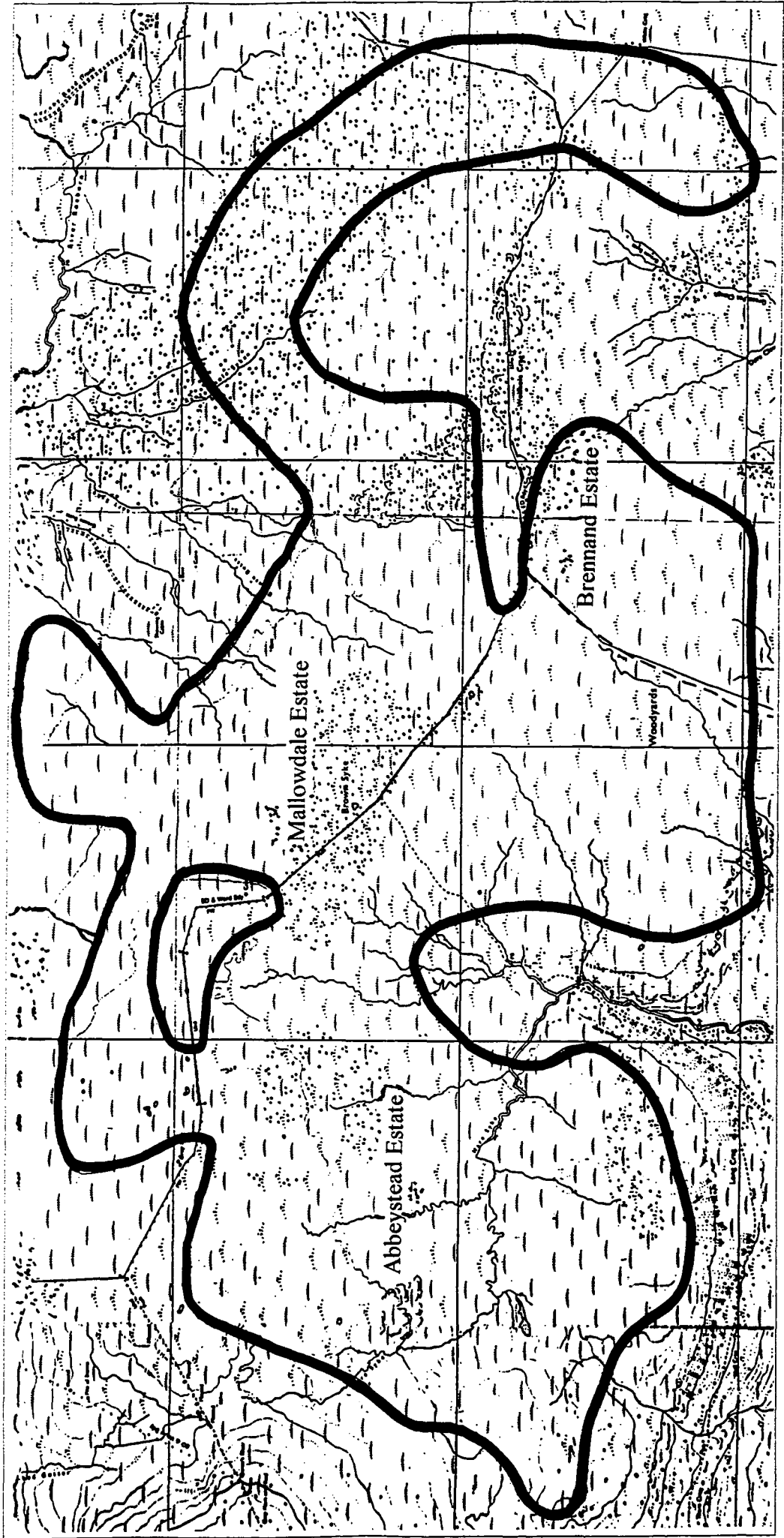
numbers at various periods of the colonies history, are dealt with fully in chapter 5. Between 1938 and 1962, the numbers of Lesser Black-backed Gulls at Tarnbrook Fell increased at a rate of 26% *per annum*. Herring Gulls first bred at Tarnbrook in the early 1950's and increased at a rate of 44% *per annum* up to the early 1970's. These rates of increase could only have been sustained through the immigration of large numbers of gulls from other areas. The importance of this will be discussed later in the chapter. The number of gulls in the colony peaked in the mid 1970's. Between 1978 and 1988 there was a large cull of adult gulls (see later) and the number of gulls in the colony was reduced by approximately 70% during this period. Since 1990, the number of gulls in the colony has remained stable and there were approximately 18,000 breeding birds at the gullery in 1994. The culls of the 1980's achieved a reduction in the number of breeding birds but the boundaries of the colony have remained fairly fixed since they were first mapped in 1972 (Greenhalgh 1973). The colony boundary when the present project started in 1992 is shown in Figure 4. Three estates have part of the gullery on their land. The area of each estate on which gulls were breeding in 1992 are as follows:

Abbeystead Estate	3.14 km ² (48%)
Mallowdale Estate	2.52 km ² (38%)
Brennand Estate	0.94 km ² (14%)
Whole Gullery	6.60 km ² (100%)

Approximately 95% of the gulls at the colony are Lesser Black-backed Gulls, the remainder being Herring Gulls. In most years a few pairs of Great Black-backed Gulls *L. marinus* also breed.

Figure 4. The Tarnbrook Fell Gully boundary 1992.

Scale: 1km



2.5. Nature of the 'gull problem' at the Tarnbrook Fell Gullery

The problems at Tarnbrook Fell reflect many of the national problems associated with gulls. They are of mainly local significance and have different sensitivities for different groups. There are also many questions relating to the responsibility for carrying out and financing control measures, and some additional conflict with government agencies over the precise methods to be used. There are four main problem areas associated with the gulls on Tarnbrook Fell:

- Red Grouse *Lagopus l. scoticus* stocks
- Water quality and livestock health
- Birds native to the fell (other than grouse)
- Vegetation on the fell

2.6. Effects of gulls on Red Grouse

All three estates on which the gullery lies are managed primarily for grouse, although sheep are also grazed on the fells by local tenant farmers. The estates' primary concern, and sole reason for wanting to remove the gulls from the area, are the perceived negative effects of gulls on the breeding Red Grouse. There are two ways that gulls potentially effect grouse: (i) indirectly, by disturbing the grouse so they become excluded from the gullery area, or (ii) directly, by predation on adults, eggs and chicks. Data that conclusively associate the presence of gulls with a downward trend in grouse numbers are not currently available to this study. Several intensive population studies have been conducted on grouse at other sites (Jenkins *et al.* 1963; Watson and Moss 1980; Potts *et al.* 1984), and have demonstrated the complex nature of their population dynamics. Grouse numbers fluctuate in 'peaks' and 'troughs' in cycles of four to seven years, depending on the particular moor involved. Factors affecting the extent and periodicity of the cycles include: amounts and age of heather, numbers of parasites (particularly the Nematode worm *Trichostrongylus tenuis*), breeding densities, proportions of young and

old birds shot and stochastic elements such as local weather patterns. Many of these are correlated with the management strategies of game keepers on the area in question. Potts *et al.* (1984), constructed a time-series model of populations of Red Grouse from data collected on 63 moors in the north of England. They demonstrated the complexity of grouse population cycles and warned against simplistic predictive models. Teasing out the effects of gulls on grouse numbers at Tarnbrook Fell is thus fraught with difficulty and beyond the scope of this thesis. Despite this, there is some information about gull/grouse interactions that can be used to address the very genuine concerns of the three estates. For instance, there are over 18,000 gulls in the gullery, and therefore not all the gulls in the Tarnbrook group can be regularly preying on grouse chicks as this far exceeds the total number of chicks produced in a season. Additionally, on the Abbeystead Estate, the gullery area remains one of the best grouse drives on the estate (I. Savage, personal communication) and during the three years of the current fieldwork no gull/grouse incidents were witnessed. This is not to say that they do not occur, but that only a few gulls must be involved in predation and many grouse still breed successfully within the gullery area. By counting grouse nests during the annual census of gulls at Tarnbrook Fell (Chapter 5), the breeding density of grouse within the gullery can be estimated. Grouse nests were found in areas of both high and low gull densities, and a mean of c. 25 grouse nests per km² was found during the three seasons of this study (1992-1994). By national standards this makes the gullery area one of the better grouse sites (Hudson 1986). Comparisons of grouse densities inside the gullery with densities in gull-free areas are made difficult because of the natural patchiness of grouse distributions and their complex relationship with vegetation types and cover, and because the situation prior to the formation of the gullery is not known. Newborn and Hudson (1982) attempted to quantify grouse densities inside and outside the gullery boundary and concluded that there were significantly fewer grouse within the gullery. However, it should be noted that they conducted their survey in late July, by which time most grouse chicks are independent from the hens and have formed small groups that move away from the natal area (Butterfield and Coulson 1975; Moss 1975). It should

also be noted, that any grouse chicks taken by the gulls may be weak (or indeed dead) birds that would have died naturally in the absence of the gulls. The gulls may thus be simply removing a natural 'surplus' from the breeding stock. Swennen (1989) describes a study of Eider *Somateria mollissima* chicks that were being predated by Herring Gulls. The chicks taken were all found to be infected with the pathogen Coccidiosis and were dying when predated.

There is also some doubt about the second potential effect that gulls may have on the grouse, namely 'exclusion'. It has been suggested by the game keepers that the presence of gulls interrupts the displays of male grouse and both they and their potential mates are then 'frightened off' by the gulls. This probably does not occur because by the time the gulls arrive back in the colony in early March the peak of grouse displaying is over and most males have already established a territory and have taken mates. Furthermore, at this time the gullery is occupied by the gulls for only a few hours each day. By the time the majority of gulls are continuously present (early April) some of the grouse are already incubating clutches.

2.7. The effects of gulls on water quality

2.7.1. Introduction

The faecal contamination of water used for human consumption by gulls remains one of the major areas of human/gull conflict. Gulls become carriers of pathogenic bacteria, such as *Salmonella*, by feeding on human waste disposal sites and sewage outfalls (see Chapter 1 for general review) and then contaminate water supplies through defecation in rivers and reservoirs. Circumstantial evidence also exists that gulls are vectors of pathogens such as *S. montevideo* and *S. livingstone* to sheep and cattle (Williams *et al.* 1977; Johnston *et al.* 1979; Coulson *et al.* 1983). The city of Lancaster in north-west England, is supplied with drinking water from two sources: (i) the River Lune and (ii)

'moor water' from a pipe situated on the southern edge of the Tarnbrook Fell Gully. This removes water from streams whose source lies within the gully area, and passes it to a nearby reservoir for future supply to Lancaster. In 1975, routine bacteriological sampling of the potable water supply, brought a potential health hazard posed by the gully to the attention of the North-West Water Authority (NWWA) who are responsible for the deliverance of clean water to households within the county. This led to a major investigation of water quality from the site in 1976, the main aim of which was to isolate and enumerate potentially harmful pathogens in the water and to make recommendations for further action to maintain the quality of water supplies (Jones *et al.* 1978). As a result of this study, a licence for large scale culling of adult gulls at Tarnbrook Fell (using the narcotic α -chloralose) was issued by the Ministry of Food and Fisheries (MAFF). The licence was issued to the shooting estates who conducted the culls from 1978-1988. Since the mid 1980's Lancaster has been using less moor water and relies more on the alternative water source from the River Lune. In 1993, an investigation was carried out to determine if water quality was being affected by the presence of gulls at Tarnbrook Fell whose breeding numbers are 70% lower than when the original samples were taken in 1976.

2.7.2. Methods.

Potentially harmful water carried bacteria are often sensitive to environmental change and are sometimes difficult and/or expensive to isolate. So studies of water contamination by animal faeces often employ more robust 'indicator' species. In order to be of use, these indicators must have the following characteristics:

- (i) they must be abundant in faeces
- (ii) they must lend themselves to easy isolation and enumeration
- (iii) they must be unable to grow in an aquatic environment

(iv) they must be more resistant to environmental stress than the pathogens for which they indicate.

The indicator species most commonly used are coliforms, especially *Escherichia coli*. The enumeration of *E. coli* is a more sensitive test of faecal contamination than 'total Coliforms', as some environments can have a natural background of some coliforms (Thom 1987).

In 1993, water sampling took place on six occasions during the breeding season between 23 March and 7 July. The samples were taken from the water entering the NWWA gully intake pipe and from a control stream on Hawthornthwaite Fell (10km south of Tarnbrook Fell) where the vegetation, altitude, weather and sheep densities were approximately the same as for the gully, but where no gulls were present. Unfortunately, because of restriction in the number of samples the NWWA could analyse for this study, only a single control site was sampled. Figure 5 shows the location of the water intake pipe. The water was collected in sterile bottles and taken for analysis to the NWWA water quality laboratory near Preston. The samples were analysed for *E. coli* and for the presence/absence of *Salmonella* sp. (not identified to serotype). Analysis was by the Membrane Filtration Technique (Appendix 1). The methods were the same for the study made in 1976 (see Jones *et al.* 1978) except in that study no control site was used and eight rather than six samples were taken during the same time period.

2.7.3. Results.

Figure 6 shows the increase in the number of *E. coli* per ml of water at the control site and water intake pipe during the 1993 gull breeding season. At the control site, the number of *E. coli* per ml of water were negligible in terms of amounts that could be deemed as contamination by the water authority, and were detected only after mid-June (two samples). The rate of increase of number of *E. coli* per ml of water from the

Figure 5. Tarnbrook Fell Gully boundary and the water catchment area within the colony contributing water to the North West Water Authority (NWWA) intake pipe.

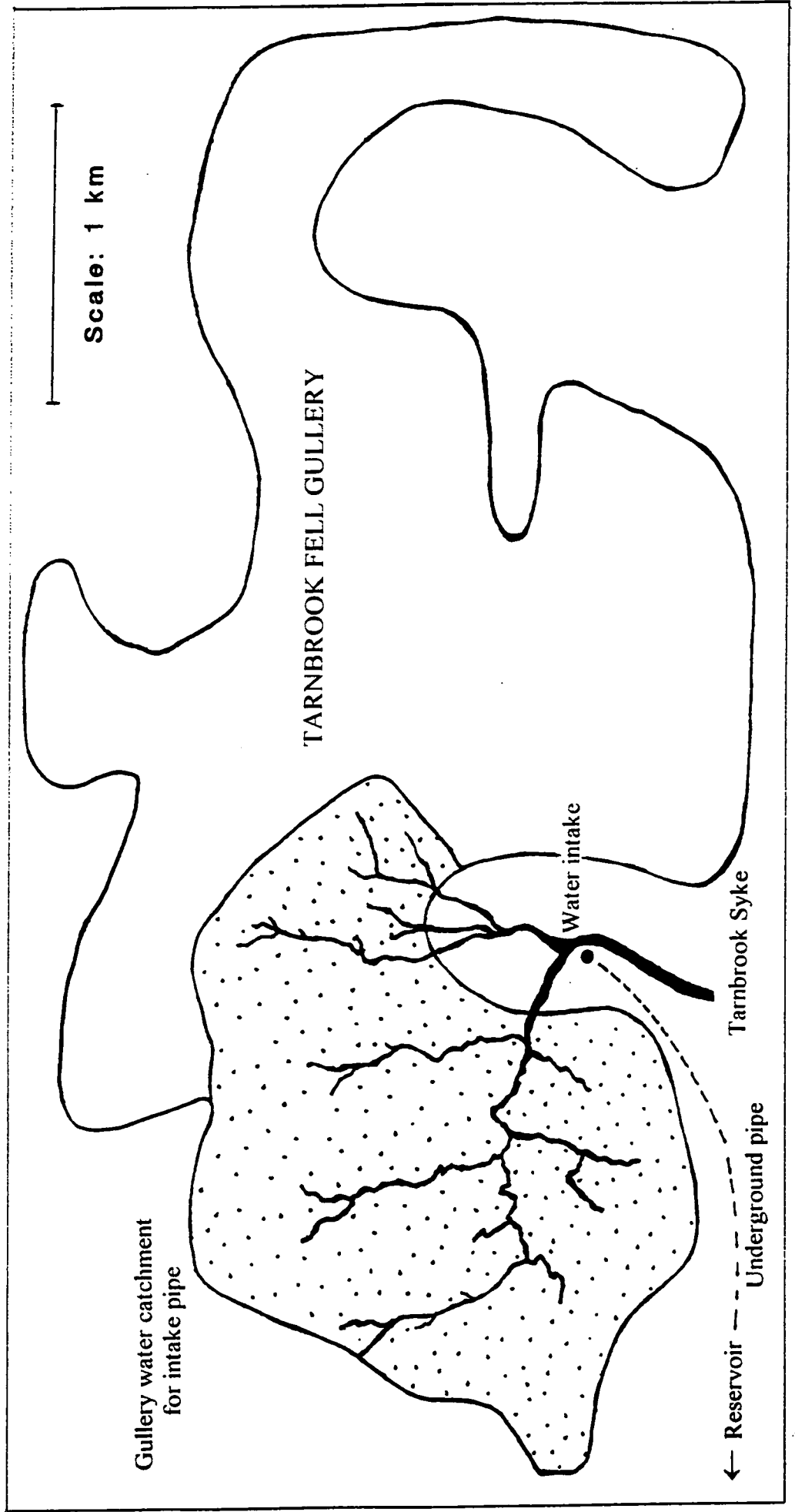


Figure 6. Increase in number of E. coli per ml of water in samples from Tarnbrook Fell Gully water intake pipe and control stream during the 1993 gull breeding season.

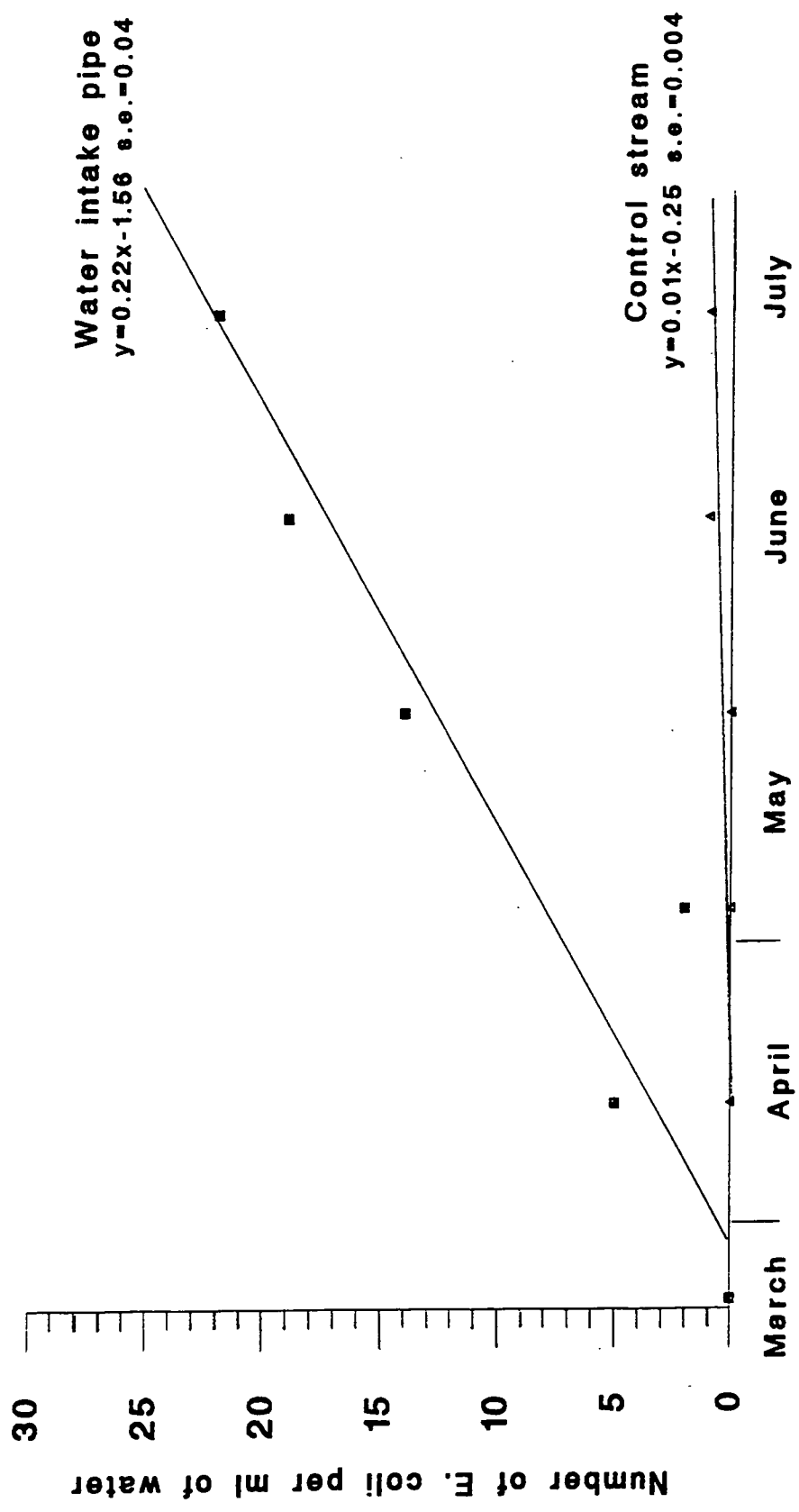
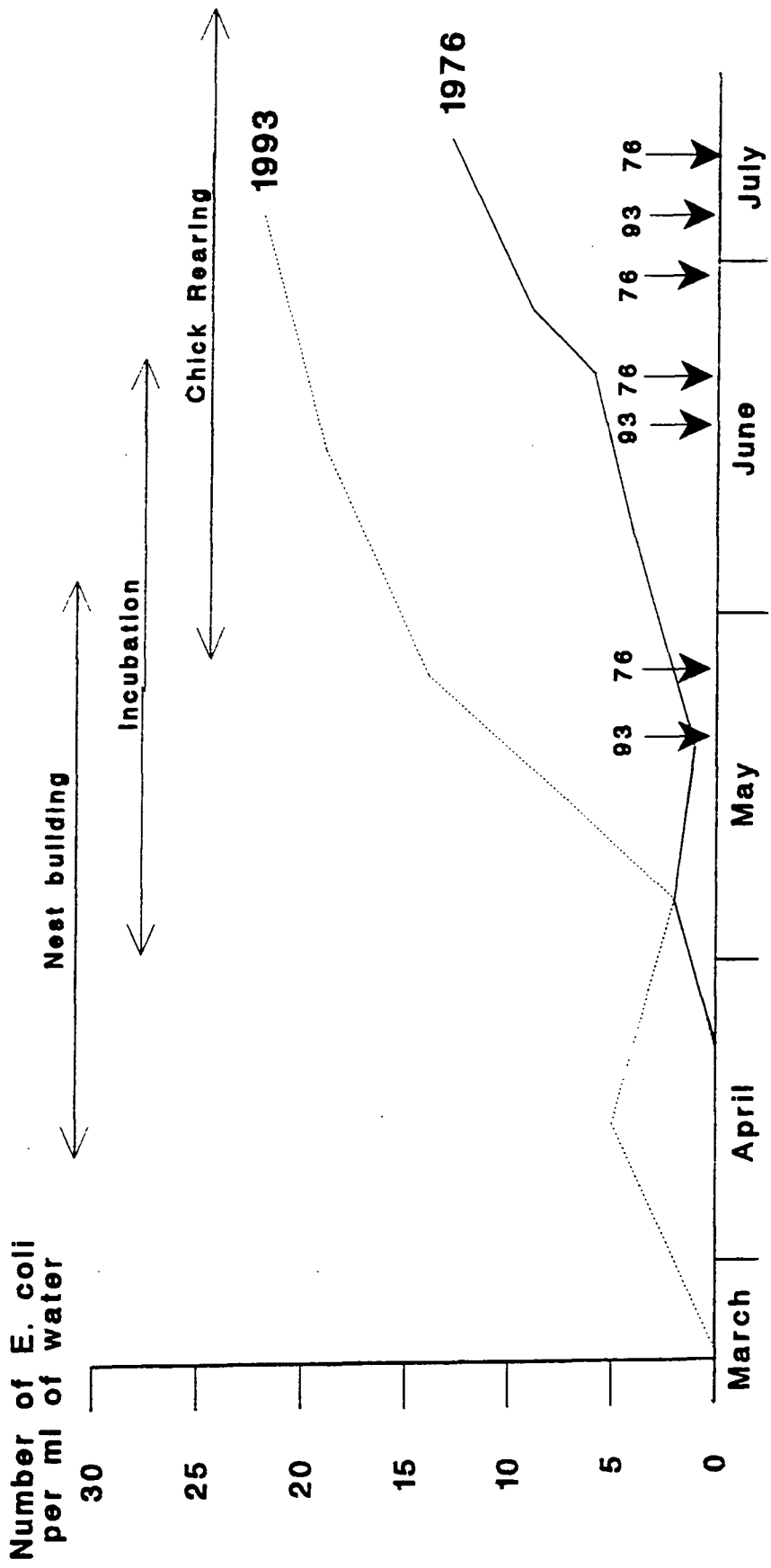


Figure 7. Number of E. coli per ml of water samples taken from the Tarnbrook Fell Gullery water intake pipe during the gull breeding season: 1976 and 1993. Arrows indicate the presence of Salmonella in water sample.

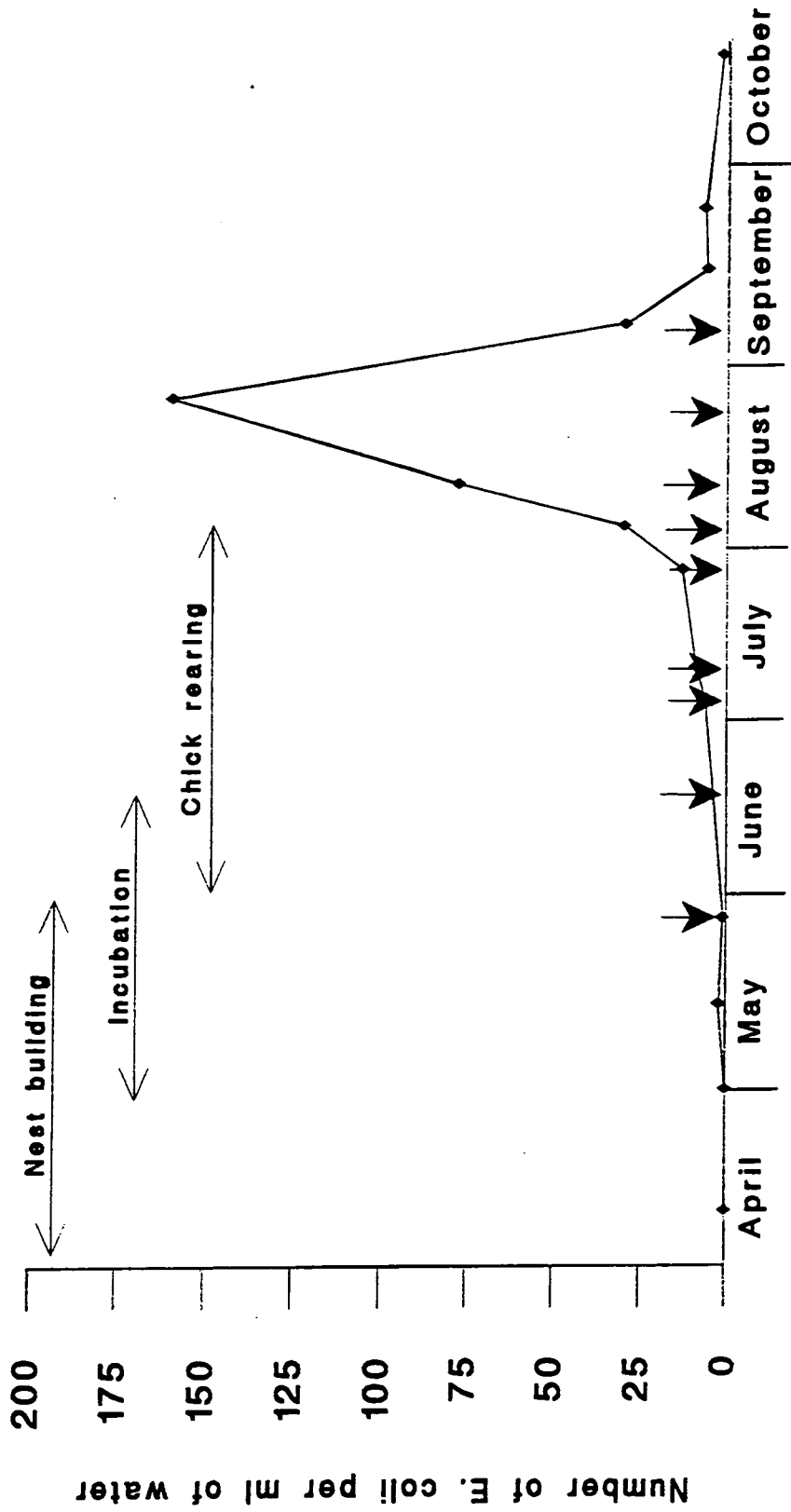


control site between 23 March and 7 July (n=6) was 0.01 per day. The rate of increase was not significant ($t=2.4$, 4 df, n.s.). At the gully water intake pipe, *E. coli* were recorded in all six samples and increased significantly during the sample period: 0.22 per day ($t=5.8$, 4 df, $p<0.01$). The difference between the rates of increase in the number *E.coli* in samples from the control and study site is significant ($t=5.5$, 10 df, $p<0.01$). The densities of bacteria recorded at the water intake pipe from May onwards would be considered as "unacceptably high" if recorded in routine water sampling by the water authority, and would lead to more frequent sampling at the intake pipe and supply reservoir, and to increased chlorination of the water supply (D. Taylor, personal communication).

From mid-May onwards, *Salmonella* positive results were obtained from the gully water intake pipe (3 samples). No *Salmonella* positive results were obtained from the control stream. The *Salmonella* isolates were recorded only for the higher levels of *E. coli* contamination, suggesting a positive relationship between the faecal indicator organism and the presence of the intestinal pathogen (David Taylor, NWWA, personal communication). The increasing levels of *E. coli* in water from the gully area during the later phases of the breeding season are a clear indication of the presence of pathogenic bacteria in the gully streams.

Figure 7 shows a comparison of the results of the 1976 NWWA investigations of water quality at the gully, and the 1993 analysis of water from the water intake pipe, in relation to the timing of breeding events within the colony. In both years, increases in the density of *E. coli* were coincident with the chick rearing in the colony. During this period, the presence of chicks increases the number of birds in the gully by 50%. Unlike adults, the chicks defecate only in the gully area and as rainfall is still frequent throughout the chick rearing period and pathogenic bacteria can remain viable outside their vector species for a considerable time, there is a heightened risk of faecal contaminants being flushed off the fell and into the water courses at this time of the season.

Figure 8. Number of *E. coli* per ml of water in samples taken from the Tarnbrook Fell Gullery water intake pipe: March-October 1976. Arrows indicate the presence of *Salmonella* in water sample. Data from Jones et al. (1976)

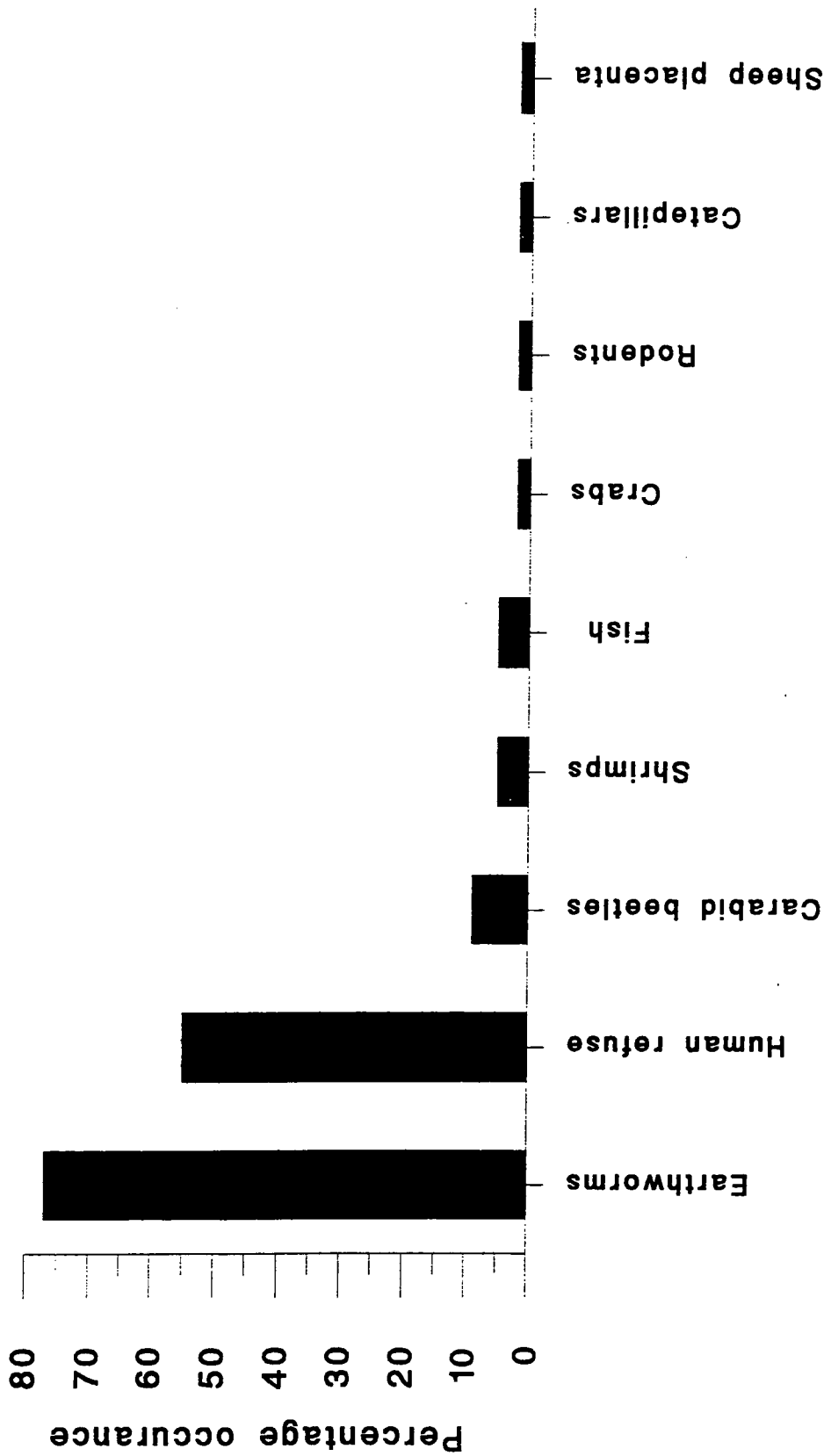


Salmonella positive results were recorded in both studies between mid-May and July. This period is when peak egg laying and chick rearing occurs in the gullery. Some caution must be exercised in making year to year comparisons however, because rainfall patterns affect the numbers of bacteria flushed into the water courses and rainfall can vary greatly between years. Indeed, in 1976, Britain was suffering a period of prolonged drought, whereas 1993 was a typically wet year. Figure 8 shows the results of the complete 1976 *E. coli* sampling programme which lasted from March until October. A peak in the number of *E. coli* in the gullery water occurred late in the gulls breeding season and reduced rapidly to pre-season levels as the gulls departed from the colony.

The results of this study have shown that the gulls breeding at Tarnbrook continue to cause faecal contamination of the raw water supply during the breeding season despite a 70% reduction in breeding numbers during the culling period 1978-1988. Monaghan *et al.* (1985) found that 10% of the adult Herring Gulls on the Clyde were carrying *Salmonella* and swabs taken from chicks at Tarnbrook in 1976 suggest that chicks are vectors of pathogenic bacteria too. During July, there are approximately 27,000 adults and chicks present in the Tarnbrook Fell Gullery. The proportion of Lesser Black-backed Gulls carrying these bacteria has not been studied and may be different to Herring Gulls because of their different feeding ecology (Straank and Vader 1992). If 10% of the Tarnbrook Fell birds were *Salmonella* carriers at any one time, then nearly 3,000 birds would be potential vectors of pathogenic bacteria. Jones *et al.* (1978) examined gull droppings at the Tarnbrook Fell Gullery during May and June and found that just over 60% were *Salmonella* positive. At this level of infection, more than 16,000 gulls would be carriers. It is known from food sampling that gulls at Tarnbrook utilise waste disposal sites for foraging and are thus potentially exposed to bacterial contamination. They will also almost certainly feed at the sewage outfalls that enter Morecombe Bay from centres of urbanisation. Analysis of regurgitated food material from chicks of various ages were made in 1993. Out of 80 regurgitates examined, 57%

contained items obtained from human refuse sites (Figure 9). The number of bacteria-carrying gulls within the gullery is

Figure 9. Percentage occurrence of food items in Gull chick regurgitates taken at the Tarnbrook Fell Gullery 1993 (n=80).



therefore, potentially high and this will remain the case while gulls breed on the catchment area of the streams feeding the water intake pipe. One of the major problems with past gull management attempts, is that they successfully reduced nest densities but failed to entirely clear gulls from these specific problem areas.

2.7.4. Discussion:

Any bacteriologically positive result obtained from a potable water supply is deemed unacceptable by the responsible water authority. When faecal contamination is recorded in routine water samples, an immediate attempt is made to rectify the problem by increasing the amounts of chlorine added to the water supply. The frequency of sampling is also increased, to monitor the situation. Ironically, chlorination often results in an increase in complaints about water 'quality' from members of the public (D. Taylor, personal communication). In government guidelines on the provision of national water supplies, the NWWA is mandated to "protect the public from all potential sources of pathogenic infection and reliance should not be placed on a single line of defence" (Welsh Office 1967). This last phrase was interpreted by Jones *et al.* (1978) as meaning that the ability to chlorinate the raw water should be seen only as the 'second' line of defence and that the first line of defence was prevention rather than cure. The only way to satisfy this requirement was by reducing both the extent of the gullery and the number of birds within it. It was this recommendation that initiated the large scale culls that occurred in the gullery 1978-1988. Despite the reduction in the number of gulls at the colony resulting from the culls, the current number of breeding gulls are still having an effect on water quality. As the season progresses, the levels of chlorination are increased to counteract the increased concentrations of pathogenic bacteria that occur. An alternative strategy would be to shut off the gullery water intake pipe during the 'sensitive' period (when the gulls are rearing their chicks in June and

July), and opening it again only when demand or water quality were sufficiently high to warrant it, would reduce the need to chlorinate the water supply.

Attempts to reduce the number of gulls at Tarnbrook Fell between 1978-1988 resulted in the culling of some 75,000 gulls at the colony but achieved a reduction in breeding numbers of only 23,000 gulls (Chapter 5). Within the catchment area of streams that feed the water intake pipe, the density of breeding gulls was reduced by the culls but complete removal was not achieved. The culls were originally licensed by MAFF so that the potential threat to human health by faecal contamination of water supplies could be removed. Reducing the density of breeding gulls does not therefore seem to have satisfactorily achieved the aims of the cull. In order to achieve a significant reduction in faecal contamination, gulls from the areas west and north of the water intake (Figure 5) must be completely cleared of breeding gulls and display groups or 'clubs'. Complete clearance of breeding gulls from the water catchment, coupled with pipe closure during chick rearing would remove any potential health hazards posed by the presence of the gullery. New gull management methods designed to completely remove gulls from the catchment area of the water intake pipe are described in the next chapter of this thesis.

2.8. Effects on birds other than Red Grouse

The effects of the presence of gulls on the 'natural' avifauna of the area are difficult to quantify as there are no detailed records prior to the existence of the gullery. Thirteen bird species² presently breed on moorland areas within the forest of Bowland and on fells adjacent to the gullery. Of these, only three regularly breed within the 6km² of the gullery (Curlew, Meadow Pipit, Wheatear). Suitable breeding habitats for the remaining

²Teal *Anas crecca*, Hen Harrier *Circus cyaneus*, Peregrine *Falco peregrinus*, Merlin *Falco columbarius*, Golden Plover *Pluvialis apricaria*, Dunlin *Calidris alpina*, Snipe *Galinago galinago*, Curlew *Numenius arquata*, Short-eared Owl *Asio flammeus*, Wheatear *Oenanthe oenanthe*, Meadow Pipit *Anthus pratensis*, Dipper *Cinclus cinclus* Ring Ouzel *Turdus torquatus*.

ten species exist within the gullery area, but are not utilised. In 1992 two incidents of Golden Plover and a Merlin being mobbed by gulls were witnessed in the gullery. In 1994 a Hen Harrier and two Peregrines were mobbed by gulls on separate occasions as they flew into the gullery area. If gulls are excluding other bird species from breeding on the gullery area it remains open to debate whether this constitutes a 'problem', as the number of individuals that could potentially breed on the gullery site, in the absence of the gulls, is unlikely to make a significant difference to their local or national populations. Brown (1993) for instance, estimated that Golden Plover breed on the fells surrounding the gullery at a density of about 2.2 pairs per km² and so only 14 or 15 pairs would normally be expected to breed within an area the size of the gullery.

2.9. Effects of gulls on moorland flora

The detrimental effects of gulls on the local vegetation cover is of great concern to the owners of the three estates on which the gullery is situated. The presence of heather is vital to successful grouse management as adult grouse feed almost exclusively on the tips of heather plants for much of the year. At Tarnbrook Fell gullery, the keepers claim that the gulls are reducing the extent of heather areas by pulling it up during displays and for nest building. There is also concern that gull faeces are detrimental to heather growth and causes the dominance of grasses. As grouse do not usually utilise grasses for food or nest sites, the keepers believe that the gulls are having an indirect effect on the numbers of breeding grouse. Despite these concerns, no specific investigation of the effect has been made, and evidence for it remains anecdotal and speculative. The vegetation changes that have been documented for the site (Duncan 1978) could equally have been caused by sheep over-grazing (Anderson and Yalden 1981), as evidenced by the fact that many other areas of Bowland have been similarly changed in the absence of gulls.

2.10. Food availability and predator control at Tarnbrook Fell

There has been much discussion on the factors that might regulate seabird numbers. Despite problems in studying a breeding group whose regulation is not already affected by humans in some fashion, most authors have agreed that seabird regulation occurs in a predominantly density-dependent way, and that food availability and predation play important roles (Croxall and Rothery 1991). Several species of gulls have attained 'superabundant' numbers (see earlier for definition) in the 20th century, and this is likely to have occurred by changes in 'natural' regulation mechanisms as a result of human activities (Blokpoel 1991). It is of course difficult to actually quantify the effects of human activities on seabird numbers. Some authors have attempted to do this by making direct comparisons of breeding parameters in colonies where, for example, anthropogenic food resources are utilised with those where they are not (Murphy *et al.* 1984; Pons 1992). Others have looked at changes in numbers at colonies influenced by humans and compared them with demographic models of theoretical growth patterns (Croxall 1992). This last approach will be described for the Tarnbrook Fell Gullery in Chapter 5. Here, I shall simply describe the human activities in the areas surrounding the Tarnbrook Fell Gullery that might have affected the number of breeding gulls at the colony:

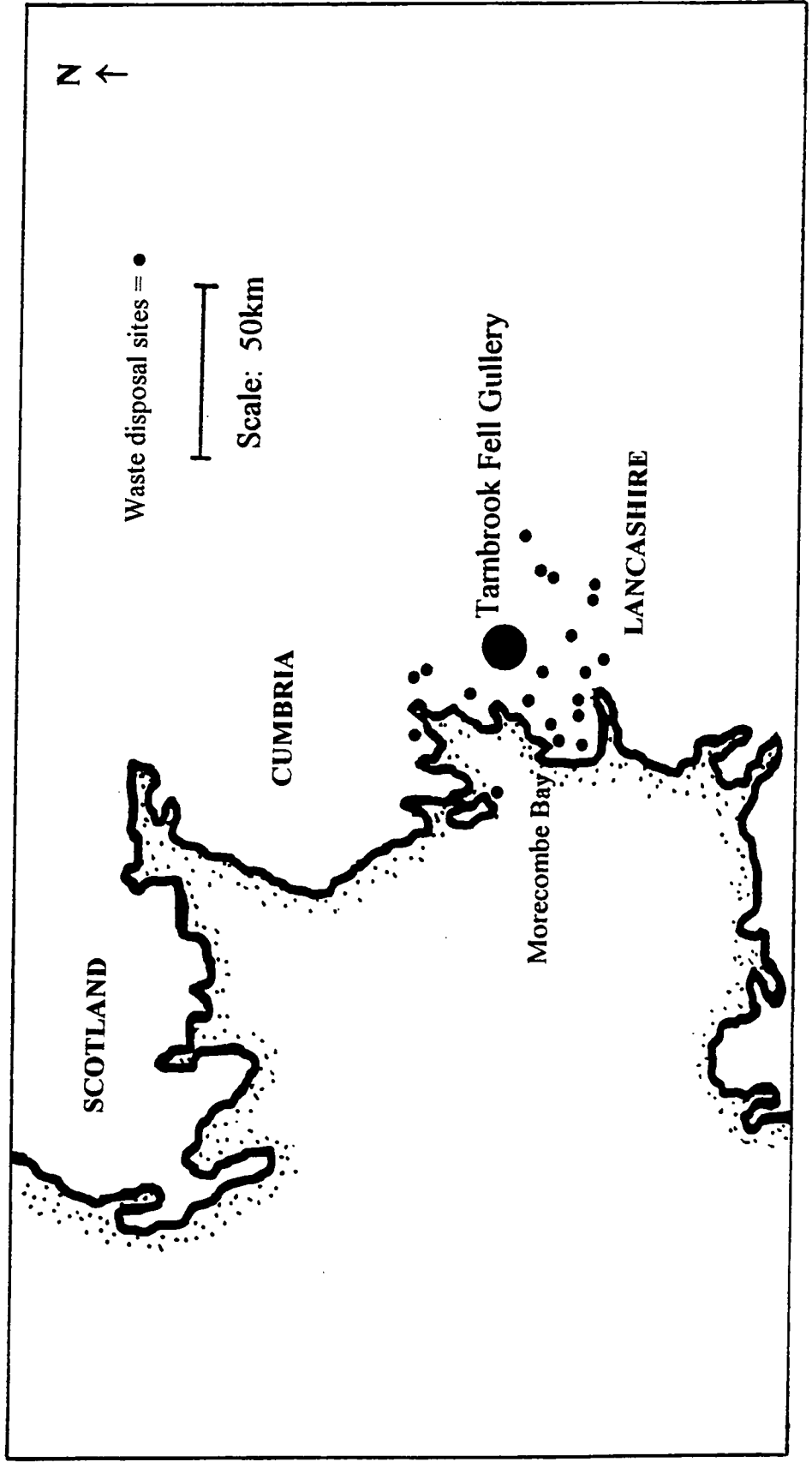
(i). Anthropogenic food sources.

Much of the research on the role of food availability as a factor influencing seabird numbers has largely been correlative or inferential. Many authors have demonstrated correlations between changes in seabird population parameters and changes in the quantities of marine prey stocks (Crawford and Shelton 1978; Monaghan and Zonfrillo 1986; Duffy and Siegfried 1987; Montevecchi *et al.* 1988). Two problems exist with this approach. Firstly, the correlations will often refer more to what is available to fishing vessels rather than to what is available to seabirds. Secondly, as pointed out by Croxall (1991), the relationships are often only detectable at extreme levels i.e. when the prey resources are at very high or low levels.

There has also been much discussion on when food availability might have its largest influences on seabird numbers. Ashmole (1963, 1971) argued that intra-specific competition for local resources during the breeding season, when foraging distances were constrained by the need to provision chicks, was a major influence on numbers. This gave rise to his idea of a food depletion 'halo' around breeding colonies. Birt *et al.* (1987) made the first attempt to demonstrate the existence of such a halo by measuring flatfish numbers by under-water SCUBA transects, around a colony of Double Crested Cormorants *Phalacrocorax auritus*. They found a significant relationship between distance from the colony and the density of flatfish. Unfortunately their work is not conclusive, because no attempt was made to measure the situation before the start of the breeding season. Lack (1954, 1966) argued the opposite case to Ashmole, asserting that it is shortages of prey in winter, rather than summer, that regulate seabird numbers. Various attempts have been made to throw light on these arguments by looking at the 'energetic' requirements of seabird species at different times of the year, and matching these to productivity models for the oceans (although Croxall 1987 urges caution when drawing inferences from this sort of work because of doubts over the nature of the assumptions required in some of the analysis). Some authors have been able to demonstrate the so called 'hungry horde effect', whereby colonies of different sizes (and therefore at-sea foraging densities) show differences in reproductive performance parameters (Gaston *et al.* 1983; Furness and Birkhead 1984, Furness and Barrett 1985; Hunt *et al.* 1986). In general therefore, there do appear to be reasonable indications that food availability affects reproductive success, is correlated with population size, and the mechanism of regulation is probably based on intra-specific competition during the breeding season (although more data are needed for other times of the year). It is therefore probable that increases in food availability from anthropogenic sources in the areas surrounding the Tarnbrook Fell Gullery have contributed significantly to the success of the colony.

There are over 18,000 breeding gulls at the Tarnbrook Fell Gullery (1994), and during the breeding season, when most pairs have one to three chicks to feed, large amounts of food will be consumed by this number of birds. A characteristic feature of the feeding ecology of Lesser Black-backed Gulls, is the enormous variety of food items they are capable of exploiting and it is known from analysis of food samples (see earlier) that birds from Tarnbrook utilise the anthropogenic food sources found at waste disposal sites. They also utilise invertebrates on agricultural fields surrounding the colony. Lesser Black-backed Gulls, radio-tracked from the Walney Island Gullery (40km west of Tarnbrook), regularly foraged for food over twenty miles from the colony (Sibly and McCleery 1983). Figure 10 shows waste disposal sites in Lancashire that are within foraging range for birds at the Tarnbrook Fell Gullery, where putrescible waste is tipped. Food at waste disposal sites is a 'predictable' resource in terms of the time and place that the gulls can find it. This reduces time spent searching for suitable food sources, and so allows chicks to be provisioned at a faster rate (Hunt and McCloon 1975; Pierotti 1991). In addition to food from waste sites, gulls at Tarnbrook Fell have the large area of Morecombe Bay as a potential source of food, as well as thousands of hectares of agricultural land within a short distance of the colony. Indeed, the commonest items of food fed to chicks at Tarnbrook are earthworms which are found in great abundance in these fields. Gulls can be seen feeding on these areas just after dawn or after silage cutting. At these times, worms are present at the surface in greater numbers and the ground is soft enough for the gulls to obtain them (Kruuk 1978). Fish items were not a major feature of the food given to chicks, despite the proximity of the Fleetwood fish quays and numerous trawlers that operate in Morecombe Bay (Sibly and McCleery 1983).

Figure 10. Waste disposal sites within foraging range of the gulls at Tarnbrook Fell Gullery, at which domestic waste is deposited (1994).



(ii). Predator control.

Whether seabird predators significantly affect their abundance can be difficult to demonstrate in some seabird species. Certainly introduced mammals such as Domestic Cats *Felis domesticus* and Rats *Rattus norvegicus* can very significantly reduce seabird numbers on isolated islands (Croxall *et al.* 1984; Moors 1985). But few empirical studies have been conducted where a 'natural' predator has been removed from an ecosystem and the demographic effects on its prey measured. The significance of a predator on seabird numbers will depend on the species involved and their colonial organisation, and even within a species will vary from colony to colony. That predation can be a strong selective force, is demonstrated by studies of small petrels who significantly reduce their attendance at breeding colonies on moonlit nights (Watanuki 1986). Also, the very reason that many seabirds nest on islands or precipitous cliffs, is probably at least in part due to predation pressures (Krebs 1985). Large gull species tend to breed on flatter, more open areas, suggesting that they may have few natural predators. The two species most likely to predate gulls at Tarnbrook Fell are Foxes *Vulpes vulpes* and Stoats *Mustela erminea*. Both these species will take bird eggs and chicks, and foxes will take adult gulls if they can catch them. Black-headed Gull colonies of less than 50 pairs can be seriously affected by such predation (Gribble 1976) and in Holland a significant reduction in numbers in several Common Gull colonies was coincident with the colonisation of the area by foxes (Corsters 1992; Wousteron 1992). Both Fox and Stoat numbers are controlled by game-keepers at the Tarnbrook Fell in order to ameliorate their predation on grouse stocks and ironically this may have had the secondary effect of being a contributory factor to the success of the gulls.

The precise role of anthropogenic food resources and predator control in the population regulation mechanisms of the gulls at Tarnbrook Fell is impossible to quantify at present. There appears to be a strong case that human influences have significantly changed the natural population dynamics of several gull species this century, at both a local and national level. In the case of waste disposal material and fishing offal, it is possible that current practises will be changed in the long-term (although gull problems

are unlikely to be the driving force behind the changes). Unfortunately, most site owners expect quick solutions to their gull problems and are sceptical of programmes that work on longer time scales.

2.11. Attempts to ameliorate the gull problem at Tarnbrook Fell 1938-1991

Attempts have been made at various times in the history of the Tarnbrook Fell Gullery to reduce the number of gulls, either by killing adults or preventing eggs from hatching. A detailed analysis and of the results of these methods on the population dynamics of the colony is presented later in this thesis (Chapter 5). Only an overview of the methods of gull control that have been employed at Tarnbrook in the past shall be presented here and suggestions made for the development of new management techniques.

(i). Culling of adults

No immediate attempts at controlling gulls were made when breeding at the site first began in 1938. Between then and the 1970's control in the form of shooting and nest destruction took place, but on a purely *ad hoc* basis. The first concerted effort to reduce the number of gulls in the colony was initiated in 1978 when a licence was granted by MAFF to kill gulls using the narcotic α -chloralose (see earlier). Between 1978 and 1988, approximately 75,000 gulls were culled in this fashion. A further 15,000 birds are estimated to have been shot in the gullery prior to this. A total of 90,000 gulls were therefore removed from the breeding population over a 50 year period. The initial small-scale shooting of adults at the gullery had negligible effects on the population, which continued to grow until numbers peaked in 1979. The culls of 1978 to 1988 reduced the number of breeding gulls at the colony by 70% but only achieved a reduction in overall nest density without a reduction in the physical extent of the gullery. Gulls were therefore still breeding on catchment areas for the stream that feeds the water

intake pipe and still potentially affecting grouse over the same area as before the culls. A similar cull of Herring Gulls on the Isle of May in Scotland, between 1972 and 1981, reduced the population by about 75% but similarly, the total area over which the surviving gulls were breeding remained the same as before the cull. Coulson *et al.* (1982) measured breeding parameters before and after the culls and found that three main changes had occurred:

- (i). there was reduction by one year in the age of first time breeding,
- (ii). there was an increase in the proportion of birds showing natal philopatry,
- (iii). body weight and wing length increased in remaining birds,

These changes occurred as a result of the amelioration of density-dependent effects i.e. at higher, pre-cull densities, only older and more experienced birds were able to acquire and maintain a breeding position within the colony. When large numbers of these birds were removed, other gulls, which previously made up a non-breeding part of the colony, were able to achieve breeding status. As well as an increase in natal philopatry, immigrant recruits find it easier to establish themselves in such 'thinned-out' colonies and hence the 'attractiveness' of the colony is enhanced (Duncan 1978). In other words there are compensatory effects in the breeding biology and population dynamics of surviving gulls that reduce the overall effectiveness of the culls. No similar pre- and post-cull data exist for the Tarnbrook Fell Gullery, but it is likely that similar changes in post-cull breeding parameters have taken place there too. Extensive culling is no longer licensed at Tarnbrook Fell, and if changes in post-cull breeding parameters have occurred there is the potential for renewed increases in the number of breeding birds at the gullery given that no areas were entirely cleared of gulls during the culling period. Complete clearance of gulls from an area using the narcotic α -chloralose has never been achieved at any of the sites where it has been used as a control method. As long as there are a few tenacious birds that survive and return to breed in an area, culling will have to take place in successive years in order to keep the numbers of gulls to the required lower levels.

(ii). Puncturing of eggs

When the licence to use α -chloralose was withdrawn in 1989, one of the shooting estates on which part of the gullery lies (Abbeystead) looked for a new form of gull management. In 1991, a programme of egg pricking was introduced and this has been continued annually up to 1994. Eight people are employed for six weeks during the egg-laying period (May to mid-June), and puncture eggs using a sharpened nail on a stick. In 1992-1994, a study was made of breeding success in areas where egg pricking took place and in areas where it did not, to evaluate the method as a management tool for reducing the number of breeding gulls at the gullery (a complete analysis of the results of this study is presented in Chapter 5). Five major problems arise from this approach to gull control:

(a). Lesser Black-backed Gulls have 3-7 years of immaturity prior to recruiting into a breeding group. Coulson (1991) estimated that between 30% and 40% of the surviving chicks born at a colony will be philopatric and return to breed there with the remaining gulls recruiting at other colonies. It has been shown that in many seabirds, including gulls, immature birds 'prospect' in a number of colonies prior to recruitment, and that the prospecting has the function of assessing the colony as a 'suitable' breeding site (Allan 1962; Scott 1970; Chabrzyk and Coulson 1976; Danchin and Monnat 1992). In the case of colonies where egg pricking has occurred, potential recruits, prospecting the area in the year prior to breeding, will see adult birds incubating pricked eggs. The presence of incubating adults may be one of the many factors affecting the choice of colony at which prospecting immatures ultimately recruit (Danchin and Monnat 1992). If this is the case, egg pricking will not discourage recruitment at the colony.

(b). Egg pricking does not produce an 'immediate' effect. This is because gulls take at least four years to reach sexual and social maturity. This means that the chicks that would have arisen from eggs at the colony (had they not been punctured) would not return to breed at the colony for at least four years. This, in turn, necessitates that egg

pricking is carried out annually for a number of seasons before any changes in breeding numbers are seen.

(c) Changes in the numbers of a k-selected species, such as the Lesser Black-backed Gull, are more sensitive to changes in adult survivorship than chick mortality (Croxall 1991). Gulls have high adult survival rates, and the pairs at a colony need to produce relatively few chicks in their lifetime to maintain numbers in the breeding group. This is analysed in more detail in Chapter 5.

(d). As already mentioned, only a proportion of the chicks fledged from a colony will return to breed there, while others will recruit at other colonies. The interchange of individuals between colonies due to this bi-modality of breeding behaviour limits the ability of egg pricking to reduce gull numbers because many of the recruits at a colony are immigrant birds.

(e). Egg pricking at Tarnbrook Fell takes place on only 30% of the total area of the colony which contains only 33% of the total number of breeding birds. This is because only the Abbeystead Estate pays for an egg pricking team and in the remainder of the gullery no eggs are pricked, (although some shooting of adults takes place).

Furthermore, the spread of egg laying dates and the topography of the gullery mean that a proportion of the eggs on the Abbeystead estate are missed, despite the efforts of the egg pricking team. This is quantified in Chapter 5.

(iii). New management techniques at Tarnbrook:

When culling began at Tarnbrook Fell in 1978, little was known of the demographic effects of culling large numbers of gulls. There is now a better understanding of the problems involved and it has become apparent that merely increasing the control effort, but using the same methods, will not resolve gull problems. Past control strategies have met with limited success because no account has been taken of the under-lying demographic processes that govern the size of the problem group. A licence for

extensive culling at Tarnbrook no longer exists and current management strategies have proved to have limited effect. New methods of gull management were investigated at the colony between 1992 and 1994 and are presented in the next chapter.

CHAPTER 3

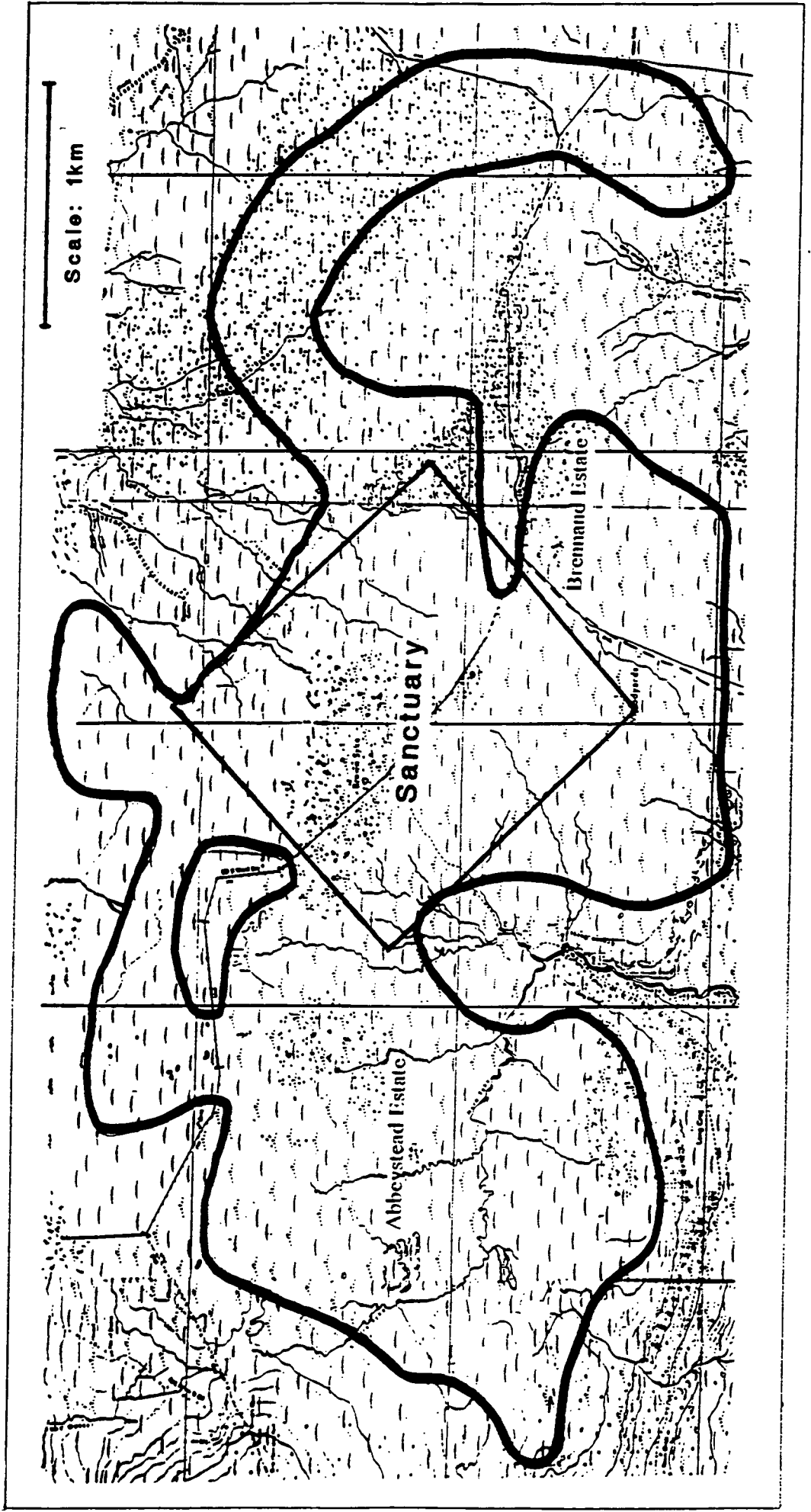
A NEW APPROACH TO GULL MANAGEMENT AT THE TARNBROOK FELL GULLERY

3.1. Introduction

In the absence of existing control measures that were able to ameliorate the gull problems at Tarnbrook Fell, a series of experiments were conducted on the Abbeystead Estate during the 1992-94 breeding seasons, to evaluate new management methods designed to entirely clear specific areas of the colony by the disturbance of breeding gulls. The experiments were limited by the area of moorland it was possible for one person to effectively monitor and were based on the following rationale:

- (i). gulls at the edge of the colony are easier to displace from breeding areas than birds in the centre of the colony.
- (ii). complete clearance of gulls from selected areas is essential. Birds remaining in an area stimulate other gulls to breed on that site.
- (iii). disturbance using several methods at one time is more effective than single tool methods i.e. the concept of a 'cocktail' of disturbance.
- (iv). an area of the colony should remain undisturbed to act as a 'sink' for displaced gulls and to act as a control for the disturbance experiments. To facilitate this, a 'Sanctuary' area was established in 1990. The Sanctuary covers 1.6 km² of the gullery on the Abbeystead and Mallowdale Estates (Figure 11), and gulls are free to breed in this area without disturbance, egg pricking or shooting.

Figure 11. Sanctuary area of the Tarnbrook Fell Gullery (1992 Gullery boundary shown).



3.2. Aims of the management experiments.

There were two broad aims of the management experiments. These were to investigate:

- **How** to disturb the gulls - to discover the relative efficacy of a variety of disturbance tools and regimes.
- **When** to disturb the gulls - at what stage of the breeding season are the gulls most sensitive to disturbance.

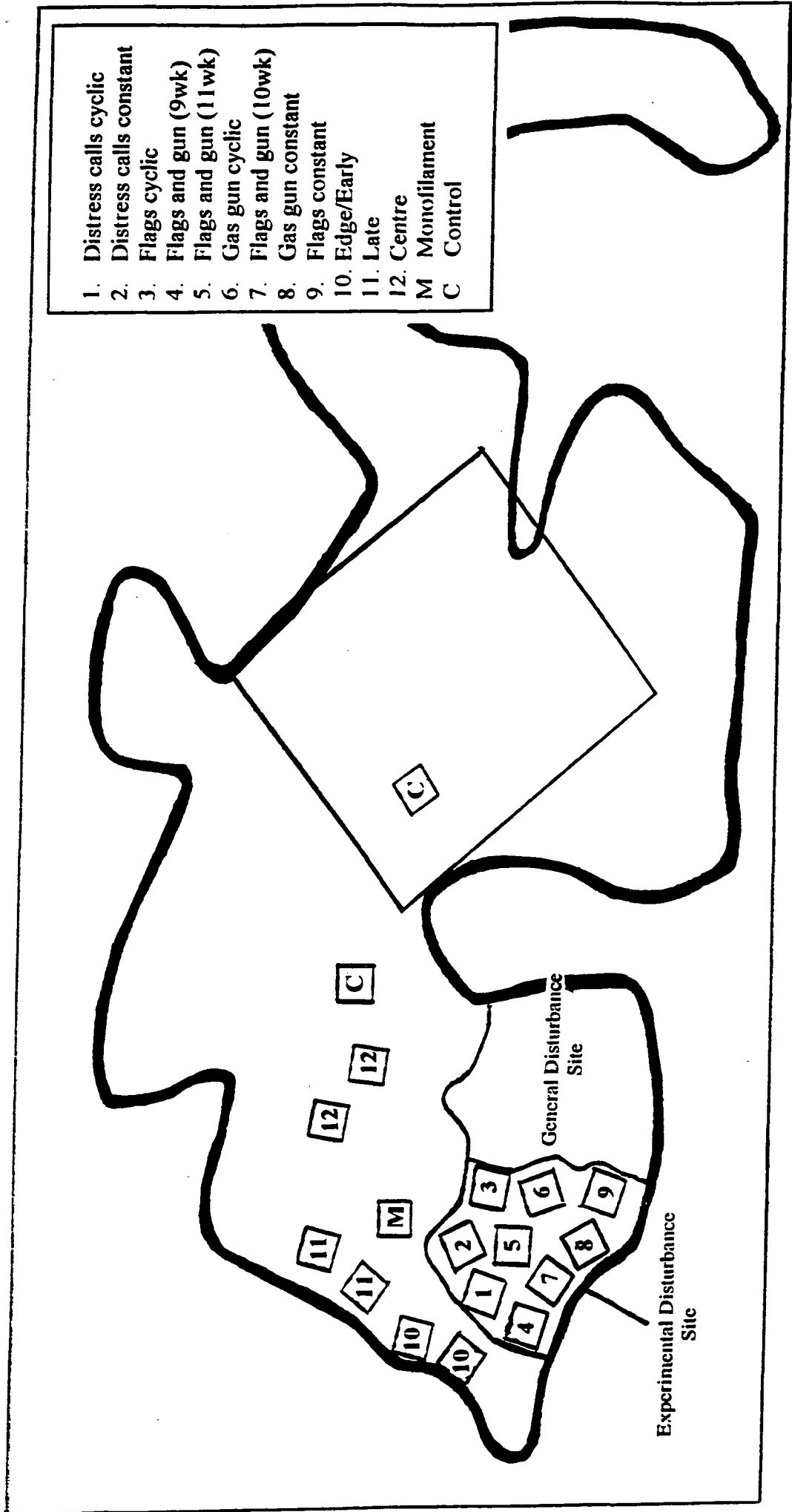
3.3. Methods.

3.3.1. Investigation of how to disturb the gulls.

Disturbance areas: The two areas used for the experiments to evaluate the relative efficacy of different disturbance tools in 1993 are shown in Figure 12. On one (the experimental site), nine experimental plots were established on which the disturbance experiments were conducted (described below). On the other (the general disturbance site), individual disturbance plots were not used. Instead, the whole area was disturbed using a single method (section 3.3.4.). The experimental site covered 30 ha, and the general disturbance site 45 ha. In 1994, the use of monofilament line to deter gulls from breeding was investigated. The area over which this disturbance took place was 0.25 ha.

Disturbance plots: Each of the disturbance plots on the experimental site were 2.25 ha in area. Where possible, topographical features such as small hillocks were used to separate the boundaries of the plots to prevent one disturbance experiment from effecting another. The distance between plots varied depending on the topographical features of each area. The position of the experimental plots and the distances between them are shown in Figure 12. The control plots (2.25 ha) for the experiments are also shown.

Figure 12. General disturbance area and experimental disturbance plots. Tarnbrook Fell Gullery 1993-94.



Disturbance tools: the relative efficacy of four disturbance tools were investigated. Specific details of the manufacturers specifications for these tools are given in Appendix 2. Disturbance was facilitated by the disturbance tools in two ways: firstly by interrupting breeding activities of birds on their territories i.e. the birds attention was focused on the source of the noise, when they would normally be engaged in breeding behaviour, and secondly by causing fear and preventing the birds from occupying their territory.

(i). Gas guns. These produced an explosive bang by the ignition of Propane gas. Gas was pressurised in a chamber and then released into a long resonance tube and ignited by a piezo-electric sparking mechanism. The guns were mounted on a swivel attachment so that the barrel pointed in a different direction each time the gas exploded. They could be set to go off at a variety of time intervals and the number of bangs (ranging from one to three) was changed with each successive ignition. The transmission of the sound from a gun was a function of the weather conditions during disturbance and varied depending on wind strength and direction, and was moderated by the presence of dense mist. Trials of the guns in 1992 where gulls reactions to the guns were observed from a distance, suggested that disturbance would be effective over an area of approximately 2.25 ha.

(ii). Distress calls. Gull distress calls played through a loud speaker, have been used to disturb gulls from a variety of sites where they have caused problems. This method has most notably been used at airports (CAA report 1990). The distress calls are recorded using captive gulls and transferred onto a high resolution magnetic tape cassette. Gulls have two sorts of calls when danger is encountered: (i) distress call, or (ii) alarm calls. The former have been shown to be more effective for scaring gulls (Blokpoel 1976) and are used by gulls when captured by a predator or attacked by other gulls. In contrast, alarm calls are given when a source of danger has been seen, but remains at a distance.

The distress calls were played on a personal stereo unit adapted to be used with a 12v car battery. The calls are first played through an amplifier and then sent to a loudspeaker. The tape recorder has auto-reverse, so that the tape is continuously played. All the units were placed in a box and waterproofed inside sheets of polythene. These kept the electrical components dry but allowed regular inspections of the equipment to be made.

(iii). Flags. White plastic flags (0.2 m²) tied to 2m bamboo canes. The flags were made from polythene 'carrier' bag material. This was light enough to be functional as a flag in moderately light wind conditions, and durable enough to resist long periods of exposure to bad weather. The material has the additional qualities of being vivid white and noisy when being wind blown.

(iv). Monofilament line. Monofilament line was used to cover a plot of 0.25 hectares. The lines were suspended from wooden posts 1m above the ground and spaced 60 cm apart. This spacing had previously been used successfully in excluding gulls from breeding sites (Blokpoel and Tessier 1983).

Disturbance regimes: the disturbance tools were used in a variety of regimes, detailed in Table 3. Repeated presentation of a stimulus to many animal species can result in a decline in the levels of response with time. This phenomenon is known as habituation and the removal of the stimulus for a period at least as long as the original application period, can lead to a recovery of the response to the stimulus when a new stimulus is re-applied (Brough 1968). In order to investigate whether stimulus removal could enhance the effects of gull disturbance at Tarnbrook Fell, the plots using only one disturbance tool at a time (flags, gas gun or distress calls) were disturbed in one of two ways:

(i) presentation of the stimulus on each day of the disturbance period. These were called the 'continuous' disturbance plots.

(ii) presentation of the stimulus for two days (the "on" cycle) and then removed for two days (the "off" cycle). These plots were called the 'cyclic' plots.

Areas between the experimental plots: whenever possible, groups of gulls attempting to land in the areas between the disturbance plots were disturbed by human presence. This happened infrequently and extra disturbance of the experimental plots caused by this activity, was kept to a minimum.

Timing of disturbance: the dates of the disturbance period on each of the experimental plots are given in Table 3. The timing of the experiments in relation to the timing of breeding events in the undisturbed areas of the colony are shown in Figure 13. In 1993, the disturbance started on 1 April and ended on 2 June. This constitutes 9 weeks of disturbance from approximately two weeks prior to the beginning of nest building up to when the eggs in 50% of nests had hatched in undisturbed areas of the colony. In 1994, the monofilament plot was disturbed for eight weeks, from 4 April to 1 June.

3.3.2. Investigations of when to disturb the gulls.

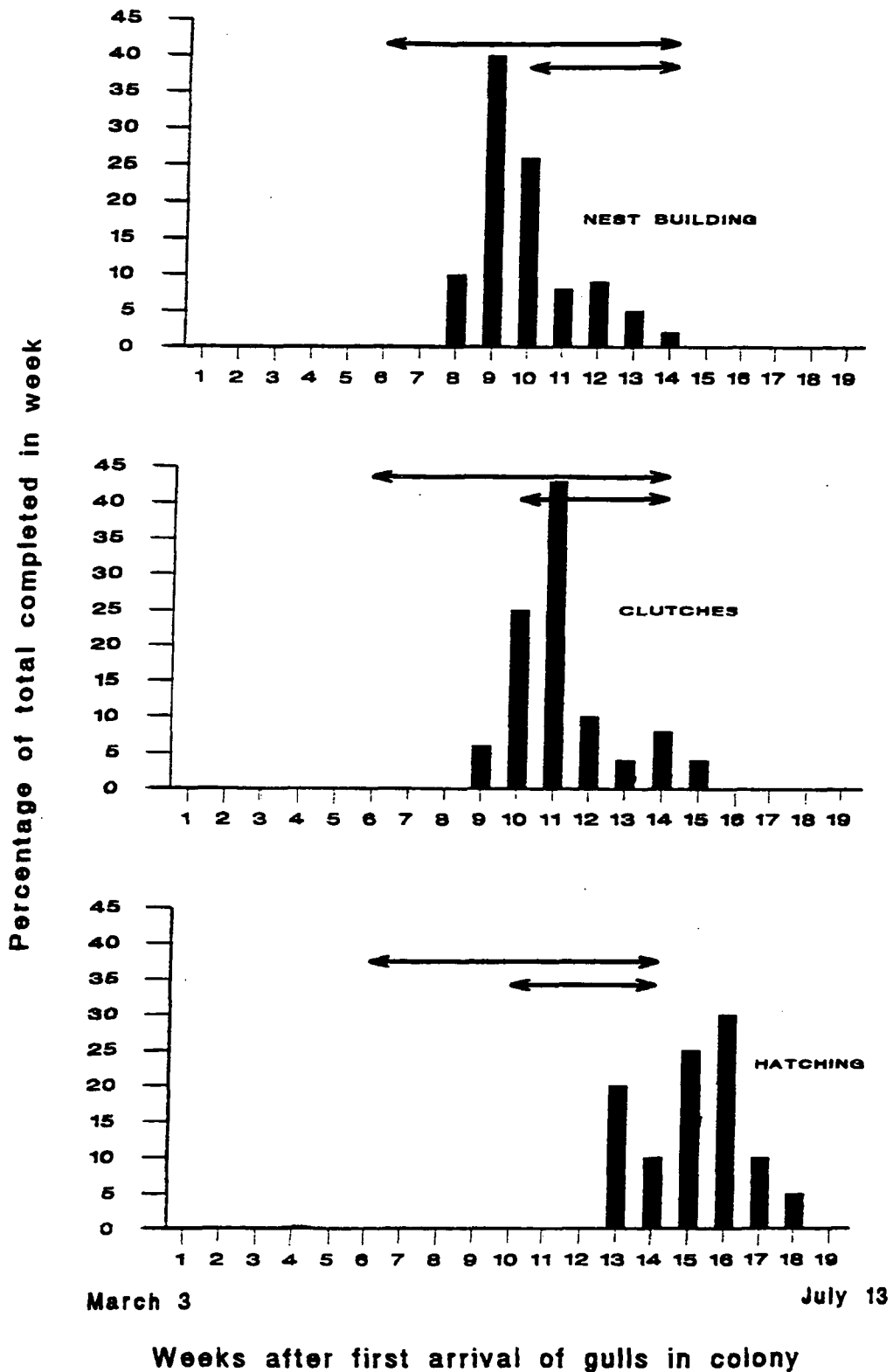
Longer disturbance periods: In 1993, in addition to investigating how to disturb the gulls, a study was made to determine if extending disturbance further into the hatching period would produce more effective clearance. Accordingly, three plots on which gas guns and flags were used simultaneously were disturbed for three different periods of time: 1 April-2 June (9 weeks), 1 April- 9 June (10 weeks), and 1 April-16 June (11 weeks).

Early and late disturbance: Preliminary disturbance trials made in 1992, suggested that disturbance of gulls once they have built nests or laid clutches would not be as

Table 3. Disturbance regimes used on the experimental plots 1993 and 1994 to clear gulls from specific areas of the Tarnbrook Fell Gully.

Plot Site	Disturbance Dates	Plot Size (hectares)	Disturbance Regime
Distress Calls (continuous)	April 1 - June 2 (1993)	2.25	<ul style="list-style-type: none"> • Distress calls played on each day throughout the disturbance period (one minute of calls in every 40 minutes)
Distress call (cyclic)	"	"	<ul style="list-style-type: none"> • As above, except that the calls were played for a two day "on" cycle alternating with a two day "off" cycle in which the calls were not played.
Gas Gun (continuous)	"	"	<ul style="list-style-type: none"> • One propane gas gun used throughout the disturbance period (one ignition every 40 minutes)
Gas Gun (cyclic)	"	"	<ul style="list-style-type: none"> • As above, except that the gas gun was used for a two day "on" cycle alternating with a two day "off" cycle in which the guns were removed.
Flags (continuous)	"	"	<ul style="list-style-type: none"> • 100 flags, each tied to equally spaced 2m bamboo canes continuously on the plot.
Flags (cyclic)	"	"	<ul style="list-style-type: none"> • As above, except the flags were removed from the plot for two day "off" cycles alternating with two day "on" cycles where the flags were put back onto the plot.
Flags with Gas Gun (3 plots)	April 1 - June 2 April 1 - June 9 April 1 - June 16	"	<ul style="list-style-type: none"> • Flags and gas gun used continuously on the same plot (see above). Three plots were used and disturbed for 9, 10 or 11 weeks.
Monofilament	April 4 - June 1 (1994)	0.5	<ul style="list-style-type: none"> • Parallel monofilament line suspended 1m above the plot from wooden posts. Each line 0.6m apart. Used continuously throughout the disturbance period.

Figure 13. Timing of disturbance periods on experimental plots 1993 and 1994 compared to timing of gull breeding events in undisturbed areas at Tarnbrook Fell. Disturbance period shown between arrows (short arrows='late' disturbance 1994).



effective as disturbance initiated earlier in the season, before these events have taken place. Four experimental plots were established in 1994 to test the relative efficacy of 'early' and 'late' disturbance (Figure 12). Two of the plots were disturbed from 4 April (prior to nest building), until 1 June (the end of egg laying in undisturbed areas). These were called the 'early' plots. On the other two plots (the 'late' plots), disturbance was not started until 29 April (by which time nest building had begun in the experimental plots and was 33 % completed in undisturbed areas of the colony), and ended at the same time as on the early plots (1 June). The timing of the disturbance in relation to breeding events in the rest of the colony are shown in Figure 13. Details of the disturbance regimes used on these plots are given in Table 4.

3.3.3. Disturbance at the edge and centre of the colony

To investigate whether disturbance at the edges of the colony is more effective than working in central areas, during the 1994 season, four 2.25 ha plots were disturbed using the same regime: two at the edge of the colony and two at the centre of the colony (Figure 12). Edge plots were sited on the colony boundary and had one side with no gulls breeding adjacent to them. The nearest point of the Centre plots were placed 0.3 km from the colony boundary, and were surrounded on all sides by breeding gulls. Disturbance took place from prior to nest building (4 April) until the end of egg laying in the un-disturbed areas of the colony (1 June) (Figure 13). The disturbance regimes used are given in Table 4.

3.3.4. The general disturbance site.

In addition to the experimental plots, a second area was disturbed in 1993. This area covered 45 ha (Figure 12) and was disturbed by human presence for a 14 week period (mid-March to the third week in June). The disturbance was not specifically experimental in nature, the aim was to achieve clearance of gulls over as wide an area as possible. Disturbance took place for two hours after sunrise and for two hours before

Table 4. Disturbance regimes on the 'edge', 'centre', 'early', and 'late' experimental plots 1994.

Plot site	Disturbance dates (1994)	Plot size (hectares)	Disturbance regime
Early	4 April - 1 June	2.25	<ul style="list-style-type: none"> • 100 evenly spaced canes with flags present throughout the disturbance period. • One gas gun used throughout the disturbance period (one ignition every 40 minutes). • Distress calls played for one day in every four (1 minute of calls in every 40 minutes). • Minimum of two human disturbance periods per day (c.30 minutes).
Late	29 April - 1 June	2.25	As above
Edge of colony	4 April - 1 June	2.25	As above
Centre of colony	4 April - 1 June	2.25	As above

sunset throughout the entire disturbance period. It was also disturbed for as many hours in addition to this as work on the other projects allowed. From mid-May onwards, an Abbeystead Estate worker disturbed the site from 0930-1630 in addition to the above disturbance. In total, 730 hours of human disturbance were carried out on this area. This represents approximately 55% of the total daylight hours during the period. The position of all nests found on the area during the disturbance period was recorded and the nests then destroyed.

3.3.5.. Evaluating the management experiments.

The effects of the different disturbance tools and regimes were evaluated in three ways:

(i). Their ability to keep gulls away from the plot during disturbance: daily counts of gulls were made on the experimental and control plots from two weeks prior to the start of disturbance until two weeks after it had stopped. The counts were made from the same position within the colony and taken within one hour after sunrise. The effect of disturbance on the daily numbers of gulls on the plots was evaluated by comparing observed number of birds with the 'expected' number of birds. The expected values were calculated by comparing counts on the experimental plots with counts on the control plots in the two weeks prior to disturbance. The assumption was made that the mean percentage difference between the two plots during this time period would have been maintained throughout the season had disturbance not taken place. The 'expected' values for the experimental plots were then calculated by adjusting counts of gulls on the control plot during the disturbance period, by the same mean percentage difference between the two plots that was obtained during the pre-disturbance period. The difference between the observed and the expected counts was then used as a measure of the effectiveness of the disturbance. This value, expressed as a percentage, was called the "disturbance effect" i.e. a disturbance effect of 100% meant that there were no gulls present on the plot. The original assumption was tested by counting two control areas

on which no disturbance occurred. Expected count values for the plots could then be calculated as described above, and the mean of these values compared to the mean of the actual counts. If there was no significant difference, the assumption was a valid one.

(ii). Their ability to totally prevent breeding or reduce the number of nests built and clutches laid: The experimental and control plots were surveyed for nests and eggs immediately after the cessation of disturbance (see above for dates). During the surveys, each nest was marked with a cane. A second survey was conducted two weeks later to assess if any new breeding attempts had occurred after the end of the disturbance period. All nests and clutches were removed during the second survey.

The observed number of nests and clutches on the experimental plots were compared to the 'expected' values. These were obtained by assuming that the observed number of birds on the experimental plots would have produced a proportionate number of nests and clutches to those that were produced by the observed number of birds on the control plots. As with the expected values for the daily counts of birds on the plots, the validity of the method was tested using the control plots in 1994. By comparing the observed and expected number of nests and clutches on the experimental plots, a measure of the effectiveness of the disturbance tool was obtained.

(iii). Their longer term effects: preventing breeding on the disturbed site in subsequent seasons. During the 1994 season, the 1993 disturbance site was monitored for the presence of birds and for evidence of breeding. Whenever possible, the entire area was observed during daylight hours from the beginning of March to the end of June. Gulls landing or attempting to land on the site were mapped and counted. These gulls were not permitted to stay on the area and were removed by human disturbance. No mechanical disturbance method was used on this site in 1994, but a 'barrier' of flags

was constructed around the entire area (five flag rows, each flag 10m apart) to deter re-invasion from surrounding areas of the colony.

3.3.6. Data analysis.

Means for count data are presented in geometric form with 95% confidence limits after an appropriate transformation. Prior to regression analysis, data were tested for linearity and normality. Chi-square tests with one degree of freedom had Yates' correction applied.

3.4. Results.

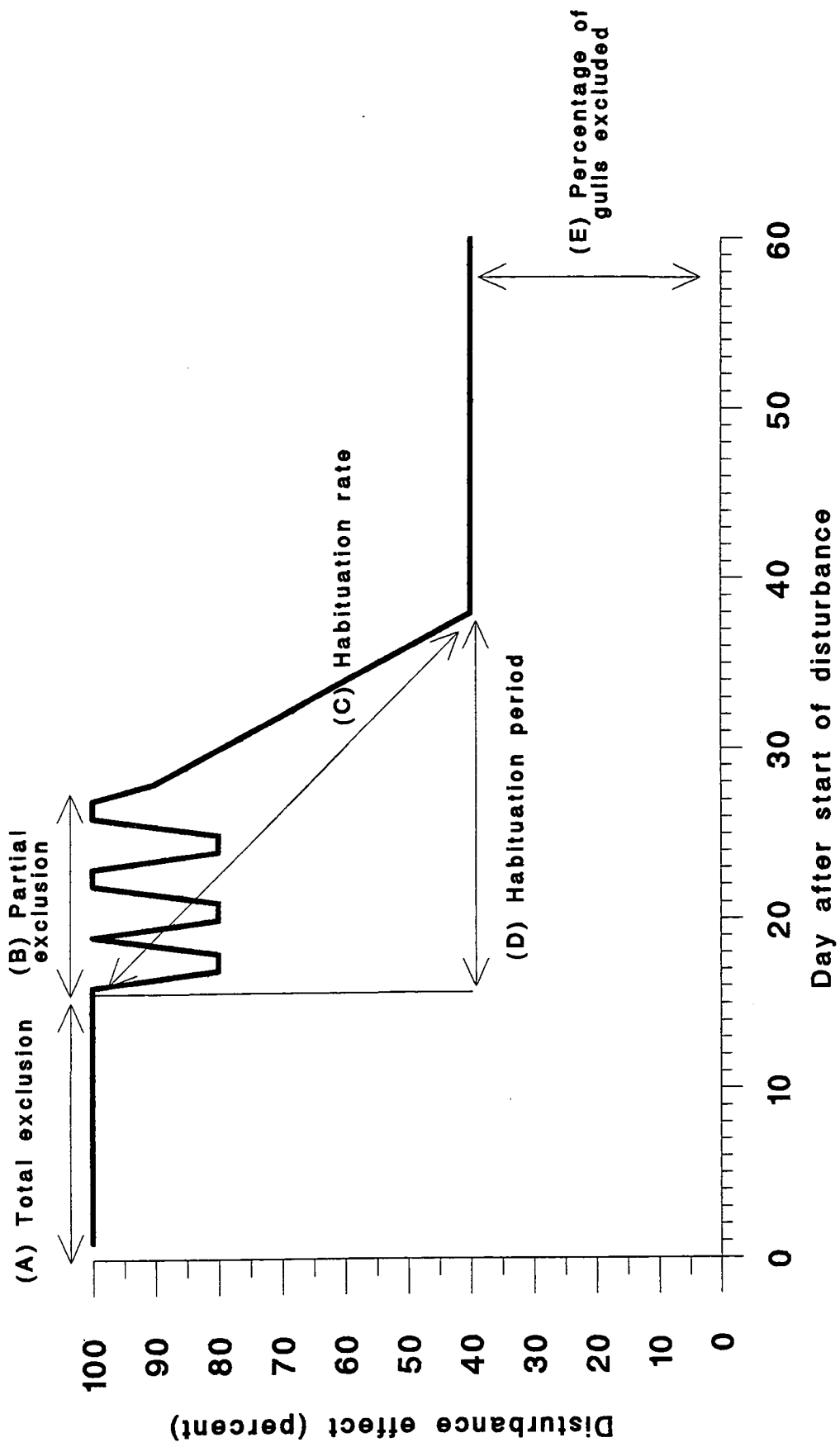
3.4.1. The behaviour of the gulls during the disturbance period.

After an initial phase during which disturbance achieved total exclusion of the birds from the experimental plots, a proportion of the gulls habituated to the disturbance and re-occupied the area. The proportion of gulls returning, the timing and number of days over which they returned, and the rate at which they returned, varied from plot to plot. However, a general pattern to the re-occupation was seen on all the plots and is shown in Figure 14. Five elements to the re-occupation pattern were identified and used to evaluate the relative effects of each disturbance method:

(A). Total exclusion period: the period during which no gulls were present on the plot and when the disturbance effect was therefore 100%.

(B). Partial exclusion period: the period in which some birds had returned to the plot but complete exclusion was achieved intermittently i.e. habituation had started, but the disturbance effect was 100% on some occasions.

Figure 14. Diagrammatic representation of the re-occupation phases of the experimental disturbance plots 1993 and 1994 by Lesser Black-backed Gulls, and the elements used to evaluate the efficacy of each disturbance method.



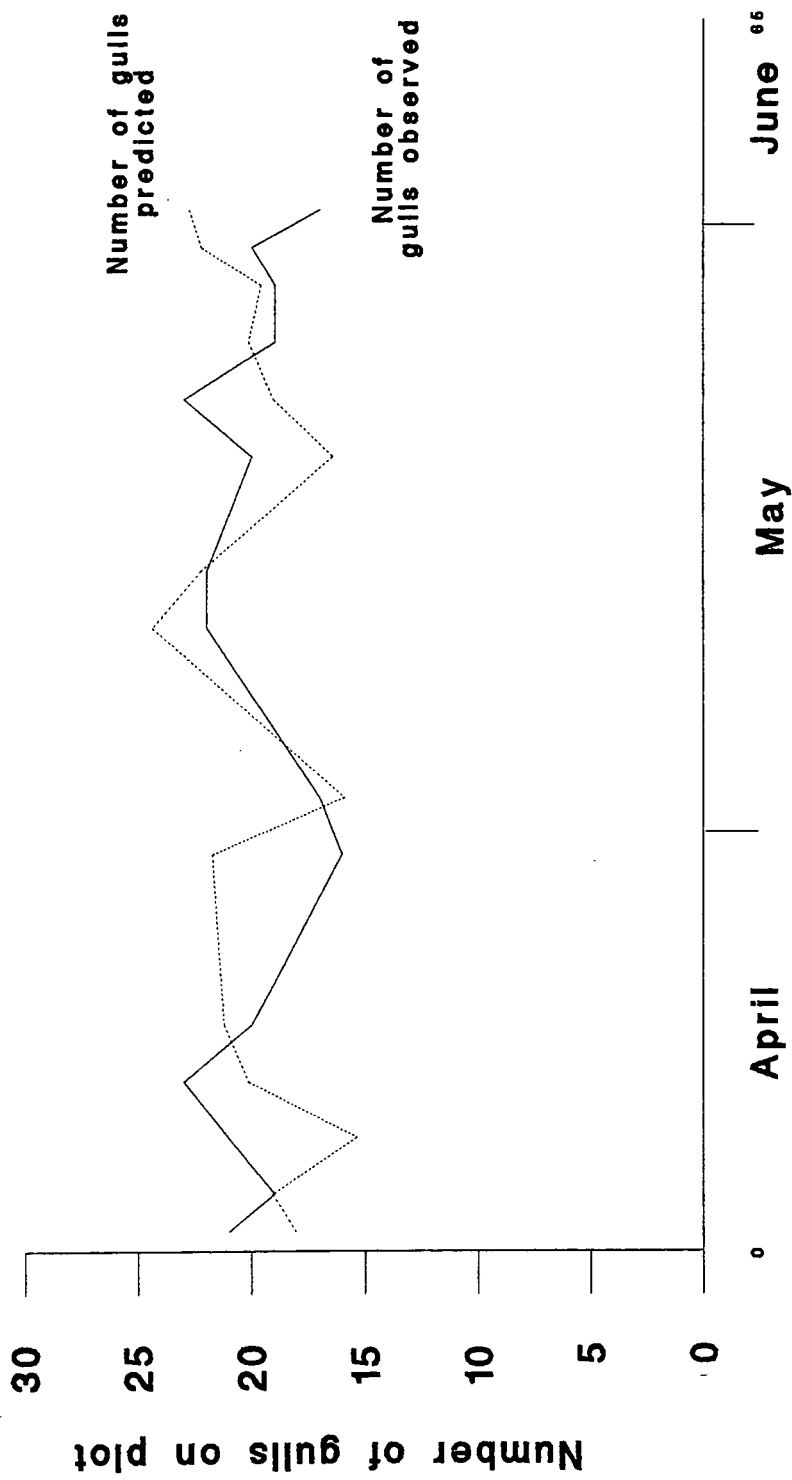
(C). Habituation period: the number of days over which habituation took place and the disturbance effect was progressively reduced. This was measured from the start of the partial exclusion period (when habituation can be said to have started) to the point at which no more gulls were returning to the plot i.e. when the disturbance effect reaches its lowest value and habituation can be said to have stopped.

(D). Habituation rate: the reduction in the disturbance effect with time. The rate was determined by the slope of a line drawn from the start of the partial exclusion period to the point of lowest disturbance effect i.e. from the start to the finish of habituation. The rate is an indication of how quickly birds returned to the plot once habituation had begun, and the start and end points of the line are therefore a function of when habituation started and the proportion of birds that became habituated (the lowest disturbance effect value).

(E). The proportion of the original number of gulls using the plot that were finally excluded: measured by the lowest value of the disturbance effect.

The disturbance effect on the experimental plots was a function of the number of birds on the control plots. In order to smooth out the effects of large daily variations of the number of birds on the control plots, the data have been converted to a five-day running mean prior to the above analysis. The calculation of the disturbance effect values were based on an assumption that the percentage difference between the experimental and control plots prior to disturbance would have been maintained throughout the season had disturbance not taken place (see methods). The assumption was made in order that an 'expected' number of birds on the plot could be calculated and compared to the actual number of birds on the plot. The results of a test of this assumption based on counts on the control plots are shown in Figure 15. There was no significant difference between the mean number of birds per day actually observed on the test plot (geometric mean=19.6; 95% limits: 18.3→21.3) and the number that were predicted (geometric mean=19.9; 95% limits: 18.6→21.1) using the method to obtain an 'expected' figure

Figure 15. Number of Lesser Black-backed Gulls counted on control plot compared to number of gulls predicted. Data used to test assumptions used in calculations of disturbance effect (see text for details and method).



(paired $t=1.47$, 28 df, n.s.). The assumption was therefore a valid one and the expected values were likely to be reasonably close to 'observed' values that would have been obtained had disturbance not taken place. The results of a test of the same assumptions made to obtain 'expected' figures for the number of nests and clutches is shown in Table 5. No significant differences were found between the predicted numbers of nests (133) and clutches (67) and the actual numbers found (134 nests and 71 clutches). The assumption was thus also a valid one.

3.4.2. How to disturb the gulls

The effects of the different disturbance methods on the number of gulls in the experimental plots are shown in Table 6. The effects of disturbance on the number of nests and clutches produced by on the plot are shown in Table 7. A comparison of the number of gulls seen on the cyclic plots during the "on" and "off" cycles is given in Table 8.

Distress calls: Disturbance by playing distress calls produced the shortest total exclusion times of any of the methods investigated (1 day on the 'continuous' plot and 2 days on the 'cyclic' plot). On the 'continuous' plot, disturbance excluded 56% of the original number of gulls, compared to 10% on the cyclic plot. The rate at which gulls habituated to the disturbance was measured by the reduction in the disturbance effect (percent) over a five day period. The habituation rate on the continuous plot (5.10% per 5 day period, S.E.=0.50) was significantly lower than on the 'cyclic' plot, where the rate was 8.37% per 5 day period, S.E.=1.56 ($t=2.1$, 12 df, $p<0.05$). On the 'continuous' plot the number of nests found (10) was significantly lower than expected (54) ($\chi^2=35$, 1 df, $p<0.01$). The number of clutches found (7) was also significantly lower than expected (24) ($\chi^2=11$, 1 df, $p<0.01$). On the 'cyclic' plot, there was no significant difference between the number of nests and clutches observed (30 and 22) compared to the number expected (42 and 18) ($\chi^2_{\text{nests}}=3.1$, 1 df, n.s.; $\chi^2_{\text{clutches}}=0.7$, 1 df, n.s.).

Table 5. Test of assumptions made in calculating 'expected' values during the evaluation of the disturbance regimes, by comparing the number of nests and clutches observed and expected in the 1994 control plots (see text for details of assumptions and methods).

	Number observed	Number expected	Percentage difference	Chi-square (1 df)	Significance
Nests	134	133	1%	<0.01	n.s.
Clutches	71	67	6%	0.24	n.s.

Table 6. Experimental disturbance plots: effect of different disturbance tools and application methods on the plot re-occupation phases by Lesser Black-backed Gulls (see text for definitions of evaluation headings). Disturbance on the 'cyclic' plots occurred in cycles, with the disturbance tool presented for two days and then removed for two days. Disturbance on the 'continuous' plots occurred without a break in the disturbance stimulus.

Disturbance method	Total exclusion period (days)	Partial exclusion period (days)	Habituation period (days)	Habituation rate: % reduction in disturbance effect per 5 day period (S.E.)	Final percentage of gulls excluded at end of disturbance period	
Distress Calls:	continuous	1	25	33	5.1 (0.50) n=5	56 %
	cyclic	2	9	57	8.4 (1.56) n=9	10 %
Gas Gun:	continuous	13	21	46	6.6 (1.07) n=8	40 %
	cyclic	6	4	48	4.1 (1.50) n=7	51 %
Flags:	continuous	11	8	43	5.9 (1.31) n=7	29 %
	cyclic	7	19	52	4.6 (0.39) n=9	49 %
Flags/Gas gun: 10 weeks	9 weeks	22	6	37	5.8 (0.58) n=8	44 %
	10 weeks	16	15	45	3.7 (0.54) n=7	67 %
	11 weeks	14	12	55	3.1 (0.70) n=8	76 %
Monofilament Lines:	5	0	24	10.1 (1.24) n=5	42 %	

Table 7. Comparison of observed and expected number of Lesser Black-backed Gull nests and clutches on experimental disturbance plots 1993 and 1994.

Disturbance Method	Number of observed and expected nests			Number of observed and expected clutches		
	observed	expected	% reduction significance	observed	expected	% reduction significance
Distress Calls:	10	54	- 81% p<0.01	7	24	- 71% p<0.01
	30	42	- 29% n.s.	22	18	- 18% n.s.
Gas Gun:	16	56	- 71% p<0.01	12	25	- 52% p<0.01
	21	53	- 60% p<0.01	9	24	- 63% p<0.01
Flags:	32	68	- 51% p<0.01	21	30	- 30% n.s.
	13	52	- 75% p<0.01	6	23	- 74% p<0.01
Flags/Gas gun:	12	53	- 77% p<0.01	4	24	- 77% p<0.01
	0	45	- 100% p<0.01	0	20	- 100% p<0.01
	0	41	- 100% p<0.01	0	18	- 100% p<0.01
Monofilament Lines:	18	24	- 25% n.s.	9	13	- 31% n.s.

Table 8. Comparison of geometric mean number of Lesser Black-backed Gulls on the experimental disturbance plots 1993 and 1994 during the "on" and "off" cycles of different disturbance regimes. Disturbance on these plots alternated between the presence of a disturbance tool for 2 days (the "on" cycle) and the alternate removal of the disturbance for two days ("off" cycle). 95% confidence limits given in parentheses.

	Geometric mean number of gulls on plot (Weeks 1-3)		Geometric mean number of gulls on plot (Weeks 4-6)		Geometric mean number of gulls on plot (Weeks 7-9)	
	On cycles	Off cycles	On cycles	Off cycles	On cycles	Off cycles
Distress Calls	1.63 (0.09→5.37) t = 0.86, 16 df, n.s.	2.89 (1.50→5.06)	18.50 (15.44→21.12) 29.02 t = 0.42, 11 df, n.s.	19.89 (13.54→)	22.44 (18.79→26.76) t = 0.73, 9 df, n.s.	20.88 (17.96→24.24)
Gas gun	1.51 (0.04→5.09) t = 0.43, 16 df, n.s.	3.37 (0.68→10.35)	8.55 (6.09→11.87) t = 2.43, 10 df, p<0.05	14.14 (10.05→19.73)	12.49 (9.85→15.77) t = 1.16, 9 df, n.s.	14.85 (11.25→19.50)
Flags	0.12 (0.01→0.48) t = 2.45, 16 df, p<0.05	2.02 (0.31→5.94)	3.79 (0.68→12.70) t = 1.61, 11 df, n.s.	9.72 (6.46→14.40)	14.49 (11.46→18.25) t = 1.23, 9 df, n.s.	11.30 (7.01→17.89)

The estimated reduction in the number of nests built on the continuous plot was 81%. This is a significantly greater reduction than on the cyclic plot where a 29% reduction was found ($\chi^2=9.9$, 1 df, $p<0.01$). The reduction in the number of clutches on the continuous plot (71%) was also significantly greater than on the cyclic plot (18%) ($\chi^2=6.3$, 1 df, $p<0.05$).

There were no significant differences in the number of birds seen on the cyclic plot during either the "on" or the "off" cycles, when considering weeks 1-3, 4-6 or 7-9 of the disturbance period (Table 8). There was no evidence therefore, that removing the stimulus in two day cycles, reduces habituation to the disturbance. On the contrary, the removal of the stimulus may actually encourage the gulls to return more quickly by allowing them time on their territories. Once this has occurred, the re-application of the distress call stimulus was not a strong enough signal to disturb them. The results show that the cyclic playing of distress calls failed to produce any significant effects on the gulls and should therefore not be used as a disturbance tool on its own. The continuous distress call regime managed to exclude a proportion of the gulls from the area (56%) and to reduce breeding overall. It did not however produce a complete clearance and should be used as part of a 'cocktail' of disturbance tools, rather than on its own.

The field use of the sound system used to play distress calls had a range of problems associated with it. The major problems were: (i) The batteries required to drive the system are difficult to carry over long distances and require daily replacement and re-charging. (ii) Using sensitive electrical systems in areas with frequent driving rain, necessitates efficient waterproofing of electrical parts. This reduces accessibility when a mechanical fault occurs. (iii) The ability of the system to transmit sound over a wide and specified area is severely limited by the strength of the wind. High winds were a common feature of the weather at Abbeystead during the disturbance period. The problems associated with the sound systems meant that their field use was costly in terms of daily maintenance time and the effort involved in replacing and moving batteries.

Gas guns: The 'continuous' gas gun regime produced the second longest total exclusion period of any of the disturbance methods used (13 days). The disturbance also excluded 40% of the of the gulls, and significantly reduced the number of nests and clutches produced (16 and 12) compared to the expected number of nests and clutches (56 and 25) ($\chi^2_{\text{nests}}=28, 1 \text{ df}, p<0.01$; $\chi^2_{\text{clutches}}=6, 1 \text{ df}, p<0.01$). The 'cyclic' gas gun regime initially achieved total exclusion, but the period of exclusion (6 days) was 46% shorter than with the 'continuous' regime . Once habituation had begun, the rate of habituation was not significantly different between the two plots: 6.6% per five day period (S.E.=1.07) on the continuous plot, compared to 4.1% per five day period (S.E.=1.50) on the cyclic plot ($t=1.4, 13 \text{ df}, \text{n.s.}$). Significantly fewer nest and clutches were produced on the cyclic plot (21 and 9) than expected (53 and 24) ($\chi^2_{\text{nests}} = 19, 1 \text{ df}, p<0.01$; $\chi^2_{\text{clutches}}=9, 1 \text{ df}, p<0.01$). The estimated reduction in the number of nests built on the continuous plot was 71%. This is not significantly different to the reduction on the cyclic plot 60% ($\chi^2=0.4, 1 \text{ df}, \text{n.s.}$). Also, the reduction in the number of clutches on the continuous plot (52%) was not significantly different to the reduction on the cyclic plot (63%) ($\chi^2<0.1, 1 \text{ df}, \text{n.s.}$).

The use of gas guns, despite not achieving total clearance of an area, nevertheless had a marked effect on the gulls and was a useful management tool. There were no significant differences in the number of birds seen on the cyclic plot during either the "on" or the "off" cycles when considering weeks 1-3 and 7-9 of the disturbance period (Table 8). In all time periods, the mean number of gulls on the plot during the "on" cycle was numerically lower than during the "off" cycle, and in weeks 4-6 the difference was significant (geometric mean during "on" cycle=8.55, 95% limits: 6.09→11.87; geometric mean during "off" cycle=14.14, 95% limits:10.05→19.73) ($t=2.6, 11 \text{ df}, p<0.05$). Removing the gas gun stimulus for 2 day on/off cycles reduced habituation but further investigation is required to determine if different periods of stimulus removal could reduce habituation more effectively. As with the distress calls, it is likely that the usefulness of gas guns would be enhanced when used in conjunction with other

disturbance tools (cocktail concept) and by periodically replacing the guns with another form of disturbance before habituation begins (see Discussion).

In terms of daily maintenance, the gas guns are easier to use in the field than the sound systems used to play distress calls. The propane gas bottles need replacing only once every three or four weeks. However, the guns require maintenance on days with wind and rain. The electronics that produce a spark to ignite the propane, are sensitive to dampness, and the design of the guns makes it difficult to protect the sparking mechanism from moisture. High winds reduce the upwind area over which the guns can be heard. The guns are heavy and extremely awkward to move around on the fell and a lot of work-hours were taken up in siting the guns on the disturbance plots.

Flags: On the two plots where flags were used as the disturbance tool, a longer total exclusion period was achieved on the continuous plot (11 days) than on the cyclic plot (7 days). Once the gulls had started to habituate, there was no significant difference in the habituation rate between the two plots (4.6 % per 5 day period, S.E.=0.39, on cyclic plot; and 5.8% per 5 day period S.E.=1.31 on continuous plot) ($t=0.92$, 14 df, n.s.). A greater proportion of the original number of gulls returned to the continuous plot (71%) compared to the cyclic plot (51%). On both plots, the presence of flags significantly reduced the number of nests built (32 on the continuous plot and 13 on the cyclic plot) compared to the number of expected nests (68 and 52 respectively) ($\chi^2=19$ on the continuous plot, $\chi^2=29$ on the cyclic plot, 1 df, $p<0.01$). On the cyclic plot, there were also significantly fewer clutches laid (6) than expected (23) ($\chi^2=12$, 1 df, $p<0.01$). On the continuous plot no significant difference was found between the number of clutches laid (21) and the number expected (30) ($\chi^2=2.4$, 1 df, n.s.). The reduction in the number of nests built on the cyclic plot was 75%. This was numerically higher, but not significantly different to the percentage reduction in nests on the continuous plot (51%) ($\chi^2=2.3$, 1 df, n.s.). Nor was there a significant difference in the reduction in the

number of clutches laid on the cyclic plot (74%) compared to the continuous plot (30%) ($\chi^2=2.6$, 1 df, n.s.).

In the first three weeks of disturbance, a significant reduction in the geometric mean number of gulls on the cyclic plot was achieved during the "on" cycle (0.12, 95% limits: 0.01→0.48) than during the "off" cycle (2.02, 95% limits: 0.31→5.94) ($t=2.2$, 16 df, $p<0.05$). After the first three weeks no further significant differences between the on/off cycles could be detected (Table 8). In other words, stimulus removal for two days on the cyclic plots enhanced the effects of the method on the number of gulls present on the plot, but only did so for a limited period of time.

The field use of flags required little attention once the disturbance areas had been established, although preparation of the flags was time consuming. Long periods of exposure to bad weather in 1993, meant that 80% of the flags had to be replaced in 1994.

Monofilament: Within five days of the erection of this plot, at least three pairs of gulls had learned to 'walk' to their territories underneath the monofilament. Others later learned to drop onto nest sites between the monofilament lines, and were not bothered by the lines touching their wings. Once the first birds had returned to the plot, the habituation rate was higher than for any other disturbance tools (10.1% per five day period, S.E.=1.24), although 42% of the original number of birds were excluded by this method. The number of nests and clutches produced by gulls returning to the plot (18 and 9) was not significantly lower than expected (24 and 13) ($\chi^2_{\text{nests}}=1.3$, 1 df, n.s.; $\chi^2_{\text{clutches}}=0.94$, 1 df, n.s.)

The effects of the use of monofilament line to exclude breeding gulls at Tarnbrook were thus limited. Reducing the distance between the monofilament lines may

discourage a greater number of birds, but some will always 'walk' to their nest sites from the sides of the plot.

Flags used simultaneously with gas guns on the same plot: Complete clearance of breeding gulls by the disturbance tools occurred on two of the three plots where flags were used simultaneously with gas guns. The longest total exclusion periods were achieved by this method (22, 16 and 14 days), as well as the two greatest final exclusion percentages: 76% and 66% (44% on the third plot) (Table 6.). There was no significant difference between the habituation rate between the 10 and 11 week flag/gas gun plots (3.7%, S.E.=0.54 and 3.1%, S.E.=0.70 per 5 day period respectively. $t=0.68$, 13 df, n.s.). The habituation rate on the 9 week plot (5.8% per 5 day period, S.E.=0.58) was significantly higher than the habituation rates on the 10 or 11 week plots ($t=2.97$, 14 df, $p<0.01$ and $t=2.65$, 13 df, $p<0.05$ respectively). On the one flags/gas gun plot where gulls did manage to breed (9 week plot), the number of nests and clutches produced by the returning birds (12 and 4) was significantly lower than expected (53 and 24) ($\chi^2_{\text{nests}}=31$, 1 df, $p<0.01$; $\chi^2_{\text{clutches}}=16$, 1 df, $p<0.01$).

In terms of the long total exclusion periods, the reduction in the number of birds on the plot and the total clearance achieved, the use of flags in conjunction with the gas guns proved to be the most successful of the methods used.

General comparison of the disturbance methods: Table 9 gives a general comparison of the disturbance tools using a ranking system. The three plots using flags simultaneously with gas guns have been pooled for this analysis. Each method has been ranked for its ability to exclude gulls from the plots and to reduce the number of nests and clutches. Eight methods are compared, so that rank 1 is the most effective method, and rank 8 least effective.

Table 9. Comparison of disturbance methods: ranking of ability to exclude Lesser Black-backed Gulls from plot and prevent breeding.

Disturbance method	Longest total exclusion period	Largest percentage of birds excluded	Greatest percentage reduction in number of nests built	Greatest percentage reduction in number of clutches laid	Average rank
Distress Calls: continuous cyclic	8	2	2	3	3.8
	7	8	7	8	7.5
Gas Gun: continuous cyclic	2	6	4	5	4.3
	5	3	5	4	4.3
Flags: continuous cyclic	3	7	6	7	5.8
	4	4	3	2	3.3
Flags with Gas Gun (pooled data)	1	1	1	1	1.0
Monofilament Lines:	6	5	8	6	6.3

Ranking order: Rank 1 = most effective method.
Rank 8 = least effective method.

In all categories, the flags used simultaneously with gas guns produced the most effective disturbance and this is undoubtedly the best method of completely clearing gulls from an area. Human disturbance on the general disturbance area, could not be evaluated in this fashion, but it too produced a complete clearance of breeding gulls over 78% of the area disturbed (see next section). The use of single disturbance tools does not appear to be effective in completely clearing gulls and the use of cyclic disturbance did not increase the ability of a disturbance tool to clear an area by reducing habituation. Different cycles to the 2 day on/off cycle used, may of course produce more effective clearance, and further investigations are required at the colony to assess this.

Human disturbance and the general disturbance area: Human disturbance was used in an attempt to prevent gulls from breeding on the general disturbance area. Of the 45 hectares disturbed, 35 hectares (78%) remained free of nests and eggs. On the remaining area, 76 nests and 41 clutches were removed (first nest on 10 May and last on 29 June). Prior to the main nest building period at the end of April, gulls landing on the site were disturbed with reasonable ease. Once nesting and egg laying begins in the gullery, the birds became extremely tenacious and required regular removal from the site. If gulls had established a particular area as a territory, the distance at which they would fly away when faced with human disturbance was greatly reduced and in some cases was as little as 50m. Once the person effecting the disturbance moved away, the gulls quickly returned to the site, and did so each time they were disturbed. Clearance of larger areas will require the use of a team of disturbance workers.

Human disturbance achieved complete clearance of breeding gulls and was therefore of great value as a disturbance tool. The total disturbance time on the area was 730 hours during the 14 weeks of disturbance.. No experiments were carried out to investigate if shorter periods of disturbance would be able to produce a similar clearance. However, the extremely tenacious behaviour of some of the birds, make it unlikely that shorter

periods of disturbance would prevent all pairs from breeding. The key to successful disturbance is not to let the birds settle on the fell at the most sensitive' period of the breeding season and unless the birds are completely kept off the area to be cleared (particularly during the nest building and egg laying period when the gulls are most tenacious), shorter periods of human disturbance than the one used, are likely to be ineffective

Duration of the disturbance period: There was no sudden increase in the number of gulls on the experimental plots after the disturbance had ended i.e. the excluded gulls did not return or others move onto the plot after the disturbance was removed. The 9 week disturbance period therefore provided adequate stimulus to prevent the return of any of the excluded birds once the disturbance tools had been stopped. The two plots where flags were used simultaneously with gas guns, and where the disturbance period was extended for one and two weeks (10 and 11 weeks of disturbance respectively), were the only plots on which complete clearance was achieved. The flags/gas gun plot that was disturbed for the same duration as the other experimental plots (9 weeks), had 12 nests built on it, in which four clutches were laid. However, the nests and clutches on the nine week plot, were produced during the disturbance period not after the disturbance was stopped. Thus any effects of the disturbance regime had already occurred during the nine week period. In the light of this, there is probably little value in extending disturbance beyond about 10 June when nest building and egg laying has finished in the rest of the colony.

Effects of the 1993 disturbance experiments in the following year: In the 1994 season, no gulls bred on the entire 75 hectares of the 1993 experimental and general disturbance sites. Gulls first returned to the gullery at the beginning of March, flying above the area until the first widespread landings occurred on 6 March. No birds landed

on the 1993 disturbance site until 13 April (5 weeks after the rest of the colony was re-occupied). Only a very few birds were involved in these initial attempts to utilise the disturbance site, but numbers peaked on 8 May at 28 individuals and then declined again in June. The numbers involved compared to the build up of birds on undisturbed sites are shown in Figure 16.

No mechanical disturbance was used on the 1993 disturbance site in 1994 and gulls attempting to use the site, were easily disturbed by human presence. For most daylight hours, no birds appeared interested in the site and most landing attempts were within two hours after sunrise and before sunset. The areas on which the gulls were attempting to land in are shown in Figure 17 and correspond to the areas where birds managed to produce nests and eggs in 1993. It is likely that the gulls attempting to land would have produced nests and eggs had they been allowed to remain on the area, and may also have attracted additional birds to the site. This means that in the year following widespread disturbance, the area disturbed in the previous season should be observed and tenacious birds kept off the site. Only minimal disturbance was necessary in 1994 to keep gulls off the 1993 disturbance areas, and this allowed new areas to be disturbed while cleared areas were 'guarded' from the few birds that remained faithful to that site.

Reduction in area of the gullery achieved by the disturbance work: A total of 75 ha of the Abbeystead Estate was freed of breeding gulls by the disturbance work in 1993. The reduction in breeding areas achieved are shown in Table 10.

The disturbance experiments in 1994 cleared an additional 15 ha, but it will not be known if these areas will remain free of breeding gulls until 1995.

Figure 16. Period in 1994 during which gulls were seen on the areas cleared of gulls by 1993 disturbance work, compared to arrival and build up of gulls on control plot.

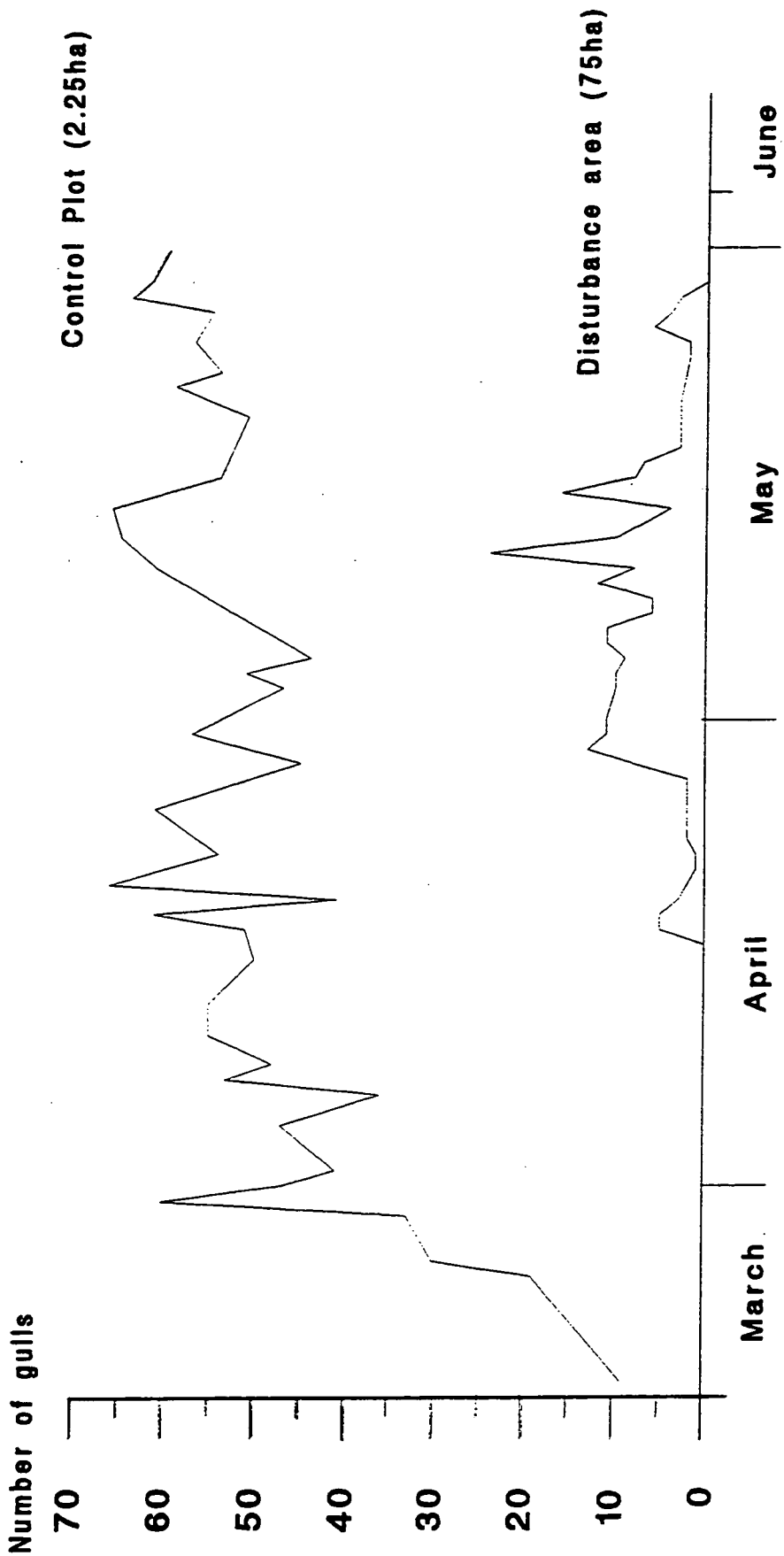


Table 11. Changes in the number of breeding Lesser Black-backed and Herring Gulls on different parts of the Tarnbrook Fell Gullery between 1992 and 1993 (pre-disturbance), and 1993 and 1994 (post-disturbance).

	Changes in Number of Gulls Between 1992 and 1993 (pre-disturbance)	Changes in Number of Gulls Between 1993 and 1994 (post-disturbance)
Abbeystead non-Sanctuary (not including the disturbance area)	+ 1421 (+ 31%)	- 768 (- 11%)
Abbeystead Sanctuary	+ 623 (+ 18%)	+ 970 (+ 24%)
Mallowdale non-Sanctuary	+ 464 (+ 14%)	+ 447 (+ 8%)
Mallowdale Sanctuary	- 50 (- 4%)	+ 97 (+ 8%)
Brennand	+ 494 (+35%)	+ 1099 (+ 57%)
TOTAL	+2952 (21%)	+1845 (11%)

Figure 17. Tarnbrook Fell Gully: 1993 disturbance areas on which gulls produced nests compared to areas where gulls were attempting to land in 1994.

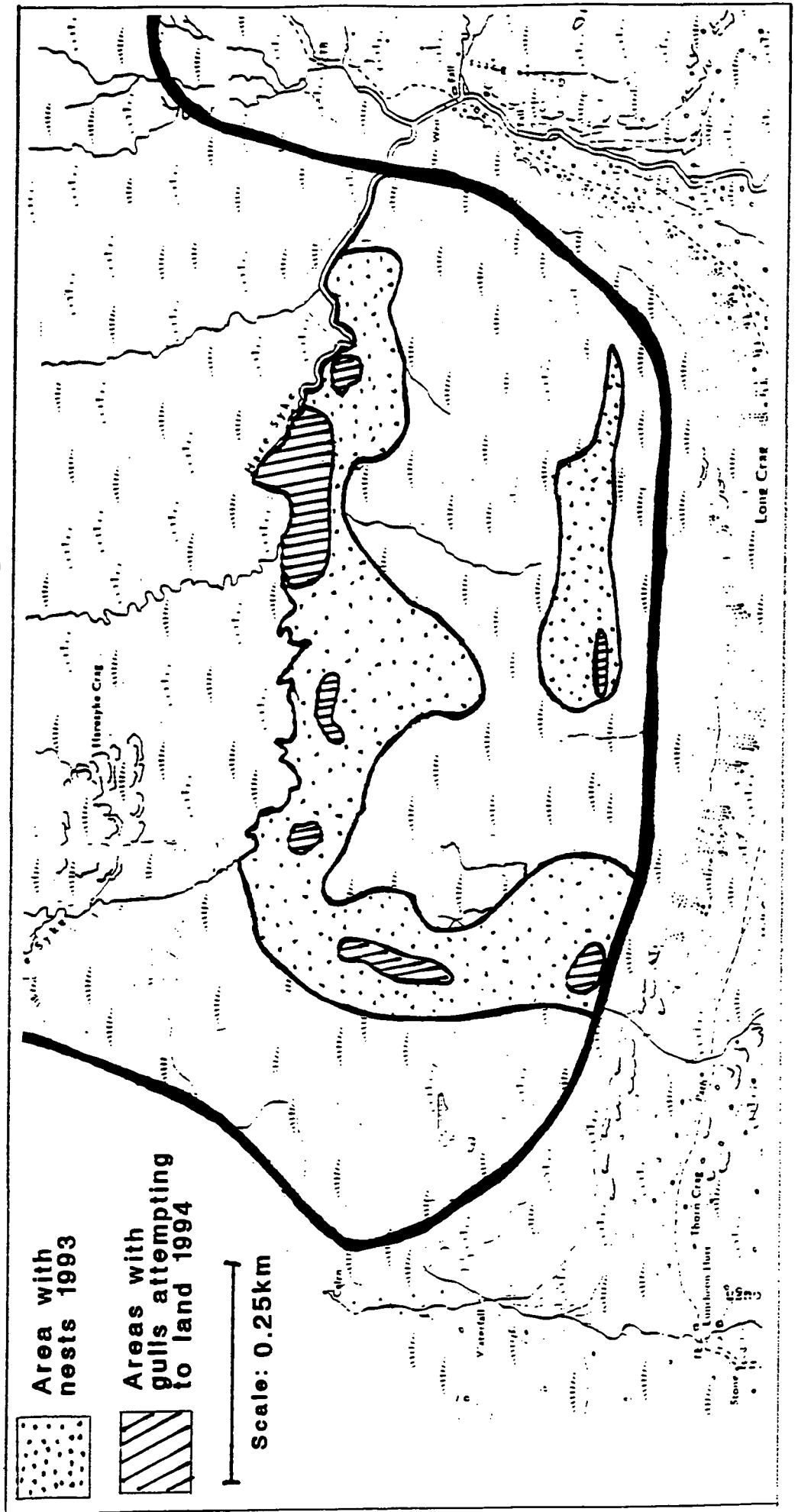


Table 10. Percentage reduction in the total areas utilised by breeding Lesser Black-backed Gulls on the Abbeystead Estate and the gullery as a whole, as a result of the 1993 disturbance.

	Area in 1992 (hectares)	Area in 1994 (hectares)	Percentage change in area 1992 - 1994
Abbeystead Estate: outside the Sanctuary	260	185	- 29 %
Abbeystead Estate: whole area	320	245	- 23 %
Total gullery area	660	585	- 11 %

Effect of disturbance on total number of nests built on the disturbance area in

1993: In 1992, a mean nest density of 9.0 (S.E.=2.4) nests per census quadrat (0.5 ha) was found on the area disturbed in 1993 (O'Connell and Coulson 1992). This was 31% lower, than the 13.1 (S.E.=2.2) nests per census quadrat on the rest of the Abbeystead non-Sanctuary area. If it is assumed that the same percentage difference would have occurred between the two areas in 1993, had the disturbance not taken place, the number of nests that would have been built on the disturbance site can be estimated. The mean nest density on the Abbeystead Estate, excluding the disturbance area and the Sanctuary, was 14.2 (S.E.=2.6) nests per census quadrat in 1993 (O'Connell and Coulson 1993). Allowing for a 31% difference between this area and the disturbance site, nest density would have been 9.8 nests per census quadrat on the disturbance site in 1993, equivalent to a total 1470 nests over the whole area (200 census quadrats per 1km²). In fact only 210 nests were found, and the disturbance reduced the number of nests produced on the area by 86% (1,260 nests). At the Tarnbrook Fell Gullery, 210 nests represent 320

breeding gulls and 1,260 nests represents 1,922 breeding gulls (see Chapter 4 for details of conversion of nest numbers to breeding gulls). In other words, disturbance in 1993 prevented about 1,900 gulls from breeding.

Movement of gulls displaced from the 1993 disturbance site in 1994: No marked individuals were available to the study and so no direct evidence could be obtained of the movements of gulls that were displaced by the 1993 disturbance. Some of the gulls may have left the gullery completely and there is indirect evidence from the annual census data (Chapter 5) of local movements within the colony: neither the 320 gulls that produced nests and eggs on the disturbance site in 1993, nor the 1,900 gulls that were excluded, bred on the disturbance site in 1994. This means that about 2,200 breeding gulls were displaced from the area in 1994. Table 11 shows the changes in the number of breeding birds in different parts of the gullery between 1992 and 1993 (pre-disturbance) and between 1993 and 1994 (post disturbance). The 11% reduction in the number of breeding birds on the Abbeystead non-Sanctuary area suggests that the disturbance work may have had an effect beyond the limits of the experimental area. The reduction also suggests that the displaced birds did not move into areas adjacent to the disturbance site but have moved further away. The largest post-disturbance percentage increases in the number of breeding gulls, were found on the Abbeystead Sanctuary area (+24%) and the Brennand Estate (+57%). However, both these areas were also increasing prior to the disturbance. On the Mallowdale Estate there was an increase of 544 gulls and the combined increases on the Abbeystead Sanctuary area and Brennand amount to 2,069 breeding gulls. This gives a total increase of some 2,600 gulls between 1993 and 1994, close to the figure of 2,200 birds displaced from the disturbance site. However, these calculations do not take into account 768 gulls that bred on the Abbeystead non-Sanctuary area in 1993 but also moved elsewhere in 1994, or the fact that there will almost certainly have been immigrant recruits to the colony in 1994. Despite the absence of direct evidence from ringed individuals, this

evidence from the colony census, suggests that at least a proportion of the birds displaced by the disturbance in 1993 moved elsewhere in the colony to breed and that some of these gulls utilised the Sanctuary area. This was one of the original aims of the disturbance policy. The census data also indicate an over-spill of breeding gulls into the Brennand Estate which increased by 57% in 1994. Future management will have to be directed on this area to contain further increases on that area.

3.4.3. When to disturb the gulls.

The effects of disturbance on the number of gulls on the 'late' and 'early' disturbance plots are shown in Table 12. The number of expected and observed nests and clutches on the plots are given in Table 13. Data from replicate early and late plots have been pooled for this analysis (after testing for significant differences) and compared to the pooled data from the control plots.

The late plots were re-occupied by gulls within an hour of the start of the disturbance, while gulls on the early disturbance plots were totally excluded for a period of seven days. The habituation rate on the late plots (19.0% per 5 day period, S.E.=4.67) was significantly higher than on the early plot (5.54% per 5 day period, S.E.=1.19) ($t=2.9$, 10 df, $p<0.05$). Also, 51% of the original number of birds were finally excluded on the early plots compared to 27% of the gulls on the late plots. A total of 38 nests had been built on the late plots when the disturbance began, but no clutches had been laid. During the disturbance period a further eight were built. This total of 46 nests was not significantly different from the expected value of 52 ($\chi^2=0.6$, 1 df, n.s.). Twenty clutches were laid on the late plots during the disturbance period. This is not significantly different to the expected value of 29 ($\chi^2=2.5$, 1 df, n.s.). On the early plots the number of nests and clutches produced (17 and 10) was significantly lower than expected (93 and 52) ($\chi^2_{\text{nests}}=61$, 1 df, $p<0.01$; $\chi^2_{\text{clutches}}=33$, 1 df, $p<0.01$). Also, the reduction in the number of nests built on the early plots (82%) was significantly greater

Table 12. Experimental disturbance plots 1994: effect of disturbance on the re-occupation phases of 'early' and 'late' plots (data pooled from replicate plots: see text for definitions of evaluation headings).

Disturbance site	Total exclusion period (days)	Partial exclusion period (days)	Habituation period (days)	Habituation rate: percentage reduction in disturbance effect per 5 day period (standard error)	Percentage of gulls excluded
Early Disturbance (pooled data)	7	0	36	5.5 (1.19) n=8	51 %
Late Disturbance (pooled data)	0	0	24	19.0 (4.67) n=4	27 %

Table 13. Comparison of observed and expected number of Lesser Black-backed Gull nests and clutches on the 'early' and 'late' plots 1994, (pooled data).

Disturbance Period	Number of observed and expected nests				Number of observed and expected clutches			
	observed	expected	% difference	significance	observed	expected	% difference	significance
'Early' plots (pooled data)	17	93	- 82%	p<0.01	10	52	- 81%	p<0.01
'Late' plots (pooled data)	46	52	- 12%	n.s.	20	29	- 31%	n.s.

than the reduction on the late plots (12%) ($\chi^2=23$, 1 df, $p<0.01$). The reduction in the number of clutches on the early plots (81%) was also significantly greater than the reduction on the early plots (31%) ($\chi^2=7.3$, 1 df, $p<0.05$) The results show that disturbance early in the season as the gulls return to the colony, has a greater effect than disturbing gulls with established territories.

3.4.4. Disturbance at the edge and centre of the gullery.

The effects of disturbance on the number of gulls on the 'edge' and 'centre' plots are given in Table 14. The number of observed and expected nests and clutches are given in Table 15. Data from replicate edge and centre plots have been pooled for this analysis (after testing for significant differences) and compared to pooled data from the control plots.

Disturbance at the edge of the colony produced a total exclusion period of 7 days compared to 2 days on the centre plots. In all, 51% of the gulls on the edge plots were excluded compared to 43% on the centre plots. There was no significant difference in the habituation rate on the edge plots (5.55% per 5 day period, S.E.=1.19) compared to the rate on the centre plots (6.61% per 5 day period, S.E.=0.83) ($t=0.73$, 17 df, n.s.). The observed number of nests and clutches on the edge plots (17 and 10) was significantly lower than expected (93 and 52) ($\chi^2_{\text{nests}}=61$, 1 df, $p<0.01$; $\chi^2_{\text{clutches}}=33$, 1 df, $p<0.01$). The number of nests and clutches on the centre plots (40 and 19) was also significantly lower than expected (74 and 41) ($\chi^2_{\text{nests}}=15$, 1 df, $p<0.01$; $\chi^2_{\text{clutches}}=11$, 1 df, $p<0.01$). Also, the reduction in the number of nests built on the edge plots (82%) was significantly greater than the reduction on the late plots (46%) ($\chi^2=10$, 1 df, $p<0.01$). The reduction in the number of clutches on the edge plots (81%) was not however, significantly greater than the reduction on the centre plots (54%) ($\chi^2=3.2$, 1 df, n.s.).

Table 14. Experimental disturbance plots 1994: effect of disturbance on the re-occupation phases of 'edge' and 'centre' plots by Lesser Black-backed Gulls (data pooled from replicate plots: see text for definitions of evaluation headings).

Disturbance site	Total exclusion period (days)	Partial exclusion period (days)	Habituation period (days)	Habituation rate: percentage reduction in disturbance effect per 5 day period (standard error)	Percentage of gulls excluded
Edge of colony (pooled data)	7	0	36	5.6 (1.19) n=8	51 %
Centre of Colony (pooled data)	2	9	41	6.6 (0.83) n=9	43 %

Table 15. Comparison of observed and expected number of Lesser Black-backed Gull nests and clutches on the 'edge' and 'centre' plots, (pooled data).

Disturbance Site	Number of observed and expected nests			Number of observed and expected clutches		
	observed	expected	% difference significance*	observed	expected	% difference significance
Edge plots (pooled data)	17	93	- 82% p<0.01	10	52	- 81% p<0.01
Centre plots (pooled data)	40	74	- 46% p<0.01	19	41	- 54% p<0.01

Disturbance at the edge of the colony was more effective than disturbing central areas and the original concept of "rolling back the edges" is therefore a good strategy. No data are available on the effects of disturbance on the edge and centre plots in the following season, but it is possible that areas cleared of gulls in the centre of the colony (and hence which are completely surrounded by breeding gulls) would be more likely to be re-occupied than areas cleared at the edge. Nevertheless, the central disturbance did have an effect on the birds and with a greater disturbance effort spread over a larger area it may have been more effective and should not be totally excluded from use in future management programmes.

3.5. Discussion.

3.5.1. Habituation to disturbance.

Habituation is defined as the progressive reduction in the level of response of an animal to repeated presentations of a stimulus, and has been recorded in many attempts to displace a variety of problem birds using 'disturbance' methods (e.g. Busnel and Giban 1960; Blokpoel 1976; Bridgman 1980). Various theories have been forwarded to explain habituation, including suggestions that sensory adaptation and/or muscle fatigue are involved. However, as Monaghan and Wood-Gush (1990) point out, these cannot completely account for the process of habituation in birds, as different individuals respond in different ways to the same stimuli, and the muscles used in responding to a stimulus are still capable of being used for many other functions. The reduction in response to a stimulus is therefore likely to be the result of changes in the central nervous system i.e. the individual learns not to respond to stimuli that are of no biological consequence to them. The functional significance of habituation in birds has also been discussed by many authors (e.g. Hinde 1954; Brough 1968; Verner and

Mulligan 1971; McGregor 1986). In songbirds, habituation to territorial singing is believed to reduce aggression between conspecifics (Petrinovich and Peek 1973), while in gulls, habituation to aggressive territorial posturing of neighbouring pairs has been recorded for both Herring and Lesser Black-backed Gulls (Tinbergen 1953). Aubin (1990) stated that the almost complete loss of response to an 'enemy' appeared to have "little adaptive value". However, in the case of the gulls on the experimental disturbance plots, long-term and continued response to the disturbance stimulus, or moving to other areas of the colony, would be deleterious to their breeding success (see earlier) and so habituation to the 'false' danger signals of the disturbance tools is therefore highly adaptive.

Russell (1943), investigated 'sign stimuli' in animal signals and concluded that there were 'cues' within the broad spectrum of signalling behaviours that were more important than others in triggering the appropriate responses in individuals receiving the signals. Also, these sign stimuli will produce behavioural responses even in the absence of the stimuli that normally accompany them. In gulls, this was demonstrated in the classic experiments by Tinbergen and Perdeck (1950) and Tinbergen (1953) where begging responses were elicited from chicks by a variety of 'super-normal' stimuli such as knitting needles with painted stripes. Super-normal stimuli have also been investigated in the context of protecting crops from birds. Murton *et al.* (1974), used a range of super-normal Wood Pigeons *Columbia palumbus* to keep wild birds away from cereal fields. Both the number of birds kept away from the fields and the rate of habituation were reduced. Super-normal acoustic stimuli have also been investigated in their ability to keep birds from airfields and reservoirs (Brémond 1980; Aubin 1990). In these experiments, habituation was reduced by electronically isolating and enhancing the sign stimuli within distress and alarm calls. More research is needed in this important field to further enhance our ability to manage problem species in a non-lethal fashion.

Thompson and Spencer (1966) described the characteristics of habituation. These characteristics became apparent in the responses of disturbed gulls during the management experiments:

(i) Responsiveness decreases with the numbers of stimulus presentations. This became a problem when disturbing gulls during the breeding season. The long periods over which the gulls are motivated to return to their breeding sites necessitated presentation of stimuli for the duration of the breeding season and this increased the risk of habituation.

(ii) Response to a stimulus can 'recover' if the stimulus is withdrawn. The longer the removal time, the larger the response recovery. However, at each new presentation of the stimulus, the rate of habituation is increased and the response level decreases. The problem encountered with the disturbance methods that were designed to allow recovery (the 'cyclic' plots) was that they also allowed the gulls to return to their breeding sites. Site attraction apparently increased with time spent on the site, and the effects of the re-instatement of the disturbance stimulus was then reduced despite recovery from the habituation.

(iii) Habituation effects increase if the stimulus is presented beyond the onset of habituation. Once habituation has occurred, continued presentation of the stimulus after the birds have ceased to respond to it, can reduce the effectiveness of a recovery period and also reduce the effectiveness of the presentation of a new stimulus. For gull disturbance, it is important that the disturbance factor should take another form as soon as the point of habituation is reached. In the experiments at Tarnbrook Fell, this would be at the end of the total exclusion period.

(iv) 'Stronger' stimuli produce slower habituation rates. In the context of the disturbance tools used at Tarnbrook Fell, 'stronger' stimuli means louder noises, distress calls played through amplifiers that more faithfully reproduce the sounds, or bigger, brighter and greater numbers of visual stimuli. Several disturbance tools used

simultaneously also represent a stronger stimulus as was demonstrated on the two plots on which successful clearance was achieved, utilising a visual and auditory stimulus at the same time.

(v) Habituation leads to 'stimulus generalisation'. Birds that have habituated to a particular type of disturbance will show less response to a 'similar' stimulus. A series of loud bangs should therefore not be replaced by a series of other loud noises, visual stimuli would be more effective.

(vi) Replacement by a different stimulus can produce 'dishabituation'. Changing the nature of the stimulus increases the levels of to the previous form of stimulus. This is important if gulls are disturbed on a site where costs prohibit the use of several different types of disturbance tools simultaneously.

3.5.2. Minimising the effects of habituation.

Habituation has been reported in many gull scaring programmes (Thomas 1972; Blokpoel and Tessier 1983; Aubin 1990; CAA report 1990; Vermeer and Irons 1991). Non-lethal management strategies at the Tarnbrook Fell Gullery must incorporate methods of overcoming this phenomenon. There is evidence that gulls can habituate to disturbance taking place over a long time period and the reactions of the gulls at Tarnbrook Fell should be monitored to investigate if the birds are habituating to disturbance year to year. An example of this long-term habituation can be seen at the gullery on Walney Island, 40km west of Tarnbrook. The gulls at that colony hardly react to humans walking amongst their nests and will fly away only when the person is a few metres away. Even then, the birds do not fly high into the air, but stay close to the nest and will often attack the intruder. This is in marked contrast to the gulls at Tarnbrook who fly up when humans are 50+ metres away and wheel high above the intruder. The gulls at Walney Island have habituated to the many thousands of people

that visit the colony each year and walk through the breeding areas. To prevent this happening at Tarnbrook, rapid and complete clearance is essential.

As mentioned above, the presentation of a 'strong' stimulus by using two disturbance tools simultaneously produced complete clearance of the gulls on two experimental plots. Gas guns and flags were used during these particular experiments, but it is likely that other combinations of disturbance tools would produce similar synergistic results. The main problem with combining disturbance tools is that it restricts the total area that can be disturbed, because two tools are used up on one site. For practical purposes the most effective way of overcoming habituation effects at Tarnbrook Fell and effectively using available resources would be to use the disturbance tools in 'rotation'. The length of time that each disturbance tool remains on a particular area, will be dictated by the ability of the tool to achieve total exclusion. The management experiments demonstrated which methods were the most effective in this regard and the period of time each tool could be used prior to the onset of habituation. Gas guns, for example are able to keep birds off an area for a relatively long time compared to distress calls which are unable to do this for more than a day or two. The latter should therefore either be rotated more quickly or used in conjunction with other tools. Rotational disturbance requires a high level of human involvement although even without rotation, daily maintenance of the disturbance tools is essential. The presence of humans has been shown to be a useful disturbance tool in its own right, and rotation of the disturbance tools would itself produce an effective disturbance.

3.5.3. Optimum size for a disturbance area.

It is unclear why disturbance using two tools at the same time should have achieved total clearance in 1993, but a similar regime on the 1994 plots did not. The answer may lie in the total area over which disturbance took place. The plots used in 1993 were surrounded by other plots on which disturbance was taking place and where only a

reduced level of breeding occurred. The entire disturbance area covered 75 hectares. The 1994 plots covered 2.25 ha and were surrounded by areas where no disturbance was taking place and where birds were successfully breeding. There is therefore the possibility that disturbance over a larger area may be a more effective strategy than the use of smaller patches.

3.5.4. Site tenacity, divorce and the consequences of moving nest site.

One of the most striking features of the behaviour of the birds on the disturbance areas has been the extreme tenacity of some individuals in the face of continuous disturbance. Given that there are large amounts of available space in other areas of the gullery (created by the 'thinning' effects of past culls) the question arises as to why the gulls are so persistent in their attempts to breed on a particular site. The answer might lie in the breeding strategies that many Larid species employ. Most gulls are perennially monogamous i.e. they maintain a pair bond with only one mate at a time, usually for several successive seasons, but usually do not maintain the pair bond outside the breeding season. Mate changes or 'divorce', can be due to either the death of a mate or the deliberate severance of the pair bond (Johnstone and Ryder 1987). The estimated divorce rate for several gulls species is shown in Table 16. Coulson (1972) found a higher percentage of gulls that were unsuccessful in their breeding attempt in one season changed mate the following season, compared to pairs that successfully raised at least one chick. The fact that mate retention occurs in gulls, suggests that there is some adaptive significance in staying with the same mate for consecutive breeding seasons. Conversely there must be consequences of divorce that can reduce a birds' lifetime reproductive success. In long lived species such as gulls, where reproductive performance is spread out over many years, significant gains in lifetime reproductive success can be achieved by retaining a successful breeding partnership over as large a number of seasons as possible.

Divorce can affect gull pairs in two main ways:

(i) Clutch initiation can be retarded in up to two breeding seasons after the divorce and clutch initiation is positively correlated with reproductive success (Wooller and Coulson 1977).

(ii) Both clutch size and fledging success are reduced in divorced gulls (Coulson 1966; Mills 1973; Coulson and Thomas 1980).

It is thought that Lesser Black-backed Gulls do not maintain the pair bond outside the breeding season and retaining a mate in consecutive years may therefore be facilitated by nest site fidelity. At the beginning of the breeding season, experienced breeding males return to approximately the same area as that in which they bred in previous years and establish a territory (Tinbergen 1961). The females then return to the same area one to three weeks later, and visual cues or voice recognition play a role in the re-affirmation of the pair bond (Brown 1967; Hunt 1980). The chances of divorce are greatly increased if



Table 16. Percentage occurrence of pair-maintenance and divorce recorded for some gull species.

Species	Percentage of Pairs Maintaining Pair-bond > 2 Seasons	Percentage of Birds widowed	Percentage of Pairs Divorced	Source
Silver Gull	82 % (n=77)	13 %	5 %	Mills (1973) Tasker and Mills (1981)
Herring Gull	79 % (n=62)	-	-	Drost et al (1961) Tinbergen (1963)
Western Gull	87 % (n=30)	-	-	Pierrotti (1981)
Kittiwake Gull	64 % (n=458)	11 %	25 %	Coulson (1966)
Glaucous-winged Gull	58 % (n=13)	23 %	23 %	Vermeer (1963)

the male establishes a territory at an appreciable distance from its position in previous years (Gratto *et al.* 1985). Gulls moved off the disturbance site are thus likely to face divorce, because the chances of finding and retaining the same mate amongst many thousands of other gulls spread over 6 km² are small. If moving site means divorce, and divorce means a lowered breeding success, this might go some way to explaining the tenacity of the gulls to the disturbance site. An additional long-term gain from disturbing gulls, is that newly paired birds (after a divorce) are far less site tenacious than birds paired for several seasons (Coulson and White 1958). If gulls divorce and move into new areas of the colony, they will be easier to move from the new area when the disturbance regime reaches that particular part of the colony.

3.5.5. Divorce and early disturbance.

Disturbance of gulls when they first return to the colony has been shown to be more effective than later disturbance. If the birds are not allowed to settle onto a site they have three choices of action:

- (i) They can give up all attempts at breeding that season,
- (ii) They can continue their attempts to breed, despite the disturbance,
- (iii) They can try to establish a territory in areas of the colony without disturbance.

Successful attempts at establishing elsewhere will only occur if the bird has a long enough time to establish a new territory and find a new partner. Early disturbance therefore has the advantage that birds moving off the disturbance site may be better able to establish territories elsewhere in the colony that season, and so will not return to the original site.

3.5.6. The 1993 disturbance site in the following season.

In 1994, there was the possibility that at least a proportion of the gulls excluded from the disturbance site in 1993 would return to attempt to breed the following season. It was also anticipated that the gulls that managed to produce nests on the site, would likewise return and attempt to breed. Although some gulls did attempt to utilise the site in 1994, the majority of the 1993 birds did not return and the area remained free of breeding gulls. These birds appear to have associated the site with danger and/or poor breeding success and so chose to breed elsewhere in 1994.

Not including the birds that were directly affected by the 1993 disturbance, there are several potential sources of the gulls that attempted to land on the disturbance site in 1994. They could have been:

- (i) Gulls from a non-breeding group in 1993 i.e. birds who normally breed on the site but took a year off in 1993 and so missed the disturbance,
- (ii) Philopatric gulls hatched on the area prior to 1993, returning to breed at the natal site for the first time,
- (iii) Gulls coming from other areas at Tarnbrook Fell or from another colony.

As seen earlier, there is circumstantial evidence that gulls displaced from the 1993 disturbance site moved into the Sanctuary area and other sites within the colony in 1994. Early disturbance of the site means that some may have been able to breed elsewhere in the colony in the same season as they were moved from the disturbance site. However, the number of gulls recorded on the experimental plots during the disturbance, suggested that many did not move elsewhere in that season, but continued to try to breed on their original nest sites i.e. the 'decision' not to breed on the disturbance site in 1994, was made as the birds returned to the colony in 1994 because they associated the area with danger and/or a lack of breeding success. There is, however, also the possibility that some of the birds may have established themselves elsewhere in the colony at the end of

the 1993 breeding season, immediately after they had failed on the disturbance site. Little attention has been paid to post-breeding behaviour in Larids, but a study of Ring-billed Gulls *Larus delawarensis* revealed that 40% of the birds at a gullery in Canada, engaged in post-breeding courtship behaviour and pairing (Fetterolf 1984). Both successful and failed breeders were involved. Fetterolf suggested that this post-breeding activity might facilitate the acquisition of both territory and a mate in the following season. In the context of the birds excluded by the disturbance in 1993, it may mean that as a consequence of failing on the disturbance site, some of the gulls established in other areas at the end of the 1993 season, and this is the reason that very little effort was required to keep the disturbance site clear in 1994.

3.5.7. Key elements of successful disturbance.

The results of the management experiments conducted at the Tarnbrook Fell Gullery suggest that there are a number of key elements to successful non-lethal control methods:

- (i) Complete clearance of the gulls is essential.
- (ii) Disturbance should be initiated as soon as the gulls return to the colony.
- (iii) Birds should be disturbed at the edge of the colony.
- (iv) A suite of disturbance methods should be used, preferably in 'rotation'. Where possible, the replacement method in the rotation should be dissimilar in nature to the previous method.
- (v) Disturbance should take place over as wide an area as resources allow for complete clearance to be effected.

(vi) The nests and eggs of any birds that do manage to breed on the disturbance site should be removed.

(vii) Tenacious gulls should be removed from the area by lethal methods.

(viii) Areas successfully cleared should be 'guarded' in the following season.

3.5.8. The role of the Sanctuary area.

At a colony such as Tarnbrook Fell, where the size of the gullery means that the clearance of gulls from the colony has to occur in targeted areas over a number of years, the provision of an area where no disturbance occurs (the Sanctuary) is an essential part of the management strategy. The area serves two main functions:

(i). it acts as a sink for gulls displaced by disturbance. These gulls might otherwise continue their attempts to re-establish themselves on their former breeding areas. A smaller, more dense breeding group is easier to manage than a widely spread colony and higher nest densities in the Sanctuary reduce the levels of immigrant recruits attracted to the colony (Chapter 5).

(ii). it provides a control site against which the changes brought about by the management policy can be evaluated.

3.5.9. Applicability to other gull problems.

The ability of a disturbance method to remove problem gulls from specified areas, will depend on two inter-related factors. Firstly, the motivation of the group to be disturbed will determine the speed and levels of habituation, depending on whether the problem birds are breeding, loafing or feeding. Secondly, the availability of other areas into which the birds can move will play an important role in the success of disturbance

programmes. Spanier (1980) found that repelling Night Herons *Nycticorax nycticorax* from fish ponds was only successful when the birds had alternative feeding sites within flying range. Brough (1969) found that feeding Starlings *Sturnus vulgaris* were harder to disperse when food in the local area was in short supply. Several studies have shown that exclusion of gulls using monofilament lines is more effective when alternative sites are available (Blokpoel and Tessier 1984; Forsythe and Austin 1984; McClaren *et al.* 1984). Thus, although there will be some disturbance tools that work successfully at a variety of sites utilised by gulls, the transferability of particular methods between problem sites should not be assumed. It is the principles used in the development of management methods that are applicable to all situations. The principles used in the development of control methods for the Tarnbrook Fell Gullery, have been to ensure that control measures are referenced to contemporaneous information on the biological and demographic processes with the gullery, and are scientifically evaluated in the light of a pre-stated set of short and long term aims. Importantly the aims of management policies should include whether a reduction in numbers is desired or a reduction of the colony area, or indeed both. Wherever possible, management strategies should also include the monitoring of the movements of the disturbed gulls. This process leads to the development of rational strategies in place of the previously used *ad hoc* control programmes. The applicability of disturbance methods to gulls in an urban context are discussed in Chapter 7.

CHAPTER FOUR.

Empty nests and failed breeding attempts at Tarnbrook Fell Gullery

4.1. Introduction

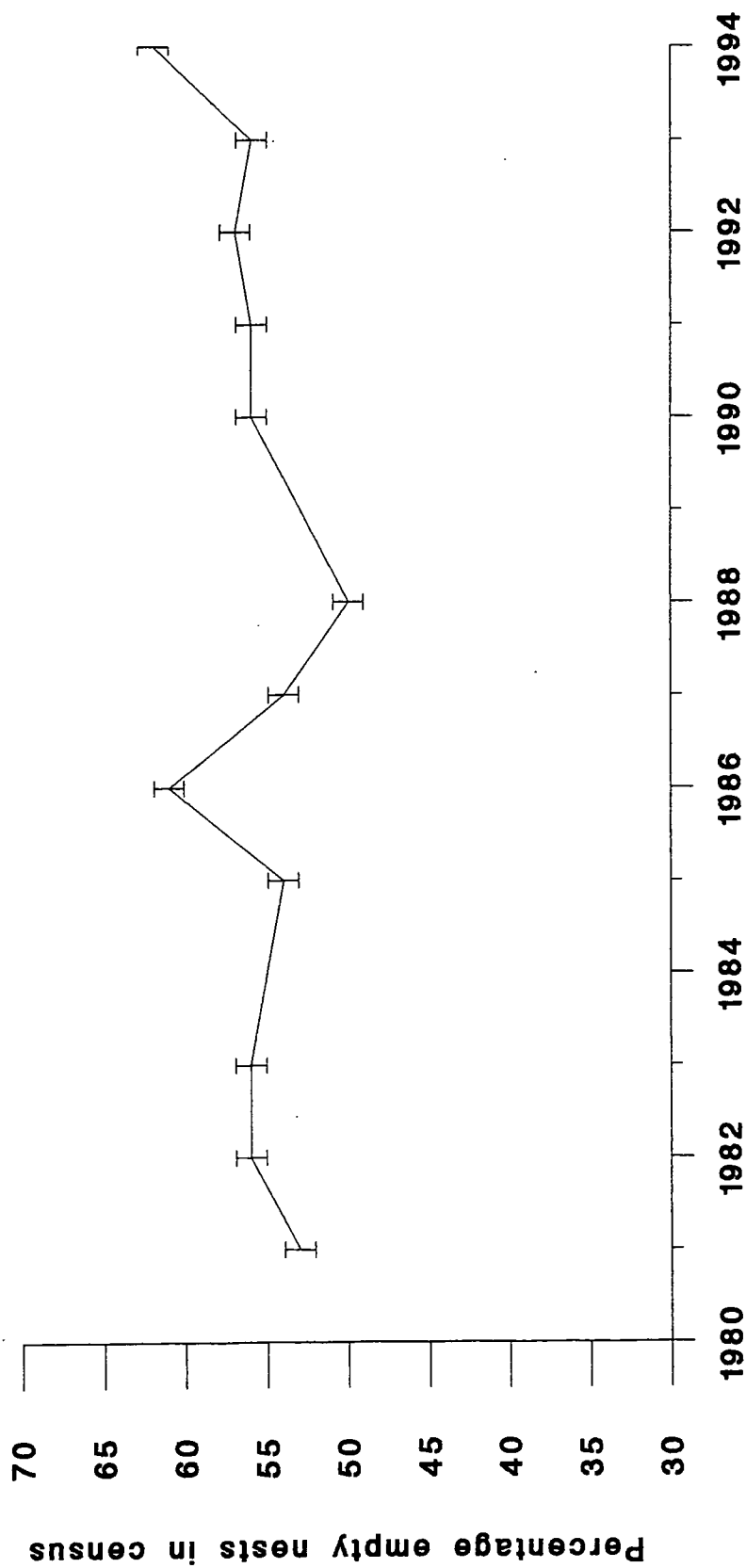
4.1.1. The function of nests

In birds, embryonic development occurs in an egg, externally to the female parent. Eggs are easily damaged and the embryo will only develop if a critical temperature is maintained. Normally, these thermoregulatory requirements are met by the eggs being incubated directly by the adults. In order to facilitate incubation, many species of birds build a nest structure, in which the eggs are laid. Nests are made from a wide variety of materials and their sole function is generally reproductive. There are however, some exceptions to this rule. Pettingill (1971) describes "cock nests" built by male Wrens *Troglodytes troglodytes* which are used for displaying and roosting but never contain eggs. Several other species have been observed building non-reproductive nests: Tyrant Flycatchers *Empidonax* sp. (Dorst 1974), Bobwhite Quail *Colinus virginianus* (Klimstra and Rosenberry 1975), and Eastern Meadowlark *Sturna magna* (Rosenberry and Klimstra 1970). In gulls, "empty" nests i.e. nests in which no eggs are subsequently laid, have been reported in Herring Gulls (Paludan 1951; Tinbergen 1961), Ring-billed Gulls (Ryder 1976), and Western Gulls (Harper 1971) (Table 17). In these species the occurrence of empty nests is limited to only a few specific gulleries and is not a typical behaviour for all individuals.

Table 17. Studies in which reference is made to gulls building nests which are subsequently not laid in.

Species	Year	Percentage of nests in which eggs were not laid	Details	Reference
Herring Gull	1943 - 1945	Not quantified	Some pairs described as having two or three completed nests at a time on one territory.	Paludan 1951.
Herring Gull	1949 - 1952	Not quantified	Empty nests described as "play" nests built by "young" birds that are not subsequently used for breeding.	Tinbergen 1960.
Western Gull	1966	54 %	Empty nests not major part of study and described briefly as "Inactive" nests.	Harper 1971.
Ring-billed Gull	1972 -73	24% and 29 %	Author suggests that empty nests are built by both first time breeders and "adult" birds. No suggestion that birds with empty nests also have a clutch nest (see later).	Ryder 1976.
Lesser Black-backed Gull	1980 - 1994	55 %	This chapter.	This thesis.

Figure 18. Percentage of total number of Lesser Black-backed Gull nests that were empty during the annual census of gull nests (9-11 May) at Tarnbrook Fell Gullery 1980-1994. Standard errors shown as vertical bars.



4.1.2. Empty nests at the Tarnbrook Fell Gullery

At the Tarnbrook Fell Gullery, the occurrence of "empty" nests has been noted since the first major surveys of the colony in the mid 1970's. Figure 18 shows the percentage of empty nests found during the annual census from 1980-1994 (Chapter 5). The proportions of empty nests have remained constant during this period (mean over 15 years = $55\% \pm 3.0$). It will be shown later in this chapter that the proportion of empty nests is the same at the end of the season as during the period of the annual census (9-20 May) i.e. empty nests found during the annual census do not have clutches laid in the nests after the end of the census. The interpretation and quantification of the presence of empty nests at a gullery is important if studies of population dynamics are based on annual counts of nests. The number of breeding pairs of gulls at Tarnbrook Fell was estimated in past surveys, by assuming that each nest, whether empty or with eggs, represented one pair. In order to test this assumption, a study of the empty nest phenomenon was made at the gullery in 1993.

4.1.3. General aims of empty nest study

- (i) To test whether one nest represents one pair of gulls at Tarnbrook and to calculate a correction factor for the annual census of nests at the gullery.
- (iii) To investigate if empty nests are built only by pairs that fail to lay clutches.
- (iv) To investigate behavioural differences in pairs that produce only empty nests and those that produce nests with clutches.
- (v) To investigate behavioural differences in pairs that produce single or multiple nests.

4.2. Methods

Prior to the return of the gulls in 1993, a study area (the EN-plot) was marked out within the Abbeystead Sanctuary. The plot covered 1.2 ha and was viewed from a canvas hide at the edge of the plot. Observations of the attendance and behaviour of the gulls on the plot were made over 56 days, from 4 April to 30 May. This period covered pre-nesting, nest building, egg laying, and the start of hatching on the plot. A total of 85 hours of observations were made on 22 occasions. The positions of the gulls on the plot were estimated using 30 marker canes and natural features within the plot, and 109 canes showing numbers that were used to mark all nests built. A map of the position of gulls on the plot was drawn at the start of each 30 minutes of observation. Birds newly arriving on the plot after the drawing of a map were also plotted. All displays, fights and mountings were recorded and mapped for each 30 minute observation period. The boundaries of a pairs' territory were determined from the observations of attendance and interactions with their neighbours. This was aided by the fact that it was possible to identify 37 (30%) out of 124 individuals using the plot, by distinctive plumage characteristics.

A complete survey of the area was made every three days and all new nests found were marked with a numbered cane. A 10m wide strip around the edge of the plot was also surveyed to include nests built outside the study area by birds whose territories extended within the plot. After direct observations had ended (30 May), all nests were monitored until mid-July and chicks ringed to determine fledging success at each nest. On 8 June 1993, a visit was made to the gullery on Walney Island, to investigate the proportions of empty nests at that colony.

Data were checked for normality prior to the use of parametric tests and, where appropriate, counts of gulls were $\log(x+1)$ transformed and percentages arcsine transformed. Where data were found not to be normally distributed, statistical tests

were carried out prior to and after transformation. Transformed data are presented only if the significance of the test was altered by transformation. Mean or median nest building dates were calculated by assigning the first date on which a nest was built as day 1 and then appropriately coding the date on which each nest was subsequently built.

In the text, nests in which no eggs were laid are called 'empty' nests and nests in which eggs were laid are called 'clutch' nests.

4.3. Results

4.3.1. Territories

The territories of gulls using the EN-plot in 1993 are shown in Figure 19. The position of empty nests and nests with clutches are shown in Figure 20. The breeding success of pairs on the plot and the number of territories are shown in Table 18. Sixty two territories were identified in which a total of 109 nests were built. Sixty four (58%) of the nests remained empty, and 45 (73%) of the nests had clutches laid in them. Three territory types were identified:

- (i) Territories with a clutch nest only = 16 (26%).
- (ii) Territories with empty nest(s) only = 17 (27%).
- (iii) Territories with a clutch nest and an empty nest(s) = 29 (47%).

4.3.2. Multiple nests

None of the territories contained two nests with clutches, but 37 (60%) of territories contained multiple nests. Figure 21 shows the percentage of territories with one, two, three, or four nests. There was no significant difference in the proportion of pairs with these number of nests, when comparing territories with empty nests and territories with clutch nests ($\chi^2=2.5$, 3 df, n.s.). For the pairs that produced clutches (n=45), the mean nest build date on territories with a single nest (n=16) was 4 May (S.E. \pm 2.9 days) Table 19. This was not significantly different to the mean nest build date (all nests) on territories with multiple nests (n=29): 7 May, S.E. \pm 1.9 (t=0.8, 43 df, n.s.). Also, the mean lay date (first egg) on single nest territories (15 May, S.E.=2.4) was not significantly different to the mean lay date on territories with multiple nests: 17 May, S.E. \pm 2.5 (t=0.6, 43 df, n.s.).

Figure 19. Lesser Black-backed Gull territories on EN-plot (Abbeystead Estate Sanctuary area). Tarnbrook Fell Gullery 1993.

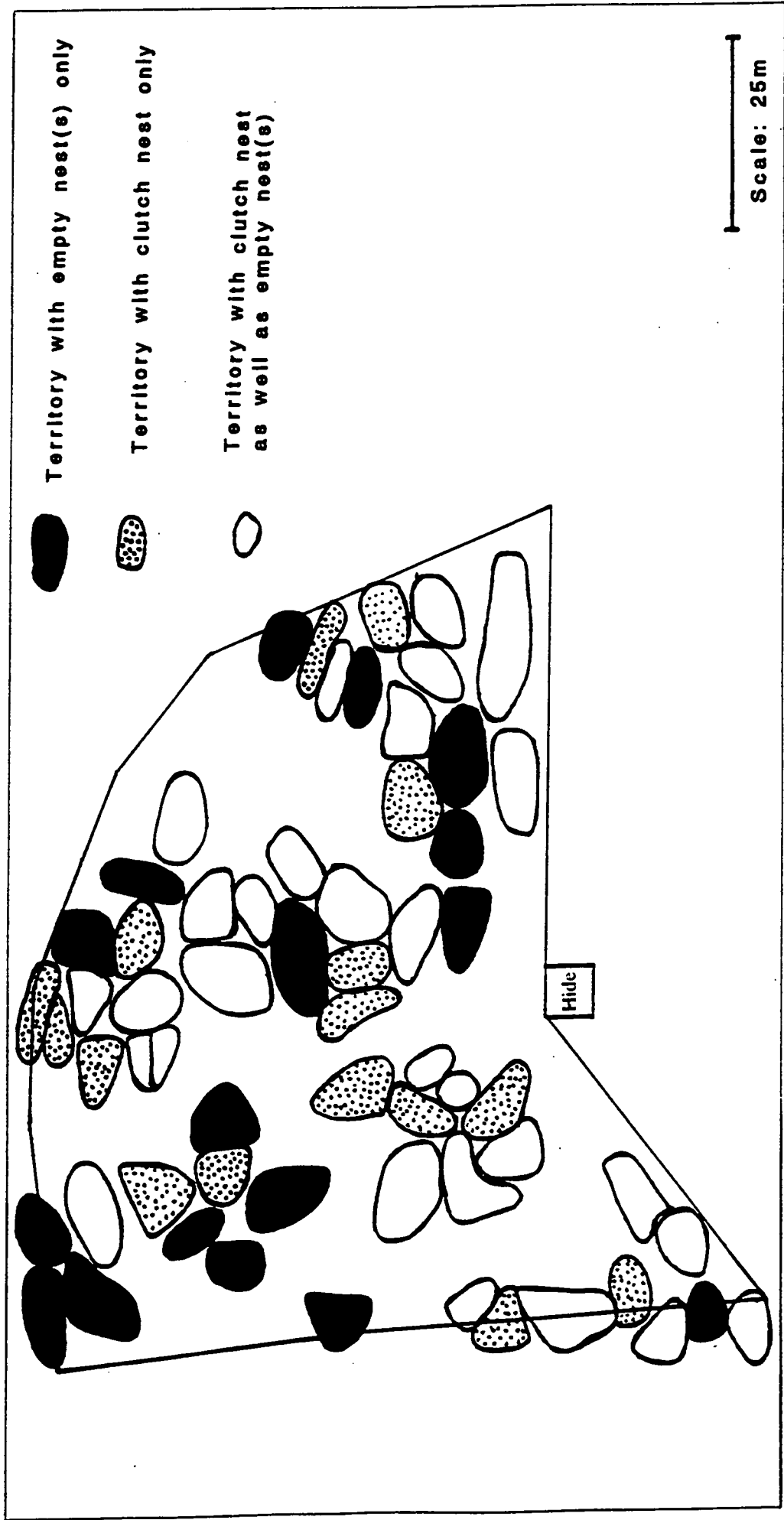


Figure 20. Position of Lesser Black-backed Gull nests with clutches and empty nests on EN-plot (Abbeystead Estate Sanctuary area). Tarnbrook Fell Gullery 1993.

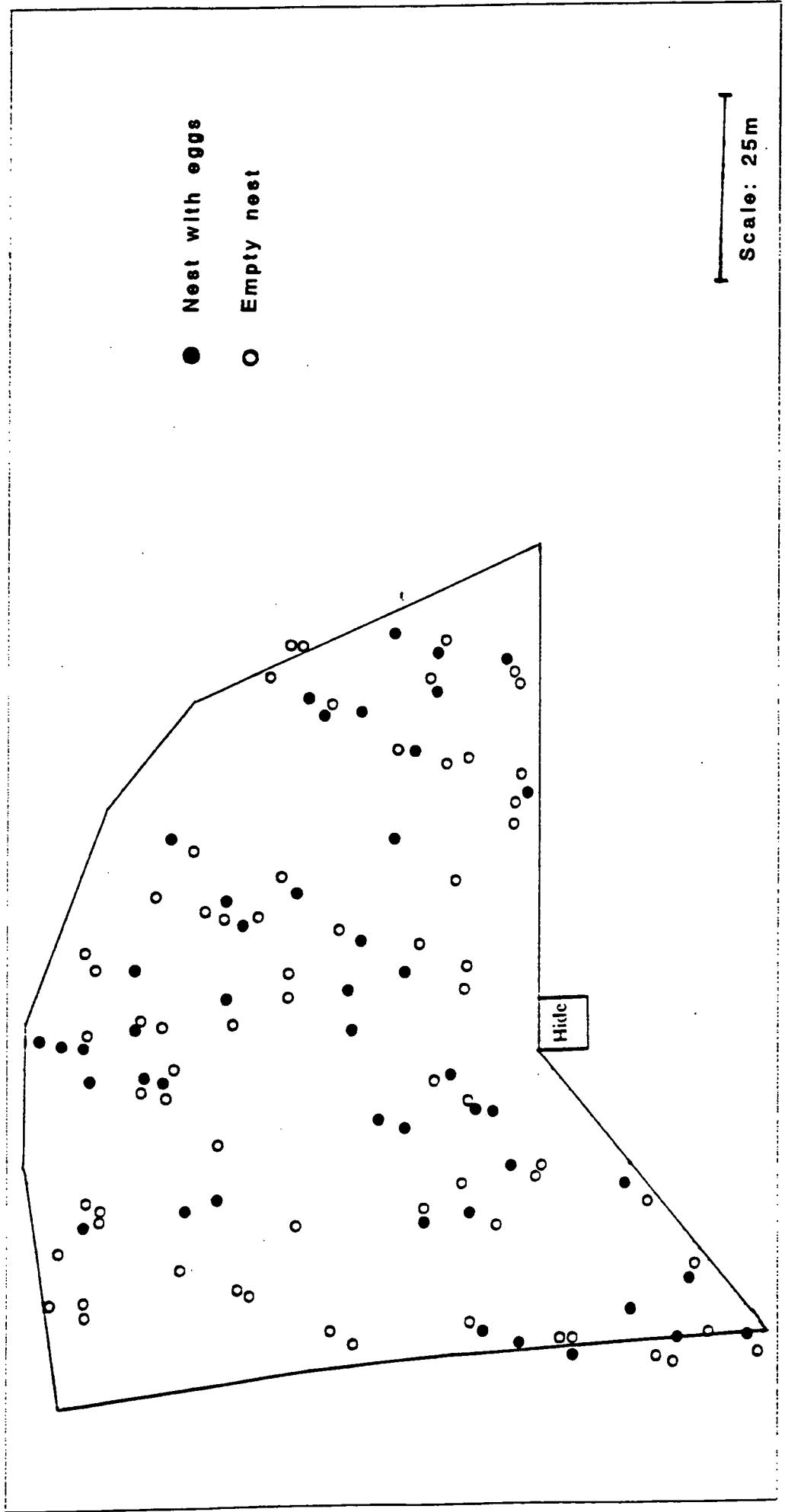


Table 18. Breeding success and productivity of Lesser Black-backed Gulls on the EN-plot 1993.

	Number	Percentage
Total nests in study	109	100 %
Total pairs	62	100 %
Territories with clutches	45	73 %
Territories without clutches	17	27 %
Territories with single nest	25	40 %
Territories with multiple nest	37	60 %
Eggs laid	122	100 %
Eggs hatched	95	78 %
Chicks fledging	69	73 %
Breeding success	69	56 %
Fledging success	69	73 %
Productivity per pair	1.53	--

Figure 21. Percentage of single and multiple nests on Lesser Black-backed Gull territories with and without clutches. EN-plot 1993.

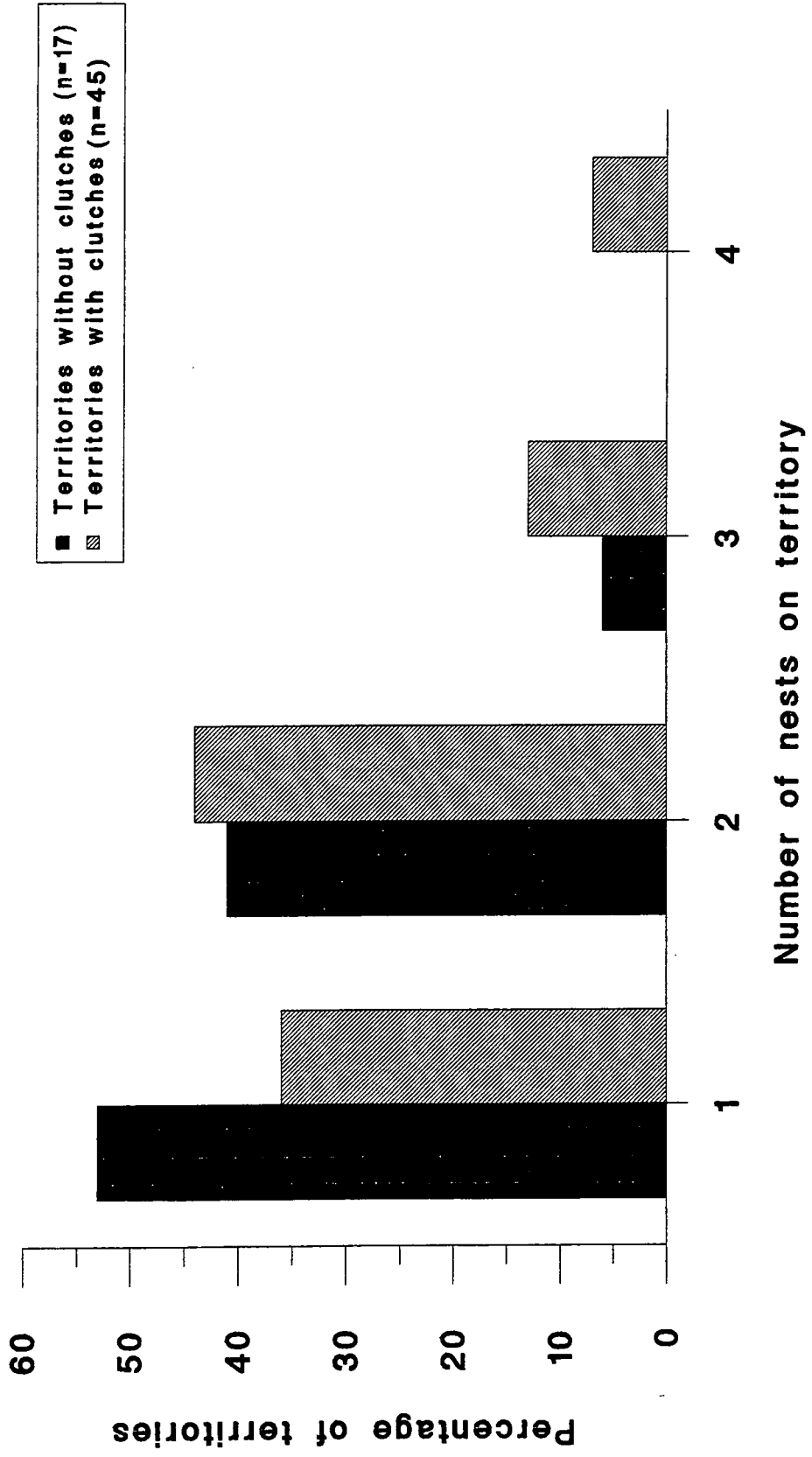


Table 19. Breeding events in Lesser Black-backed Gull territories with single or multiple nests (for pairs that laid clutches). EN-plot 1993 (standard errors given in parentheses).

	Territories with single clutch nest only (n=16)	Territories with clutch nest and empty nest(s) (n=29)	Significance
Mean nest build date	4 May (2.9)	7 May (1.9)	t=0.8, 43 df, n.s.
Mean lay date (1st egg)	15 May (2.4)	17 May (2.5)	t=0.6, 43 df, n.s.

4.3.3. Empty nests and nests with clutches

Empty nests were built both by pairs that failed to lay clutches and also by pairs that successfully produced eggs. Of the 64 empty nests on the study plot, 63% were built by pairs that also produced a clutch. When considering all 109 nests, there was no significant difference in the mean build date between empty nests (5 May, S.E.±1.6 days, range: 14 April-30 May=47 days) and nests with clutches (6 May, S.E.±1.7 days, range: 15 April-22 May=38 days) (t=0.5, 107 df, n.s. Table 20). The accumulative percentage of the total number of empty nests and nests with clutches built on the EN-plot are shown in Figure 22 and a histogram of frequency of building of the two nest types is shown in Figure 23.

Figure 22. Accumulative percentage of total number of lesser Black-backed Gull nests built on the EN-plot 1993.

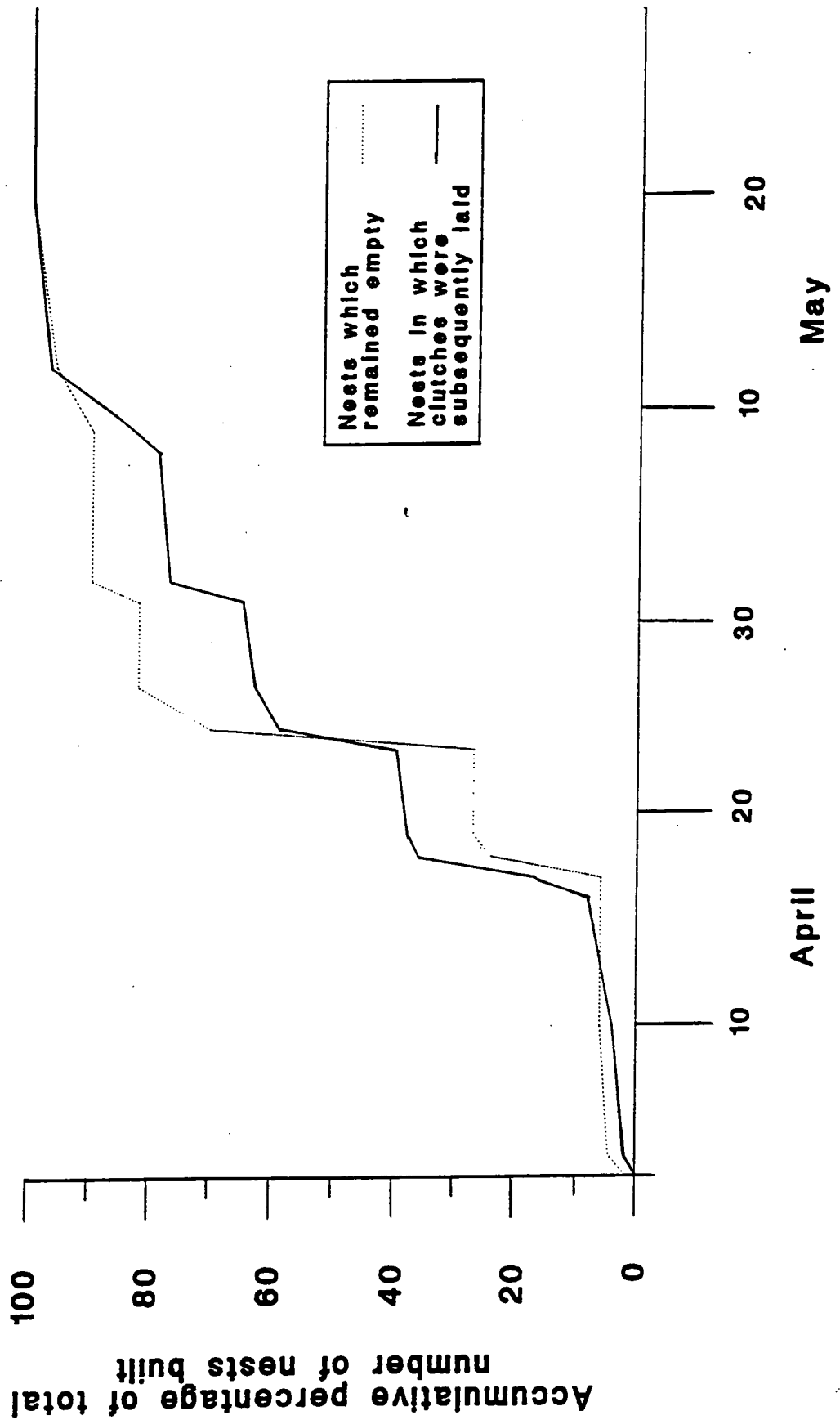


Figure 23. Frequency of nest building by Lesser Black-backed Gulls on EN-plot April-May 1993: empty nests and nests with clutches.

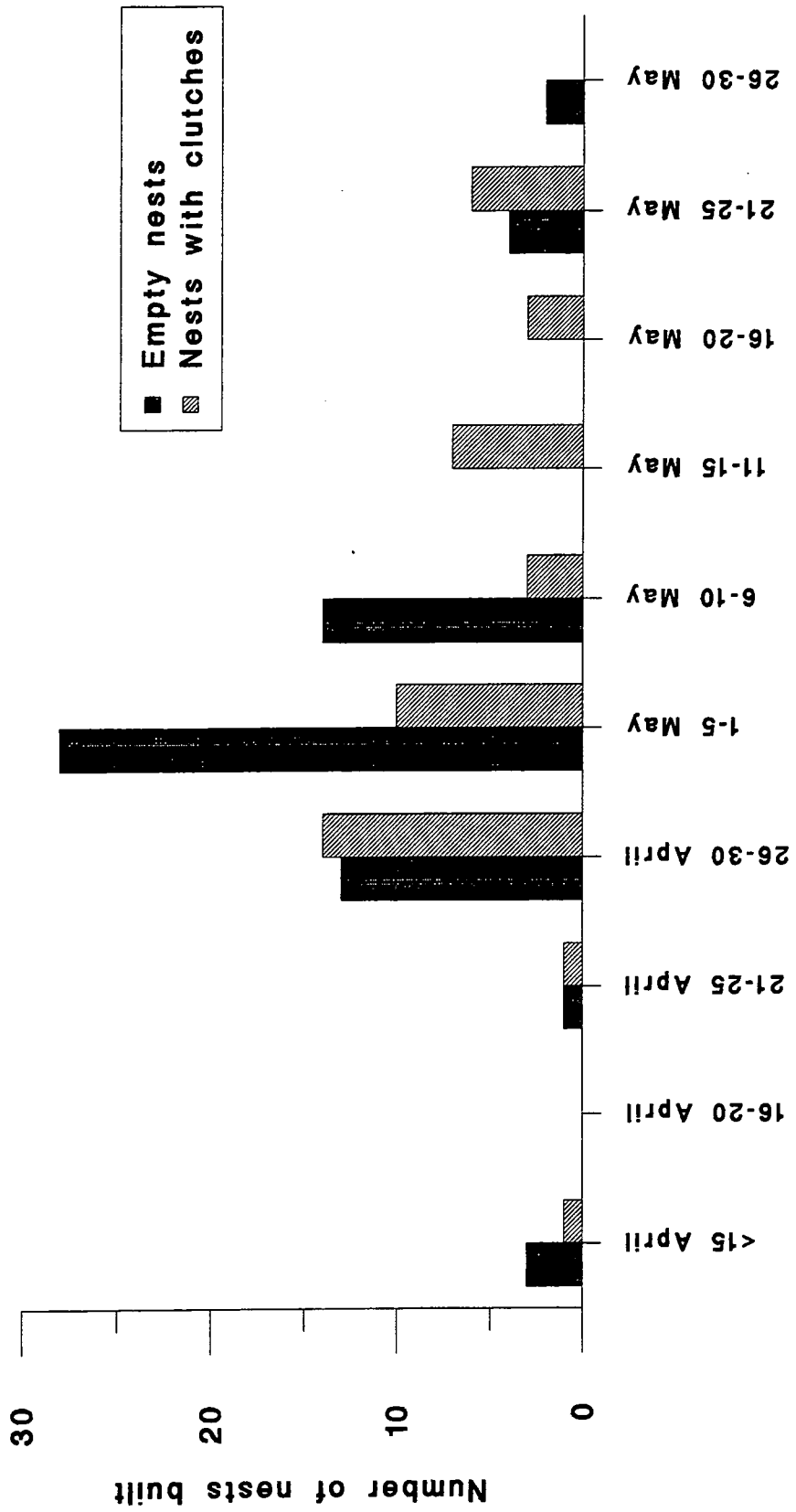


Table 20. Timing of building of empty and clutch nests by Lesser Black-backed Gulls on the EN-plot 1993 (standard errors in parentheses).

	Mean nest build date	Range
Empty nests	5 May (1.6) n=64	14 April - 30 May (47 days)
Nests with clutches	6 May (1.7) n=45	15 April - 22 May (38 days)

When considering only the empty nests built on the plot, the mean empty nest build date on territories where no eggs were laid was 6 May, S.E.±1.7 days (range: 21 April-22 May=32 days), compared to 4 May, S.E.±2.4 days (range:14 April-30 May=47 days) for empty nests on territories where a nest with eggs was also built. The difference is not significant: $t=0.8$, 62 df, n.s. (Table 21).

Table 21. Timing of building of empty nests on territories with only empty nests and territories where a nests with eggs was also built. EN-plot 1993 (standard error in parentheses).

	Mean nest build date	Range
Empty nests on territories without clutches	6 May (1.7) n=26	21 April - 22 May (32 days)
Empty nests on territories with clutches	4 May (2.4) n=38	14 April - 30 May (47 days)

4.3.4. Empty nests and nests with clutches on the same territory

In all, 29 (47%) of the pairs that laid clutches also built one or more empty nests. On 20 of these territories it was possible to discern the sequence in which the nests were built. The clutch nest was built first on 45 % of the territories on which the building sequence was known (31% of the total). On the remaining territories, the clutch nest was built either second, third or in one case fourth (Table 22). There was no significant difference in the number of nests with clutches that were built before an additional empty nest had been built, compared to nests with clutches built after an additional nest ($\chi^2 = 0.2$, 1 df, n.s.). On all the territories with both clutch and empty nests, no

additional nests were built after the first egg was laid. In other words, for pairs building multiple nests, selection of the clutch nest occurred after a range of nests had been built and the nest building urge stopped after egg laying began.

4.3.5. Nest density and the proportion of empty nests

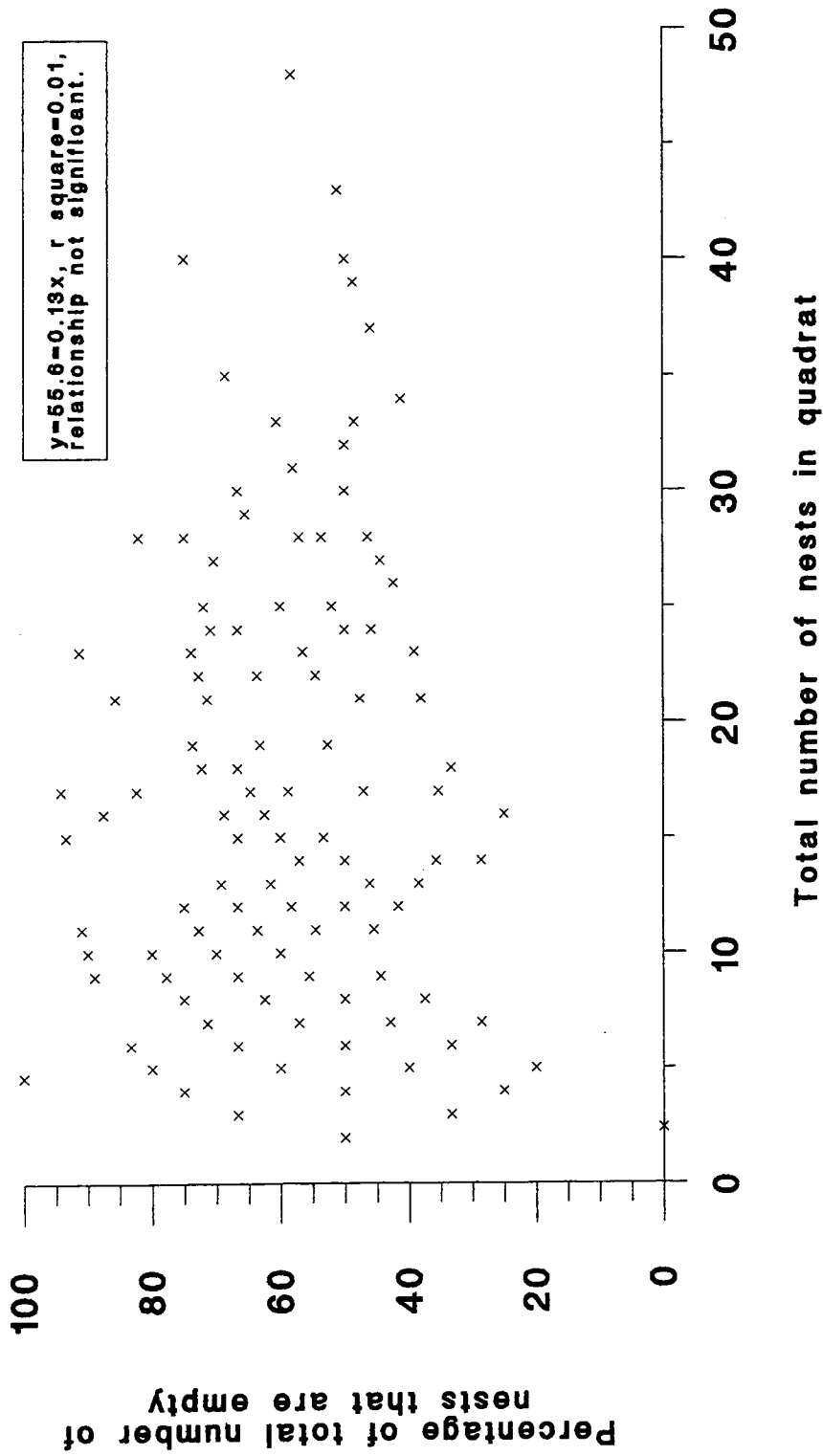
Data on nest density and the proportion of empty nests were collected during the annual gullery census (Chapter 5). A plot of the percentage of empty nests in a census quadrat (0.5 ha) against the total number of nests found is shown in Figure 24.

Information from the 1992-1994 surveys have been included. Data from quadrats in which 100% of the nests found were empty ($n=9$) and where 0% of the nests found were empty ($n=3$), were pooled for the analysis. No significant relationship was found between the proportion of empty nests in a quadrat and the nest density (number of nests). In other words, empty nests are found in the same proportions in areas of high or low nest densities.

Table 22. Sequence of building empty and clutch nests on Lesser Black-backed Gull territories with multiple nests: EN-plot 1993.

	Number of territories	Clutch nest built first	Empty nest built first	Nest building sequence unknown
Clutch nest and one empty nest	19	6 (32%)	6 (32%)	7 (36%)
Clutch nest and two empty nests	7	2 (29%)	3 (42%)	2 (29%)
Clutch nest and three empty nests	3	1 (33%)	2 (66%)	0
All territories with clutch and empty nests	29	9 (31%)	11 (38%)	9 (31%)

Figure 24. Relationship between total number of Lesser Black-backed Gull nests in a census quadrat and the percentage that are empty nests. Data from Tarnbrook Fell Gullery census 1992-1994 (n=172 quadrats).



4.3.6. The occurrence of empty nests at Walney Island

The Walney Island Gullery is 41 km west of Tarnbrook Fell and contains approximately 23,000 breeding pairs, of which 65% are Lesser Black-backed Gulls and 35% are Herring Gulls (T. Dean, personal communication). The number of empty nests and nests with clutches on 8 June 1993 compared with the EN-plot are shown in Table 23. Only 2% of the nests found at Walney Island (n=141) were empty compared with 64% at Tarnbrook at that time (109). The difference is highly significant: $\chi^2 = 107, 1$ df, $p < 0.001$. It is unknown whether the empty nests found at Walney Island had previously or subsequently contained eggs.

4.3.7. Territory attendance

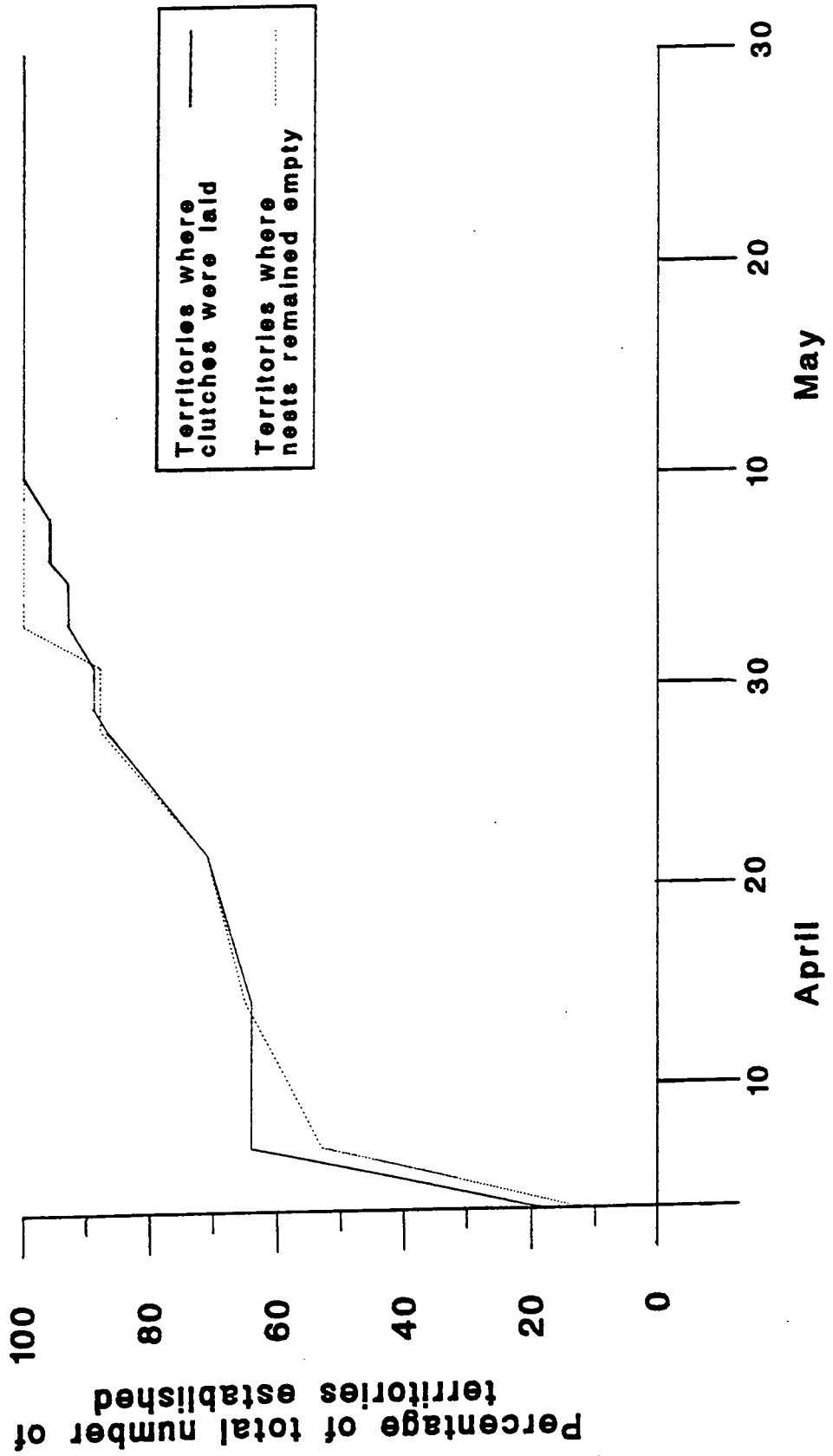
(i) Occupation of territories

There were no appreciable differences in the establishment of new territories (first date on which one bird of pair was seen on territory), for pairs that laid eggs and those building only empty nests (Figure 25). Prior to the start of egg laying on the plot (3 May), there was a significant difference in the geometric mean percentage of established territories that were occupied per day, between pairs that laid clutches (71%, 95% c.l.:68.2→73.3) and those that did not (76%, 95% c.l.:73.4→77.6) ($t = 3.9, 14$ df, $p < 0.01$) (Table 24). After 3 May, the geometric mean percentage of occupied territories occupied per day was 80% (95% c.l.:79.4→80.5) for pairs with clutches, compared to 62% (95% c.l.:60.1→63.7) for pairs without clutches. The difference is significant ($t = 2.8, 24$ df, $p < 0.01$). Considering the geometric mean percentage of occupied territories for pairs that produced clutches there was a significant increase in territory occupation (data given above) after 3 May ($t = 9.3, 19$ df, $p < 0.01$). The territory

Table 23. Comparison of percentage of total number of Lesser Black-backed Gull nests that were empty or contained eggs/chicks, on the EN-plot (Tarnbrook Fell Gullery) and at Walney Island: 8 June 1993.

	Percentage of empty nests	Percentage of nests with eggs	Percentage of nests with chicks
EN-plot: all nests (n=109)	64 %	18 %	18 %
EN-plot: nests with eggs (n=39)	--	49 %	51 %
Walney Island (n=141)	2 %	52 %	46 %

Figure 25. Establishment of Lesser Black-backed Gull territories on the EN-plot 1993.



occupation by pairs that did not lay clutches (above) significantly declined after 3 May ($t=5.8$, 19 df, $p<0.01$).

Table 24. The geometric mean percentage of established territories occupied per day prior to and after the start of egg laying on the EN-plot (3 May 1993), for Lesser Black-backed Gulls that laid clutches and those that did not (95% confidence limits shown in parentheses).

	Geometric mean percentage of territories occupied by pairs that produced clutches	Geometric mean percentage of territories occupied by pairs that did not produce clutches	Significance
4 April - 2 May	71% (68.2-73.3) n=8	76% (73.4-77.6) n=8	$t = 3.9$, 14 df, $p<0.01$
3 May - 30 May	80% (79.4-80.5) n=13	61% (60.1-63.7) n=13	$t = 2.8$, 24 df, $p<0.01$
	$t=9.3$, 19 df, $p<0.01$	$t=5.8$, 19 df, $p<0.01$	

There was no significant change in the attendance of gulls on the plot between 4 April and 2 May, for pairs that produced clutches ($t=1.2$, 6 df, n.s.) or for pairs that did not ($t=0.02$, 6 df, n.s.) (Figure 26). After egg laying had started on the plot, there was a significant drop in the percentage of occupied territories between 3 May and 30 May for pairs that did not produce clutches ($t=5.8$, 11 df, $p<0.01$). No significant change with time occurred during this period, in the attendance of pairs with clutches ($t=0.9$, 11 df, n.s.) (Figure 27). The slopes of the two regression lines for the attendance of the two types of territory holders after 3 May are significantly different to each other ($t=5.3$, 24 df, $p<0.01$).

Figure 26. Occupation of established Lesser Black-backed Gull territories prior to the start of egg laying (3 May) on the EN-plot 1993.

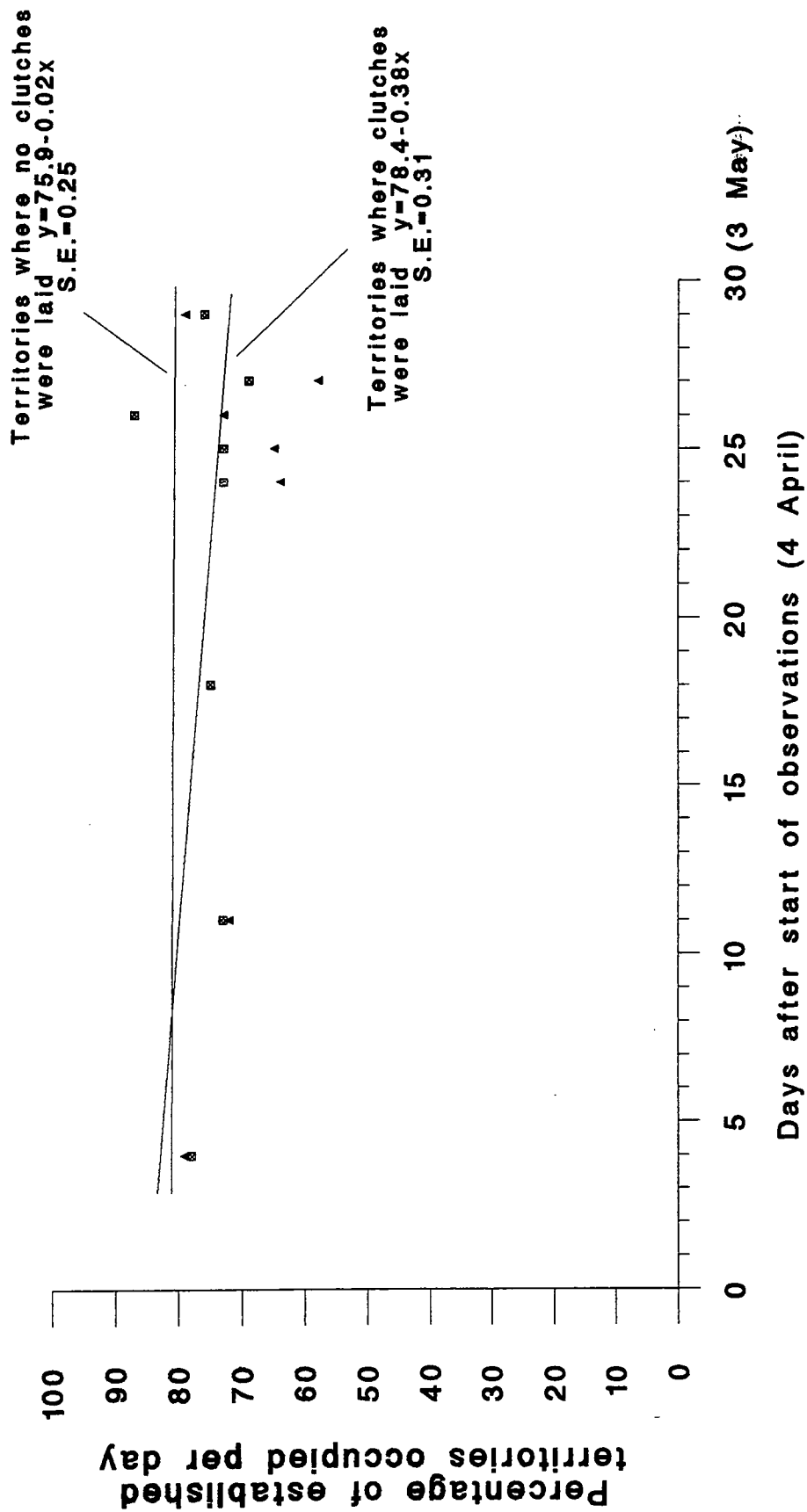
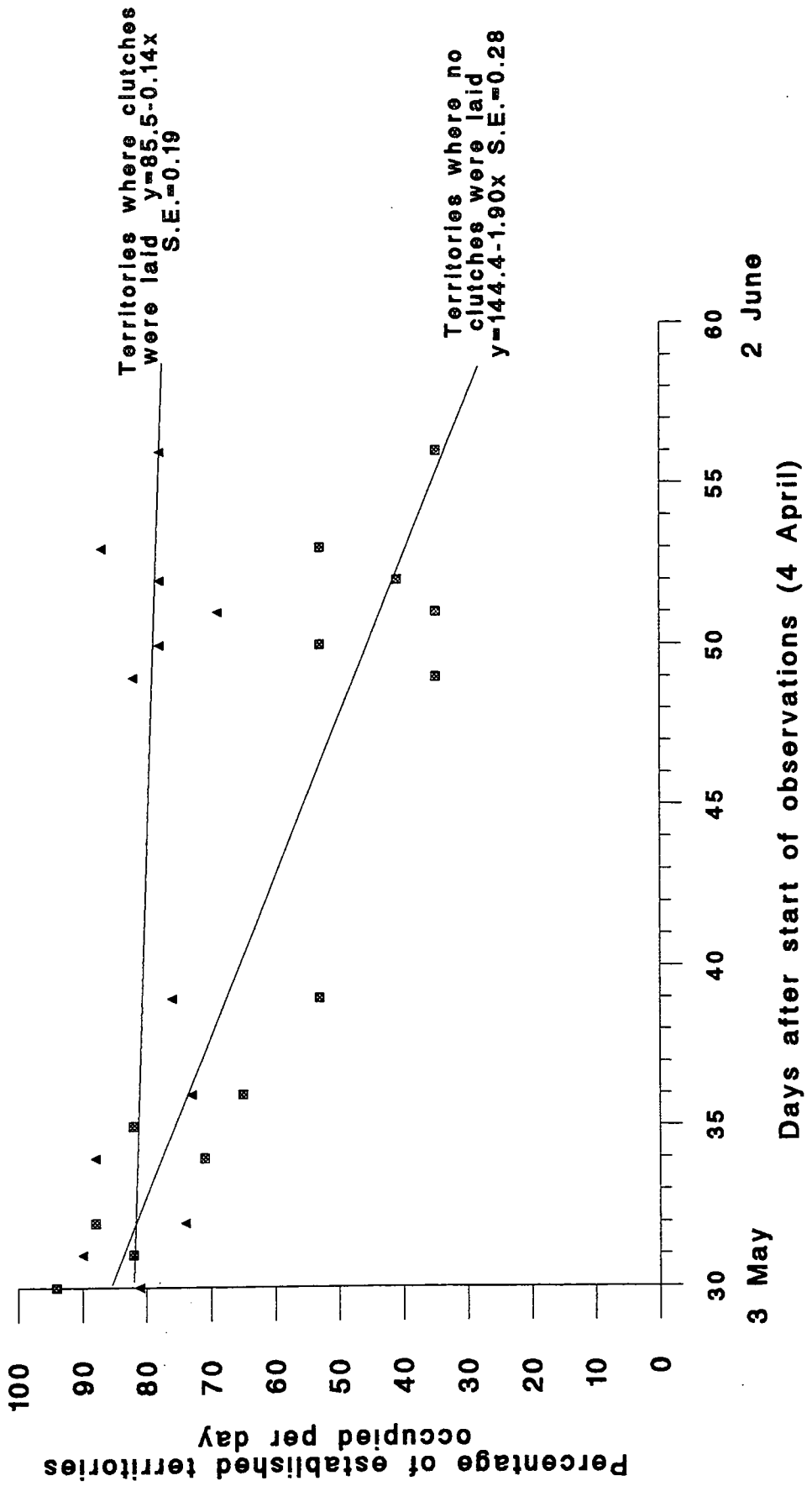


Figure 27. Occupation of established Lesser Black-backed Gull territories after the start of egg laying (3 May) on the EN-plot 1993.



(ii) Attendance of pairs:

Table 25 shows the percentage of 30 minute observation periods in which gulls were present on their territories either as a pair or singly. Attendance on all occupied territories has been summed for the analysis. When considering the entire study period, there was no significant difference in the percentage of the total number of 30 minute observation periods in which gulls that produced clutches were seen as a pair (48% attendance as pair) compared to birds that did not produce clutches (47% attendance as pair) ($\chi^2=0.2$, 1 df, n.s.). When comparing attendance as a pair between these two groups before and after the start of egg laying (3 May), significant differences were found: prior to egg laying, the percentage of attendance time as a pair was 69% for gulls that produced clutches. This was significantly higher than the 58% attendance as a pair for gulls who built only empty nests ($\chi^2=7.9$, 1 df, $p<0.01$). After egg laying had started, attendance as a pair by birds that produced eggs dropped significantly from 69% of total attendance time to 41% ($\chi^2=146$, 1 df, $p<0.001$). A smaller but still significant drop from 58% to 52% was found for birds that did not produce eggs ($\chi^2=13.6$, 1 df, $p<0.01$). For birds that produced clutches, the reduction can be accounted for by the fact that birds are present on the territory as a pair only when they change over incubating the eggs. This does not account for the fall in attendance as a pair on territories without clutches, but suggests that these non-breeding birds become progressively less interested in attending the territory. After egg laying had started, there was no significant difference in the percentage of total attendance time that the birds were present as a pair for birds that produced clutches (41%) and those that did not (42%) ($\chi^2=0.1$, 1 df, n.s.) but their behaviour was different with the former incubating eggs.

Table 25. Percentage of total number of 30 minute observation periods in which Lesser Black-backed Gulls were seen attending their territory as a pair or on their own (n = summed total number of observation periods for all territory holders in attendance on the plot). EN-plot 1993.

	Before start of egg laying (4 April-2 May)	After start of egg laying (3 May-30 May)	Whole observation period (4 April-30 May)
	Percentage of total attendance time as pair or single.		
	Pairs	Pairs	Pairs
	Singles	Singles	Singles
Gulls that produced clutches (45 pairs)	69 % n=430	41 % n=830	48 % n=1260
	31 % n=194	59 % n=1185	52 % n=1379
Gulls that did not produce clutches (17 pairs)	58 % n=115	42 % n=191	47 % n=306
	42 % n=84	58 % n=266	53 % n=350

4.3.8. Mounting behaviour

A total of 69 mounting events were recorded on the EN-plot during the study of which only 9 were made by pairs that did not produce clutches. Two types of mounting behaviour were classified: 'successful' mounting, where cloacal touching occurred, and 'unsuccessful' mounting where the male mounted the female but did not achieve copulation.

(i) All mounts seen on the study plot

Table 26 summarises mounting behaviour on the study plot for successful and unsuccessful mounts combined. The first mountings by birds that subsequently produced clutches was on 7 April. Although this was two weeks earlier than the first mountings by birds that did not produce clutches (21 April), only 3% of the total mountings had occurred in the first group by this date. There was no significant differences in the median mounting date for pairs that produced clutches (6 May) and for those that did not (7 May) ($U=256$, n.s.; Mann-Whitney U-test). Also there was also no appreciable difference in the cumulative percentage of observed mounts between the two groups (Figure 28). The geometric mean number of mounts per hour of attendance as a pair (mounting rate) for birds that produced clutches was 0.05 (95% c.l.:0.02-0.08). This was not significantly different to the mounting rate of pairs that did not produce clutches: 0.02 per hour (95% c.l.:0.01-0.05) ($t=1.15$, 60 df, n.s.). Nor was there a significant difference in mounting rates between the two groups after the start of egg laying on the plot: 0.08 per hour (95% c.l.:0.04-0.10) for pairs with clutches and 0.02 (95% c.l.:0.01-0.05) for pairs without clutches ($t=1.9$, 60 df n.s.).

So when all mounting activity is taken into account i.e. successful and unsuccessful combined, there were no appreciable differences between pairs that produced clutches and those that did not.

(ii) 'Successful' mounting

Table 27 summarise successful mounting behaviour on the study plot and Figure 29 shows the accumulative percentage of successful mountings on the study plot for pairs that laid clutches and those that did not. The first successful mountings for pairs without clutches was 5 May by which time 46% of successful mounts by birds that laid clutches had occurred.

Table 26. Comparison of mounting behaviour for Lesser Black-backed Gull pairs that produced clutches and those that did not on the EN-plot 1993. 95% confidence limits given for transformed means (see text).

	Pairs that produced clutches (n=45 pairs)	Pairs that did not produce clutches (n=17 pairs)	Significance
Number of mountings observed	60 (1.3 per pair)	9 (0.5 per pair)	--
Median mounting date	6 May Range: 7 April→25 May	7 May Range: 21 April→26 May	U=256, n.s. Mann-Whitney U- test
Percentage of total mountings before and after start of egg laying (3 May)	Before: 28 % After: 72 %	Before: 22 % After: 78 %	--
Geometric mean number of mountings per hour of attendance as pair before the start of egg laying period (3 May)	0.05 (0.02→0.08)	0.02 (0.01→0.05)	t=1.2, 60 df, n.s.
Geometric mean number of mountings per hour of attendance as pair after the start of egg laying period (3 May)	0.08 (0.04→0.12)	0.02 (0.01→0.05)	t=1.9, 60 df, n.s.

Figure 28. Accumulative percentage of total number of Lesser Black-backed Gull mountings (successful and unsuccessful) on territories where clutches were produced and territories where they were not. EN-plot 1993.

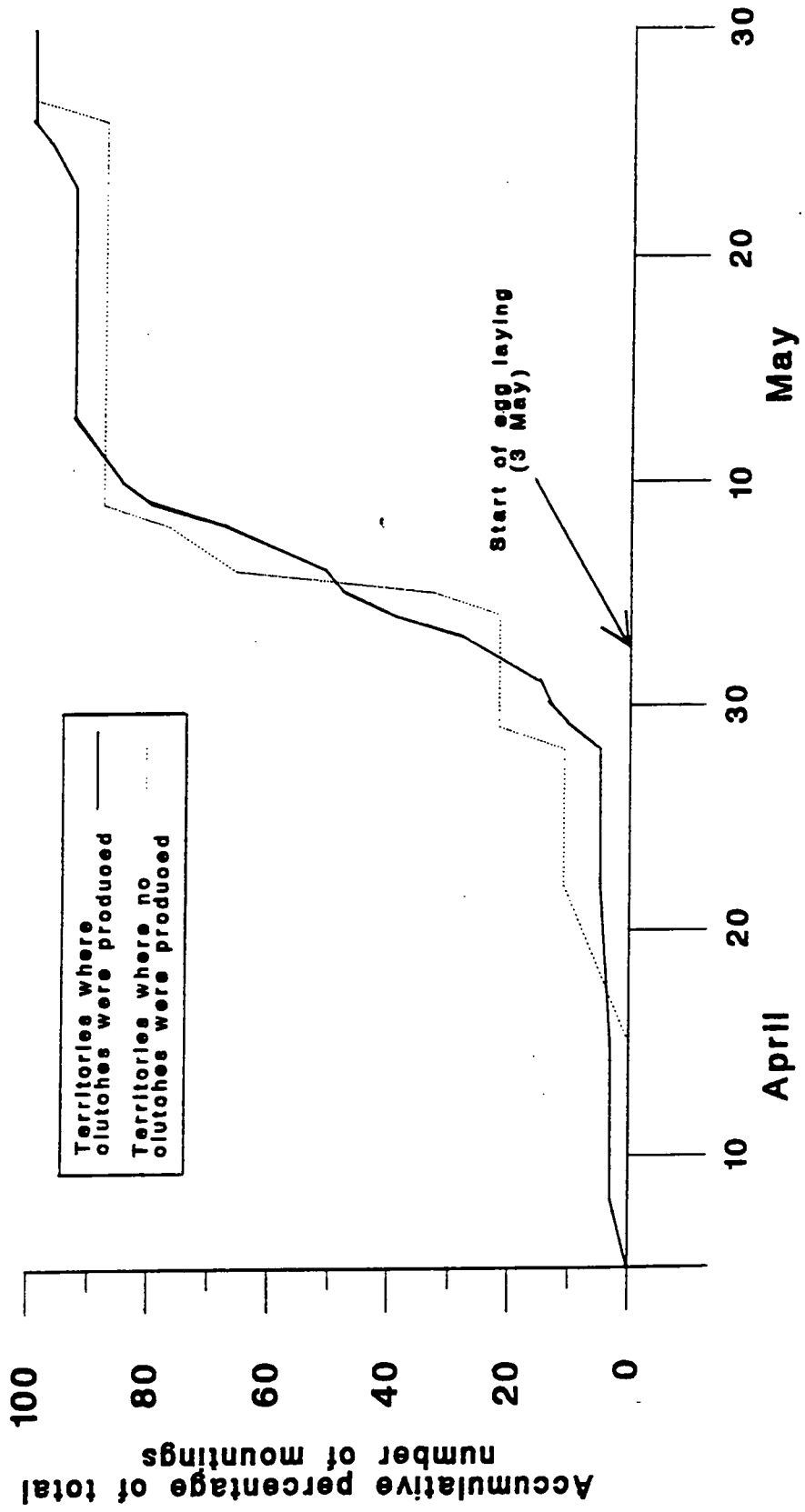
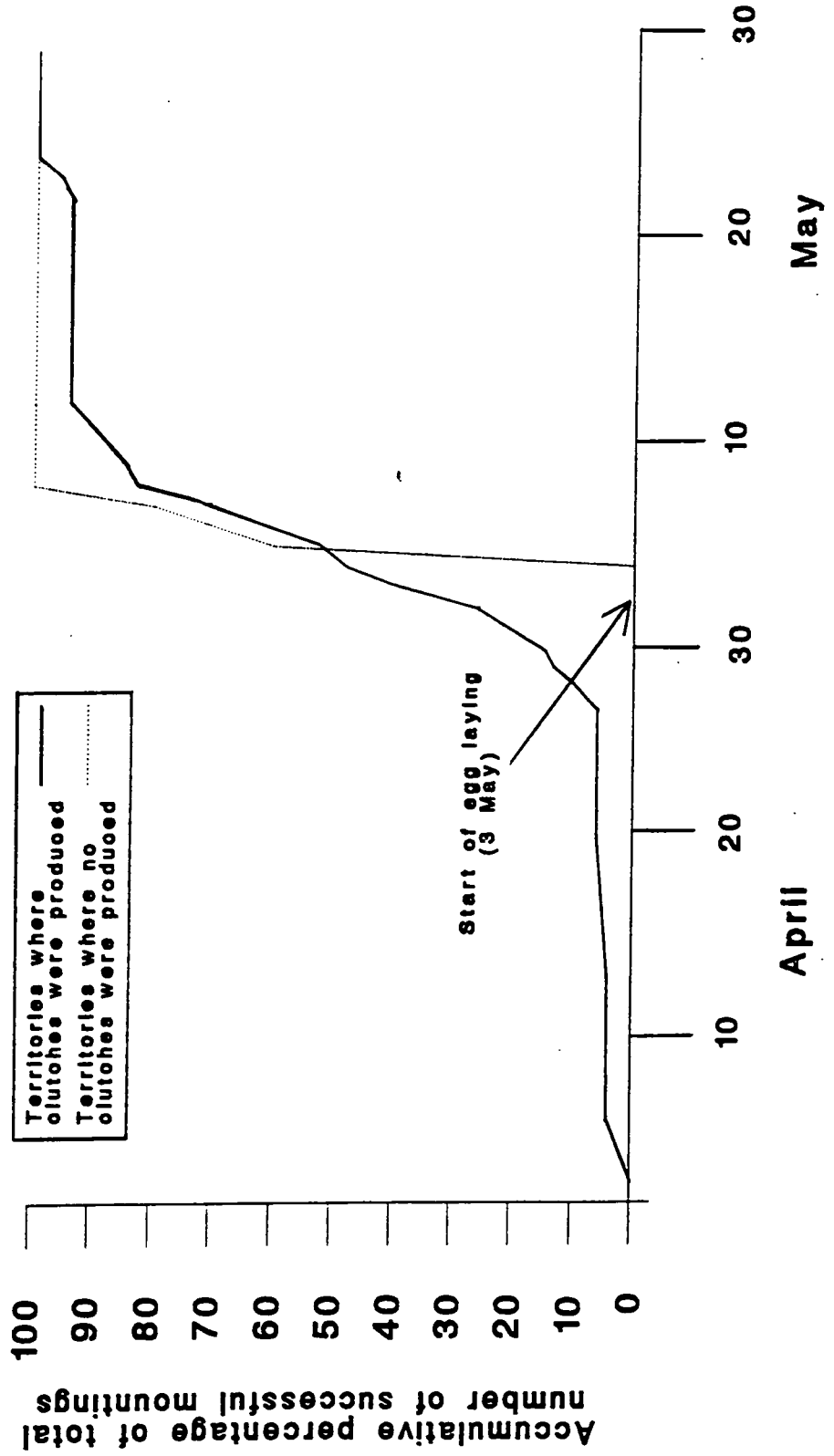


Table 27. Successful mounting behaviour (cloacal contact) for Lesser Black-backed Gull pairs that produced clutches and those that did not on the EN-plot 1993. 95% confidence limits given for transformed means (see text).

	Pairs that produced clutches (n=45)	Pairs that did not produce clutches (n=17)	Significance
Number of successful mountings observed	54 (1.2 per pair)	5 (0.3 per pair)	--
Percentage of total mounts that were successful	90 %	56 %	--
Median successful mounting date	2 May Range: 7 April→25 May	6 May Range: 5 May→8 May	U=114, n.s. Mann-Whitney U-test
Percentage successful mountings before and after start of egg laying (3 May)	Before: 30 % After: 70 %	Before: 0 % After: 100 %	--
Geometric mean number of successful mountings per hour of attendance as pair before the start of egg laying period (3 May)	0.04 (0.02→0.06)	None	t=2.3, 60 df, p<0.05

Figure 29. Accumulative percentage of total number of successful Lesser Black-backed Gull mountings (cloacal contact) for territories where clutches were laid and territories with only empty nests. EN-plot 1993.



Also, 90% of mountings were successful for birds that laid clutches compared to 56% for those that did not. The median successful mounting date was not significantly different between the two groups: 2 May for birds that laid clutches, 6 May for those that did not ($U=114$, n.s.; Mann-Whitney U-test). None of the pairs that failed to produce eggs achieved successful mountings prior to 3 May (the start of egg laying on the plot). The geometric mean number of mounts per hour of attendance as a pair (mounting rate) prior to egg laying was 0.04 (95% c.l.:0.02→0.06) for birds that produced clutches. The difference is significant ($t=2.3$, 60 df, $p<0.05$). After egg laying, the mounting rate was 0.08 per hour (95% c.l.:0.05→0.12) for birds that produced clutches and 0.02 per hour (95% c.l.:0.01→0.04) for those that did not. The difference is significant ($t=2.1$, 60 df, $p<0.05$).

4.3.9. Territory size

The mean territory size for pairs with and without clutches are shown in Table 28. The mean size of territory for birds with clutches ($n=45$) was $35.2 \text{ S.E.} \pm 2.3\text{m}^2$. This is not significantly different to the $35.3 \text{ S.E.} \pm 2.6\text{m}^2$ for birds that failed to lay clutches ($n=17$) ($t=0.01$, 60 df, n.s.). The mean territory size for birds with clutches that built only one nest was $30.8 \text{ S.E.} \pm 1.9\text{m}^2$. This is numerically smaller, but not significantly different, to the $37.7 \text{ m}^2 \pm 17.5$ for birds that produced a nest with a clutch and one or more empty nests ($n=29$) ($t=1.5$, 43 df, n.s.). In other words, the pairs that did not lay eggs or produced only a single nest, did not establish significantly smaller territories than pairs that laid eggs or built multiple nests.

Table 28. Mean area of Lesser Black-backed Gull breeding territories (m²) on the EN-plot 1993. (Standard error given in parentheses).

	Mean territory area (m ²)	Range (m ²)	Number of territories
All territories	35.3 (1.8)	12 - 91	62
All territories with clutches	35.2 (2.3)	12 - 91	45
Territories with only empty nest(s)	35.3 (2.6)	21 - 56	17
Territories with single nest with clutch	30.8 (1.9)	16 - 43	16
Territories with single clutch nest in addition to one or more empty nest	37.7 (3.3)	12 - 91	29

4.3.10. Correction factor for Tarnbrook census data based on nest counts

Every year since 1979, the census of breeding birds in the gully has been carried out between 1-20 May (Chapter 5). At this time, 80% of the final number of nests have been built (O'Connell and Coulson 1992). In 1993, a total of 98 nests had been built on the EN-plot at the time of the census. To obtain the number of breeding pairs, it would normally have been assumed that one nest represents one pair and that the nests found were only 80% of the final total. Thus, the number of breeding pairs would have been calculated as follows:

$$\text{Number of breeding pairs} = \text{number of nests found} \times (100+80)$$

$$= 98 \times 1.25 = 123 \text{ pairs.}$$

The empty-nest study showed that there were in fact only 62 pairs attempting to breed on the area. A correction (multiplier) factor of 0.50 would have to be applied to the nest total in order to correctly calculate the actual number of breeding pairs. During the census, an average of 17% of the nests in a census plot are missed (Chapter 5) but it was known that the number of nests used in the above calculations, was the total number that had been built i.e. 100% rather than 83% of all the nests because the plot was surveyed every three days. In an average survey of the plot during the census, 81 out of 98 nests would have been found and the number of breeding pairs on the plot would have been calculated as:

$$\text{Number of breeding pairs} = 81 \times 1.25 = 101 \text{ pairs.}$$

To obtain the actual number of breeding pairs (62) a correction multiplier of 0.61 must be applied to the count of nests in a census. Data presented in this thesis concerning the number of breeding gulls in the colony (based on nest counts), have been appropriately corrected.

4.4. Discussion

4.4.1. Number of breeding gulls in colony

It has been shown that at Tarnbrook Fell, empty nests are not solely associated with pairs that fail to lay eggs and the assumption on which all past census work at the colony has been based i.e. one nest represents one pair, has been shown not to be true. Nest counts from past surveys can nevertheless provide a useful 'index' of changes in gull numbers at Tarnbrook Fell (or can be converted by multiplying by the 0.61 correction factor). It should be noted that the number of "breeding" birds estimated by applying the correction factor to counts of nests, includes the 27% of pairs that held territory but failed to produce eggs and this must be accounted for in any estimates of chick productivity for the gullery.

4.4.2. Empty nests

Although the building of 'empty' nests has been noted in other larid species, the Tarnbrook Fell Gullery appears to be the only colony of Lesser Black-backed Gulls where this activity has been recorded. During courtship in this species, the female of a pair follows the male as he walks around the territory and both stop at a number of different places to give the 'choking' display. Each of these stops represent a potential nest site and eventually the pairs' attention and choking displays are confined to one area where the nest that will contain the eggs is subsequently built (Brown 1967). On the

EN-plot, the same birds were seen chocking at several sites on their territory on different dates. Ground scraping and the moving of nest material also occurred at these sites and these accounted for the empty nests i.e. the gulls at Tarnbrook build 'complete' nests at sites where in other gulleries, only chocking displays would occur. The 1993 empty-nest study at Tarnbrook has quantified the number and proportion of empty nests in relation to the number of breeding pairs, but the reasons why the birds should build them in the first place remains unexplained. The nests could possibly be the result of a surfeit of nesting material available to the gulls at Tarnbrook or due to snow covering up nests in April (nest building time) causing birds to build new nests. Neither of these explanations, however, can account for the fact that only some pairs show this behaviour and not others or why the proportion of empty nests is so constant from year to year. It also does not explain why the behaviour is not seen at other colonies. No relationship was found between the proportion of empty nests and nest density, and empty nests were not solely the result of failed breeding (64% of successful pairs also build empty nests in addition to the clutch nest). Nor was territory size different between pairs that built single nests compared to pairs that built multiple nests.

4.4.3. Pairs that do not produce clutches

The study of empty nests also revealed that 27% of pairs that held a territory did not subsequently produce eggs. Attendance on the territory by these pairs was significantly lower compared to pairs with eggs and attendance declined with time after the start of egg laying by other pairs on the study plot (3 May). Birds that failed to produce eggs also achieved significantly fewer mountings and successful copulations. Why these gulls should establish territories but not be able to achieve similar numbers of copulations as pairs that produced eggs is unclear. There are several possible explanations:

(i) Culling of large numbers of adults in the gullery during the past, has altered the age structure within the gullery and reduced the age of first breeding. This occurred after culling of adults on the Isle of May, in Scotland (Coulson *et al.* 1982) where the mean age of first breeding was reduced by a year. It is possible that the gulls without clutches may be young, inexperienced breeders who are able to establish a territory, but are not experienced enough to take their breeding attempt through to the egg laying stage. There are several problems with this idea. Firstly, the culls on the Isle of May did not result in high proportions of pairs building nests but not laying eggs. Secondly the number of gulls killed in each year of the culls at Tarnbrook were highly variable between 1978 and 1988 (Chapter 5) and no large scale culls have occurred at the colony since 1988. This being the case, one would expect a higher degree of variability in the proportion of empty nests than has been recorded since 1980. It should also be noted that only one single bird and two pairs from the group that failed to produce clutches, had physical characteristics that suggested recent immaturity e.g. dull leg colour, brown or very worn remiges or retrices, or the presence of a gonys ring (Cramp and Simmons 1983). Also, one individual and three of the pairs that did produce a clutch, showed some or all of these characteristics. Ryder (1976) studied a group of Ring-billed gulls *L. delawarensis* and was able to separate 'young' (first time breeders) and 'adults' (experienced breeders) by plumage characteristics. He found that 29% of the nests built (n=194) were not subsequently laid in, and that 68% of the empty nests had been built by adult birds. In other words, failure to produce eggs was seen in both adult and young birds.

(ii) The territory holding pairs without clutches may be birds that are not in good enough breeding condition to produce eggs. A major factor in attaining suitable breeding condition is the availability of food (Bolton 1991), although it is hard to see why food availability should be markedly different for Tarnbrook Fell gulls compared to those at the two nearby gulleries at Walney Island and Ribble Marshes, where empty

nests do not occur. Also the productivity of the pairs that did produce eggs on the EN-plot in 1993 (1.53 chicks fledged per clutch laid) was relatively high compared to productivity at other Lesser Black-backed Gull colonies (Chapter 5) suggesting that food acquisition, at least during chick rearing, is not a problem for the Tarnbrook Fell gulls. It is possible that the altitude of the gullery and its position on the western edge of the Pennines may have an effect on the gulls' breeding performance. The entire gullery is above 450m and the weather encountered by the gulls early in the season is more severe than at Walney Island which is coastal and at sea level. Frost and snow regularly occur during nest building and immediately prior to egg laying at Tarnbrook Fell, and this may adversely affect some of the gulls by interrupting their pre-egg laying courtship behaviour and/or energetically stressing the birds and preventing the mobilisation of sufficient body reserves to produce a clutch of eggs. Again, it is hard to see why this behaviour would not also be seen at other colonies in occasional years of very severe weather. It should be noted that inclement weather conditions do not directly cause empty nests i.e. there was not a widespread loss of clutches during periods of bad weather.

(iii) There is evidence that gulls which formerly bred on the experimental disturbance site have moved to other areas of the gullery to breed. Birds that establish new territories at an appreciable distance from the previous years' breeding site are not likely to retain their original mate i.e. the pair become 'divorced'. This was discussed fully in Chapter 3, but here it is important to note that the main consequence of divorce is a reduction of breeding success in up to two breeding seasons after the acquisition of a new mate (Wooller and Coulson 1977, Coulson and Thomas 1980, Fretterolf 1984). It is possible that the disturbance experiments and past culling activities (which would tend to increase divorce when one partner of a pair was culled) between 1978 and 1994 have increased the proportion of divorced gulls within the colony. The gulls that fail to produce clutches may be divorced birds attempting to establish themselves on a new

area with a new partner. Of course divorce occurs at other colonies in the absence of disturbance and culling and the culls on the Isle of May did not produce this effect. The proportion of gulls maintaining a pair bond for less than two seasons has been estimated to range from 5% in Silver Gulls (Tasker and Potts 1981) up to 25% in Kittiwakes (Coulson 1966). In all cases where divorce has been recorded, the divorced birds have been able to produce clutches in subsequent seasons and it was clutch size and fledging success that was reduced rather than a total inability to produce eggs.

The investigation of empty nests in Ring-billed Gulls by Ryder (1976) and the descriptions of empty nests by Paludan (1951), Tinbergen (1960) and Harper (1971) do not allow comparisons of nest density, colony size, vegetation, topography or territory size to be made with the Tarnbrook Fell Gullery. Variables that may have given rise to empty nests at these colonies and not others can not therefore be investigated and a satisfactory answer to the question of why the gulls at Tarnbrook build empty nests is still required. The major problem is to discern why the activity does not occur at other colonies and why only some of the gulls at Tarnbrook build empty nests. It is also unclear why the proportion of empty nests is unrelated to density and why it has been constant since at least 1980.

CHAPTER FIVE

POPULATION DYNAMICS AT TARNBROOK FELL GULLERY: the development of rational management strategies for gulls.

5.1. INTRODUCTION

The assumption that killing large numbers of individuals of a pest species will have the immediate effect of substantially reducing their numbers, has been shown to be mistaken in the case of a variety of serious avian pests e.g. Red-billed Queleas *Quelea quelea* (Elliot 1988), Feral Pigeons *Columba livia* (Lefebvre 1985), and European Starlings *Sturnus vulgaris* (Feare 1989). Major culling programmes have been followed by compensatory effects in breeding parameters of surviving birds that reduce, or completely compensate for the overall effectiveness of the culls. An example of this occurred on the Isle of May where large numbers of gulls were culled during the 1970's. The culls resulted in increased breeding success, a reduction in the age of first breeding, and increased recruitment into the breeding group (Coulson *et al.* 1982). It has also been recently recognised that different species will have different sensitivities to control methods depending on the particular breeding system and life history of the species involved (Croxall 1991). Long lived birds with low reproductive rates i.e. K-selected species such as gulls, are affected to a greater extent by control measures directed at adult mortality than fecundity. This will be looked at more closely later in this chapter.

An understanding of the population dynamics of a species is therefore essential if the problems it causes are to be successfully managed. The complexity of most larid

population dynamics necessitate the use of demographic 'models' to describe the processes involved in a simplified and meaningful way. Estimation of several demographic parameters are required for the modelling process.

5.1.1. Demographic parameters

(i) Productivity

Estimates of gull productivity are obtained by monitoring individual nests and marking chicks to determine the number fledging. Productivity used in population models must be derived from up-to-date information gathered from the particular problem group in question because large variations can occur between years and between different colonies. This is illustrated in Table 29:

Table 29. Number of chicks fledged per pair of Lesser Black-backed Gull on Skomer Island and Isle of May in 1989 and 1991. Data from JNCC report (1992).

	1989	1991
Skomer Island	0.04	0.45
Isle of May	0.98	0.54

(ii). Survival rates

Survival rates for gulls have generally been estimated from ringing recovery data i.e. the sightings of ringed individuals at various points of time after they were initially ringed. Table 30. shows the variation in the published survival rates of adult Herring Gulls determined by this method. It is generally accepted that survival is slightly lower in the first year of a gulls life, although after the first year, survivorship of immature birds appears to be almost identical to that of breeding adults (Coulson and White 1959; Chabrzyk and Coulson 1976).

Table 30. Variation in published Herring Gull adult survival rates.

Estimated adult survival rate	Geographical area	Reference
0.85	Denmark	Paludan (1951)
0.90	Germany	Drost <i>et al.</i> (1961)
0.66	North America	Hickey (1952)
0.70	Fenno-Scandia	Olsson (1958)
0.91	North America	Kadlec and Drury (1968)
0.94	Britain	Harris (1970)
0.90	Britain	Parsons (1971)
0.93	Britain	Chabrzyk and Coulson (1976)

(iii) Immigration and emigration rates

Realistically estimating immigration and emigration rates presents many practical and theoretical difficulties and many population models have been unable to incorporate

empirical data. The 'process' of immigration into a particular colony can be demonstrated from ringing recoveries, but few ringing schemes have so far been extensive enough to quantify actual rates of immigration. It is also possible to estimate immigration from differences between the total number of breeding gulls in a colony and colony productivity in previous years (Duncan 1981; Wanless and Langslow 1983).

Emigration poses an equally difficult problem in modelling the dynamics of gull numbers. Tinbergen (1953) recorded gulls ringed as chicks returning to breed in their natal colony (philopatry) and assumed that this was 'typical' behaviour. It was not realised at the time, that only a proportion of Herring Gulls display philopatry i.e. a proportion of chicks return to breed at their natal colony while others emigrate to breed elsewhere. Coulson (1991) was able to use data from the Isle of May ringing and culling programmes of the 1960's and 70's to estimate emigration rates of Herring Gulls and found that approximately 30% of the chicks that survived to breeding age returned to their natal island (normally within 200m of their place of birth) and 70% bred at other colonies.

This sort of information is not available at most colonies, and as with productivity, emigration and immigration rates are likely to be colony specific and will be affected by colony size and density, and the distance to the nearest neighbouring colony

(iv) Number of non-breeding birds

The presence of non-breeding birds in a population is an important issue in the management of a problem species. Lesser Black-backed Gulls do not breed for at least the first three years of their lives and many will not breed until their sixth year or more. The non-breeding component of gull populations therefore consists mostly of young birds that have not started to breed, but also includes adults that have bred in the past but have not done so in one particular year. Young non-breeding birds are important

because they will ultimately recruit into the breeding group and will thus require management in future years i.e. in species where there is a large number of non-breeding birds, management efforts will have to be spread over a number of years. It is rarely possible to estimate the number of non-breeders in a population, but attempts have been made to estimate the numbers of immature pre-breeders by recording the distribution of ages at which ringed individuals were first seen to breed or from life tables (Chabrzyk and Coulson 1976; Weimerskirch and Jouventin 1987; Croxall *et al.* 1990).

(v) Number of breeding birds

An evaluation of the efficacy of management strategies depends on reliable estimates of the number of individuals both locally and nationally. A variety of techniques have been employed to estimate gull numbers: counts of nests in whole colony, sub-sections or line transects, and direct counts of breeding birds (headcounts) in entire colony or using sub-sections (see Lloyd 1991 for review). The methods used depend on the species involved, the purpose of the study and the human resources available. The accuracy of the estimate is affected by differences in observer ability, daily and seasonal variations in the number of gulls in the colony, and the size and breeding habitat of the group to be counted. Standardisation of methods is crucial if the data are to be used for modelling trends in group size. The methods used to estimate gull numbers at Tarnbrook Fell are evaluated later in this chapter.

5.1.2. Modelling changes in gull numbers

The aims of demographic modelling are extremely varied. Some models can assist the conservation of an endangered species, while in contrast, others may help to control a pest. The function of a model is to provide information on the changes in the number of

individuals *per se*, but perhaps more importantly, to shed light on the processes involved in bringing about these changes. They also allow predictions to be made of the likely effects of a particular management strategy. The complexity of the model used will, to some extent, reflect the overall aims of the study, but will also be a function of the availability and accuracy of the demographic parameters described earlier. In some instances, a range of demographic parameters can be used in the model to overcome shortcomings in the available data. A model of gull numbers at Tarnbrook Fell is developed later in this chapter and used to evaluate the relative efficacy of the different management methods that have been tried at the colony.

5.2. METHODS

5.2.1. Estimating gull numbers at Tarnbrook Fell and Walney Island

Tarnbrook Fell Gullery

The number of gulls at Tarnbrook Fell has been estimated in a variety of different ways since the colony was first established in 1938. The methods are summarised in Table 31. Prior to 1973, estimates were based on headcounts of adults present in the colony during May or early June. Since then, surveys have been based on counts of nests. The two methods produce dissimilar results (Lloyd 1991) and the estimates of the number of birds in the colony before and after 1972 have been treated separately.

Walney Island

Population estimates from Walney Island play an important role in understanding the dynamics of gull numbers at Tarnbrook Fell. Walney lies 41km west of Tarnbrook, and was established at approximately the same time as the Tarnbrook colony. Sixty-five percent of the birds are of Herring Gulls and 35% Lesser Black-backed Gulls. Between 1934 and 1991 a total of 14 surveys of the gullery were made using nest counts. An estimate based on adult gulls was also conducted in 1994 (T. Dean, personal communication).

Table 31. Census methods for assessing the number of breeding gulls at the Tarnbrook Fell Gullery 1938 - 1994.

Census Year	Count date	Count method	Reference
1938 - 1973	?	Head counts from vantage points.	Duncan 1978
1974 - 1975 and 1979	May	Number of nests counted in 85 quadrats (0.5ha) placed randomly on fell and in 1979 nest counts in a 2m x 8.4 km line transect.	Duncan 1978; Wanless and Langslow 1980
1980	1-20 May	Colony divided into five areas. On Abbeystead Estate, a grid of 150 x 150m cells used to divide area with one quadrat placed on each intersection of the grid. On Mallowdale and Brennand quadrats were placed "haphazardly". 100 quadrats were surveyed for nests. There were three quadrat sizes: 0.5ha, 0.25ha and 0.04ha.	Wanless and Langslow 1980
1981 - 1988	9-16 May	Number of nests counted in 65 quadrats (0.5ha), sited on the colony using a random number generator. From 1986, 60 quadrats (0.5ha) were surveyed.	Wanless and Langslow 1981 and 1982; Tasker and Langslow 1983; Griffiths and Tasker 1984; Benn and Tasker 1985; Beveridge and Tasker 1986; Ward and Tasker 1987; Thomas and Tasker 1988
1990 - 1991	8-18 May	As above, with 12 old quadrats removed in the Sanctuary area and replaced with 20 new ones.	Peck and Coulson 1991
1992 - 1994	11-20 May	Number of nests in 57 quadrats (0.5ha) in the non-Sanctuary area based on a stratified grid system over whole colony and 24 quadrats (0.5ha) on a smaller stratified grid for the Sanctuary area (see text).	O'Connell and Coulson 1992 and 1993(a); Royle and Coulson 1994

5.2.2. The annual nest census 1992-1994

In 1992 a new quadrat system was introduced to estimate gull numbers at Tarnbrook Fell. The previously used 'random' system made no provision for quadrats that were selected in adjacent positions. This meant that some areas of the fell were under-represented in the census. Accordingly, a grid was drawn over a map of the colony and two quadrats placed randomly within each grid square (Figure 30). Figure 31 shows the number of old quadrats in each of the new grid squares. A total of 57 new quadrats were established and used to census the whole colony. These quadrats will be called the 'large grid system'. To obtain more detailed information of the changes occurring in the Sanctuary area, a grid system was also drawn over this area but the grid squares were a quarter the size of the large grid system squares. One quadrat was then randomly sited in each of the smaller cells giving a total of 24 quadrats (Figure 32). These quadrats will be called the 'small grid system'. The new system thus provides a randomised design but ensures that each unit area of the fell is equally represented. The number of quadrats chosen for the new system was a compromise between obtaining a reasonable sample size and the number of quadrats it is possible to survey in the time 'window' allocated to the census (see later). In 1992, both the old and the new quadrat systems were surveyed, to allow comparisons to be made between the 1992 old system data and that of previous years, as well as the new system data with future years. In 1992, each quadrat was permanently marked with a large wooden stake in the bottom left hand corner of the quadrat. This means that the 1992-1994 data were collected from exactly the same areas. In surveys prior to 1992, the position of each quadrat on the fell could only be positioned approximately during the census.

In 1993, seven of the large grid system quadrats were not surveyed because of the disturbance experiments taking place in the colony (Chapter 3) and the associated reduction in the colony boundary. In 1994, the number of quadrats was reduced by a further five for the same reasons.

Figure 30. Grid used to position quadrats for the annual census of gull nests at Tarnbrook Fell Gullery 1992 onwards - large grid system.

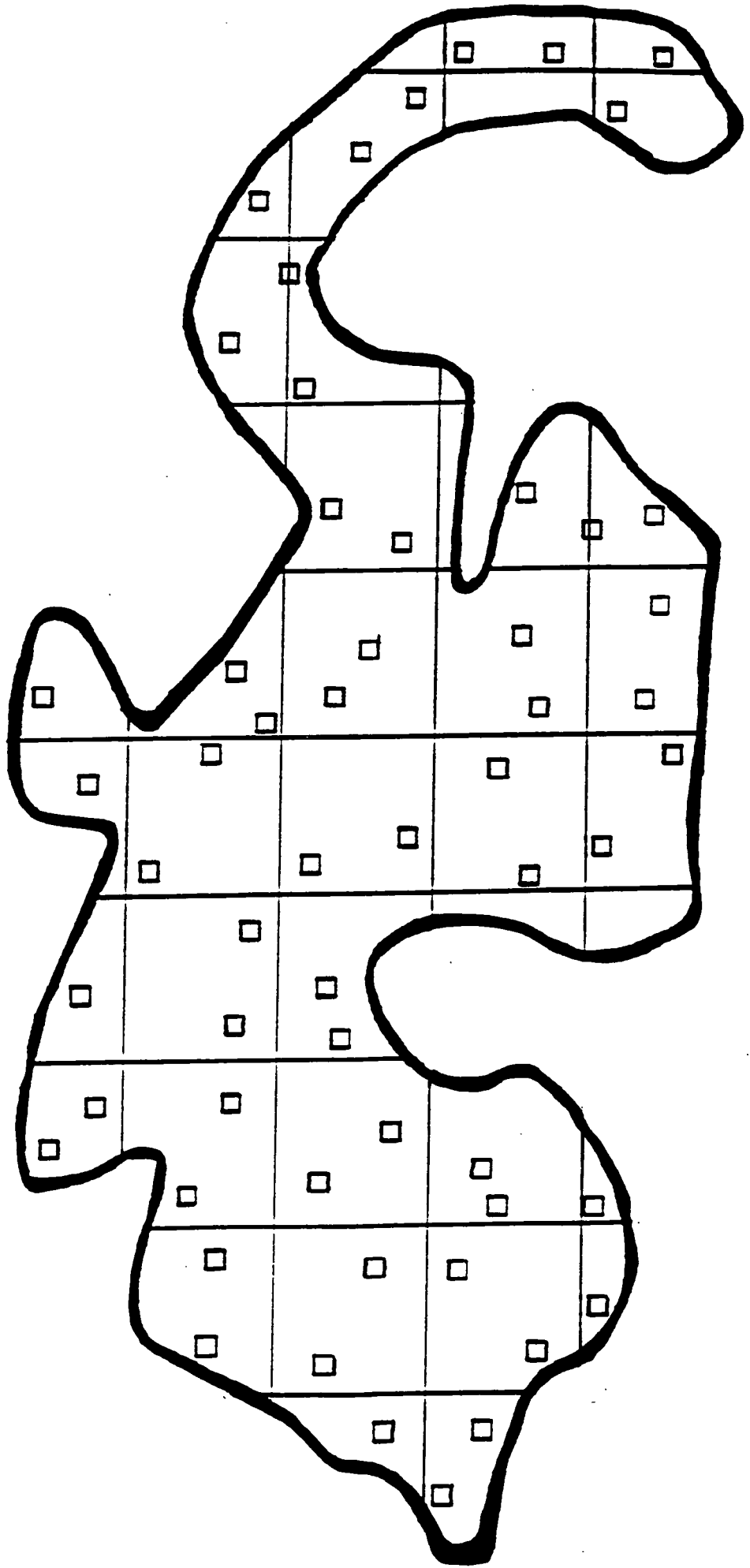


Figure 31. Number of quadrats used to census gulls at Tarnbrook Fell prior to 1992 that were contained within each of the grid squares used to position quadrats from 1992 onwards (2 quadrats per grid square). See also Figure 30.

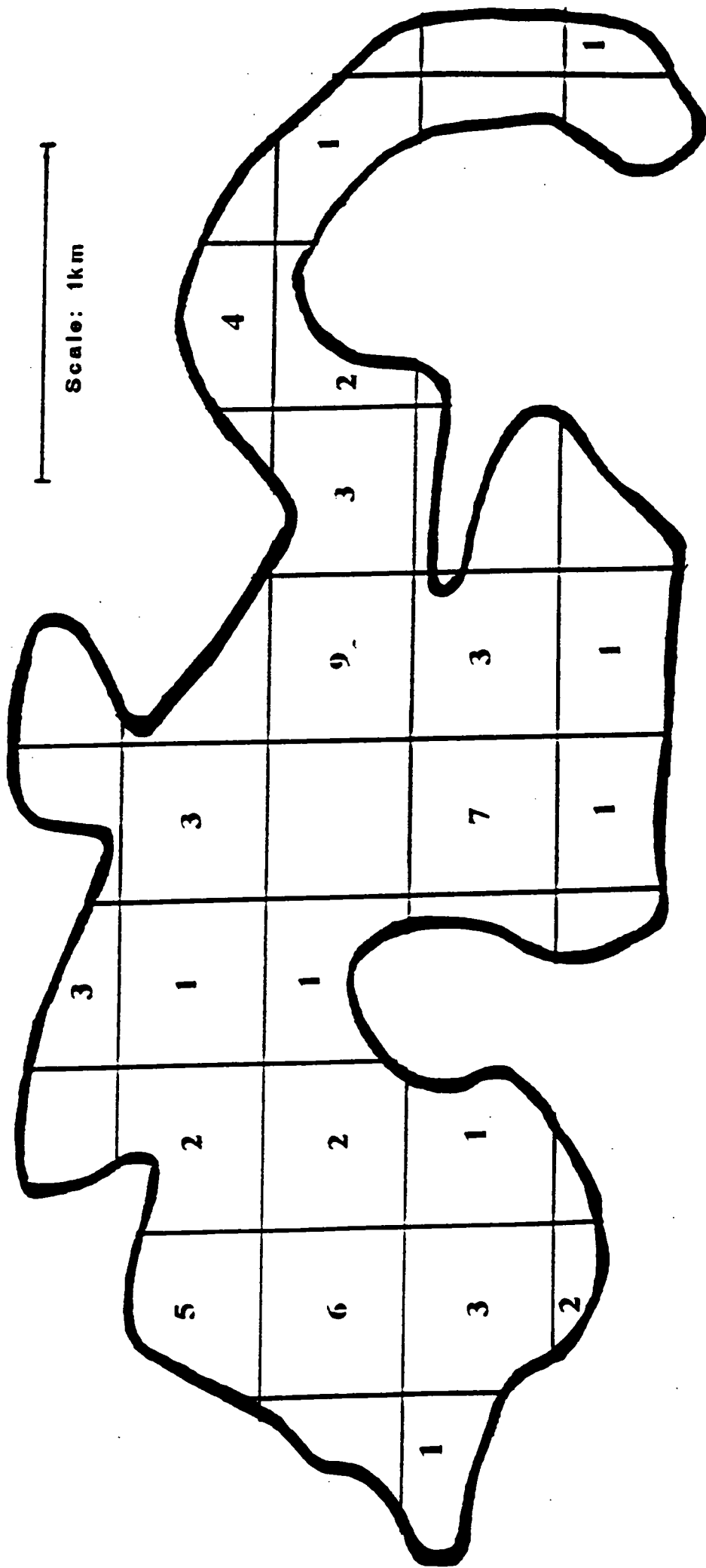
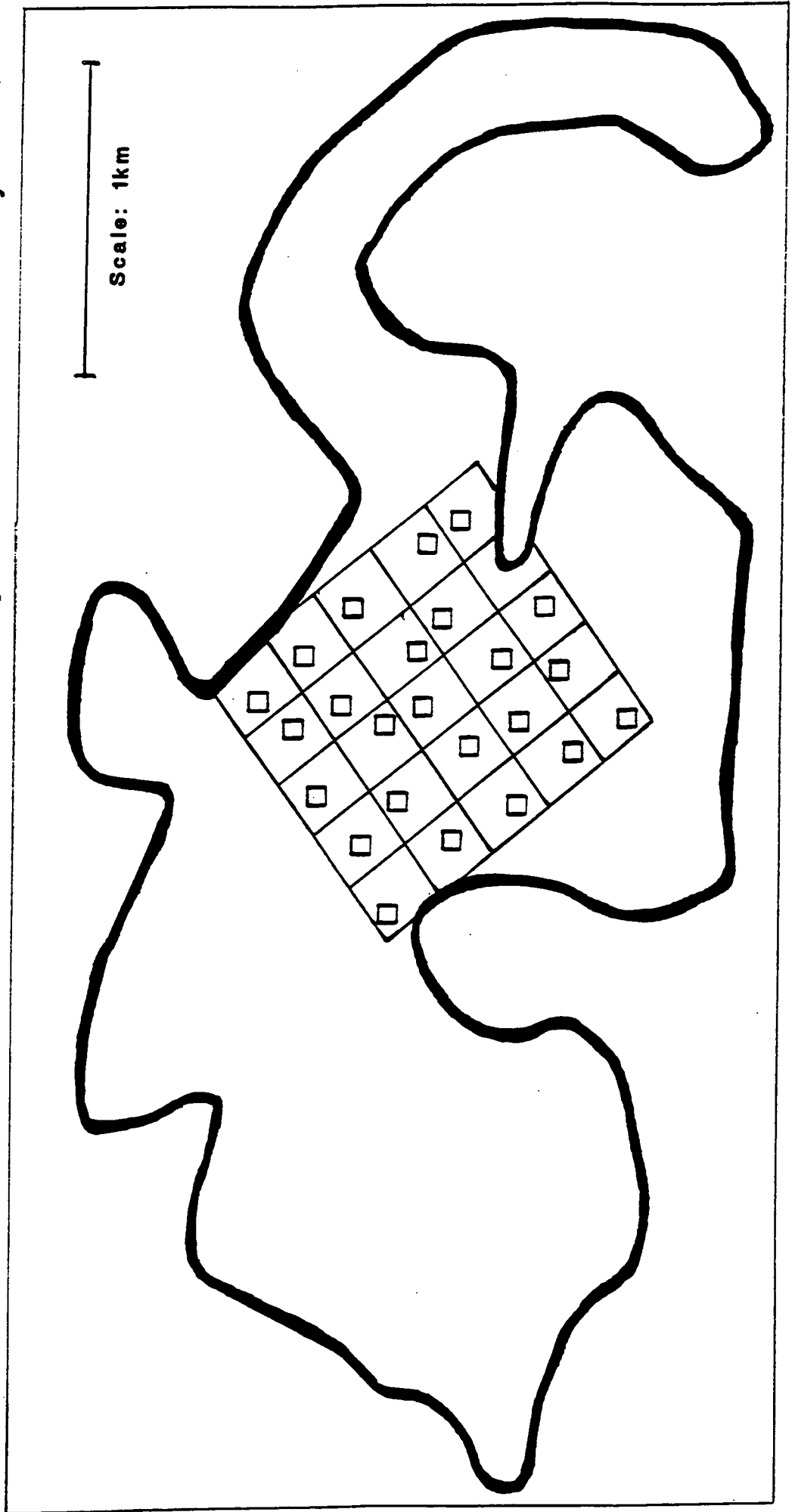


Figure 32. Grid used to position quadrats for the annual census of gull nests at Tarnbrook Fell Gullery 1992 onwards - small grid system for the Sanctuary area.



5.2.3. The colony boundary and the percentage composition of gull species

Changes in the extent of the colony during the early years after its establishment were not monitored or recorded. Since 1976, the colony boundary has been mapped prior to the start of the census, by observing the position of nests and by direct observation of breeding birds from suitable vantage points. The ratio of Herring and Lesser Black-backed Gulls was also estimated by counting groups of standing birds on all three estates and calculating the appropriate percentages.

5.2.4. Timing of the census since 1980

The three surveys between 1992 and 1994 were conducted from 11 May to 20 May inclusive. The current number of census quadrats require a minimum of a week to completely survey, depending on the speed of the team and the weather conditions during the census period. All surveys since 1980 have been conducted at approximately this time. Wanless and Langslow (1980) estimated that 80% of the total number of nests in the colony had been built by the mid-point of the census period (15-16 May) and this assumption has been used in the calculations of the number of breeding birds (see below). In 1992-1994 nests in ten study quadrats were monitored every three to five days from the date of construction until the end of the breeding season. This permitted the assumption of 80% nest completion at the time of the census to be tested. In 1992, all the monitored nests were in the non-Sanctuary area. In 1993 and 1994, the number of monitored nests was approximately equal between the Sanctuary and non-Sanctuary areas (details in section on breeding success).

5.2.5. Estimation of number of breeding gulls

The number of breeding birds in the colony was estimated by calculating the mean number of nests per quadrat and multiplying by the appropriate scalar to obtain an estimate for the entire gullery area. This was then corrected for the 80% factor mentioned above i.e. multiplied by 1.25. The colony area was measured in km² and there were 200 quadrats in 1 km². Thus:

$$\text{Number of breeding pairs} = \text{mean number of nests per quadrat} \times 1.25 \times 200 \times \text{colony area}$$

This however, is based on the assumption that one nest represents one pair. At the Tarnbrook Fell Gullery, this has been shown not to be the case (Chapter 4) and a correction factor of 0.61 must be applied to the above figure to obtain the number of breeding pairs. The correction factor was not quantified until 1993, but nest counts of nests from previous surveys are presented in the corrected form.

5.2.6. Census protocol 1992 - 1994

As well as refinements in the sampling regime, a more rigorous nest search protocol was followed for the 1992 -1994 surveys. Three people were used in each census, and the quadrats delineated using six 2m canes with flags. A 50m length of rope, parallax and compass bearings ensured that the quadrats were oriented correctly and that the sides were straight, the correct length and perpendicular. The quadrats were searched by walking from one side to the other in a series of sweeps, 10m wide. All nests were

marked with a flag. At the end of the search, the flags were collected and the number of nests and clutches recorded.

5.2.7. Estimating breeding success and productivity

In 1993, 109 nests in the Sanctuary and 105 nests in the non-Sanctuary were monitored every three to five days throughout the breeding season. In 1994, 167 nests in the Sanctuary and 133 nests in the non-Sanctuary were monitored. The chicks produced at these nests were ringed and monitored until fledging. Breeding success was also monitored by the same method at the Ribble Marshes Gullery (D. Lambert and Lancashire Ringing Group) in 1993 and 1994. This mixed colony of Herring and Lesser Black-backed Gulls is 40km south-west of Tarnbrook and contains 1500 pairs of gulls (1994). Comparisons of breeding success at the two gulleries are made later in the chapter.

5.2.8. The culling period 1978-1988

The problems that precipitated the culling of gulls at the Tarnbrook Fell Gullery between 1978 and 1988 have already been discussed in this thesis (Chapter 2). Only the methods and effects of the culls are discussed here.

Culling took place over an eleven year period (1978-1988) using the narcotic α -chloralose to kill adult birds. The narcotic was mixed with soft animal fat and placed onto bread baits and placed inside nests. This meant that it was largely breeding birds were affected and because baiting took place in late May and June (i.e. after the main nest building period) the number of nests in each census during the cull period provided an accurate measure of the number of breeding gulls. Egg-pricking and egg destruction

also took place in most years (I. Savage, personal communication) although no detailed records of the results of this activity were kept. The percentage of laid baits that were eaten by the gulls (baiting efficiency) was measured from 1982-1988. No α -chloralose baits were used in 1981, but approximately 2,000 adult birds were shot, and these have been included in the culling figures.

5.2.9. Population models

The population model presented later in this chapter, is a discrete time model written in PASCAL. It allows the modelling of an age structured population, the incorporation of age specific productivity and survivorship, and the presence of a pre-breeding group. A "harvest" function allows simulations to be developed of the removal of any number of individuals from the breeding and non-breeding groups at any point in time.

5.3. RESULTS

5.3.1. The colony boundary

The colony boundary was not mapped until 1972 (Greenalgh 1973) and little is known of the extent of the gullery during its early years. By the time a map was produced, the number of breeding gulls in the colony was at a peak and the boundary at its maximum extent (R. Challenor and I. Savage personal communication). There was no reduction in the colony's size during the ten years of the culling period (1978-1988) and the boundary during the first year of the present project was little different to its 1972 position. The largest changes in the extent of the colony occurred in 1993 and 1994 as a result of the non-lethal management experiments (Chapter 3).

5.3.2. Timing of the annual nest census

The total number of breeding birds from 1980 onwards was estimated by assuming that 80% of the total number of nests had been constructed by the mid-point of the annual census (15 May). Table 32 shows the results of nest monitoring programmes in the study quadrats for 1992-94. In 1993, there was no significant difference in the percentage completion of nests at the time of the census between the non-Sanctuary (79%) and Sanctuary (86%) areas ($\chi^2=1.5$, 1 df, n.s.). Nor was there a difference in 1994 (87% in non-Sanctuary, 89% in Sanctuary. $\chi^2=0.1$, 1 df, n.s.). The overall percentage of nests completed was 78% in 1992, 82% in 1993 and 88% in 1994. There was no significant difference in the percentage completion between 1992 and 1993 ($\chi^2=1.7$, 1 df, n.s.) or 1993 and 1994 ($\chi^2=2.9$, 1 df, n.s.). The percentage completion in 1992 (77%) is however, significantly lower than the 1994 value (88%) ($\chi^2=10.5$, 1 df, $p<0.01$). This may be due to the 1992 data being obtained from only the non-Sanctuary area, but it may also indicate that 1994 was an 'early' year. As a result, the 1994 calculation of the number of breeding gulls assume 88% nest completion at the time of the census instead of the usual 80%. Over the three years of this

Table 32. Number of Lesser Black-backed Gull nests built at time of census compared to the final number of nests built in Sanctuary and Non-Sanctuary study plots of the Abbeystead Estate, Tarnbrook Fell Gullery 1992-1994.

Area	1992		1993		1994		1992-1994	
	Total nests	Nests at census	Total nests	Nests at census	Total nests	Nests at census	Total nests	Nests at census
Sanctuary		Not recorded	109	94 (86%)	167	149 (89%)	276	243 (88%)
Non-Sanctuary	205	158 (77%)	104	82 (79%)	133	116 (87%)	442	356 (81%)
All study plots	205	158 (77%)	213	176 (83%)	300	265 (88%)	718	599 (83%)

study, the overall percentage completion of nests by the mid-point of the census was 83%. The assumption used in the calculation of number of breeding birds, that 80% of nests are completed at the time of the census, is thus probably reasonable, although it may have to be adjusted for late or early breeding in some years. Earlier completion of nests at the time of the census in the Sanctuary area suggests that future surveys should begin with searches of the Sanctuary quadrats to compensate for this effect.

5.3.3. Number of gulls in the colony 1938-1972

The first Lesser Black-backed Gulls were recorded breeding at Tarnbrook Fell in 1938. The growth in the number of recorded adults 1938-1972 is shown in Figure 33. Up to 1965 there was a significant increase in the number of gulls in the colony ($t=7.2$, 4 df, $p<0.01$) equivalent to 26% *per annum*. At the end of this period, there were a little over 32,000 gulls in the gullery. Between 1965 and 1972, the growth rate slowed to about 2% *per annum* ($t=1.7$, 5 df, n.s.) and the number of recorded gulls peaked at 41,000 birds in 1972.

The first Herring Gull was recorded breeding in 1951 and there was a significant increase in the number of gulls recorded up to 1972 ($t=14.5$, 7 df, $p<0.01$). The annual rate of growth of was about 44% during this period. This was a significantly higher rate of increase than the 26% shown by the Lesser Black-backed Gulls during their growth phase ($t=3.8$, 13 df, $p<0.01$) and by 1972 there were 7,000 Herring Gulls recorded at the gullery.

5.3.4. Number of breeding gulls 1974-1994

In 1974 there were approximately 16,000 breeding Lesser Black-backed Gulls at Tarnbrook Fell (Figure 34). This figure was calculated using nest counts and does not

Figure 33. Log number of Herring and Lesser Black-backed Gulls at the Tarnbrook Fell Gullery 1938-1972 (numbers based on headcounts - see text for details).

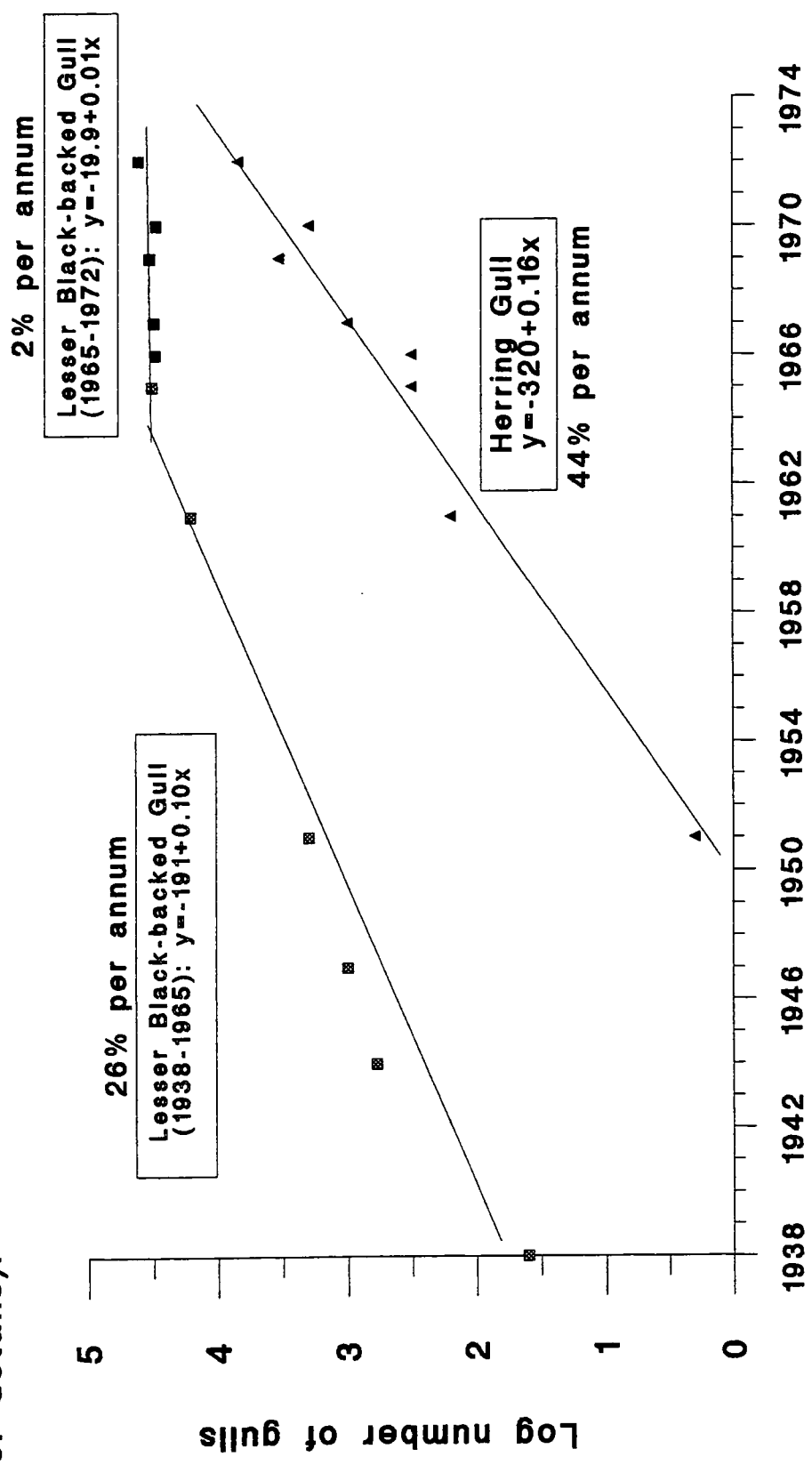
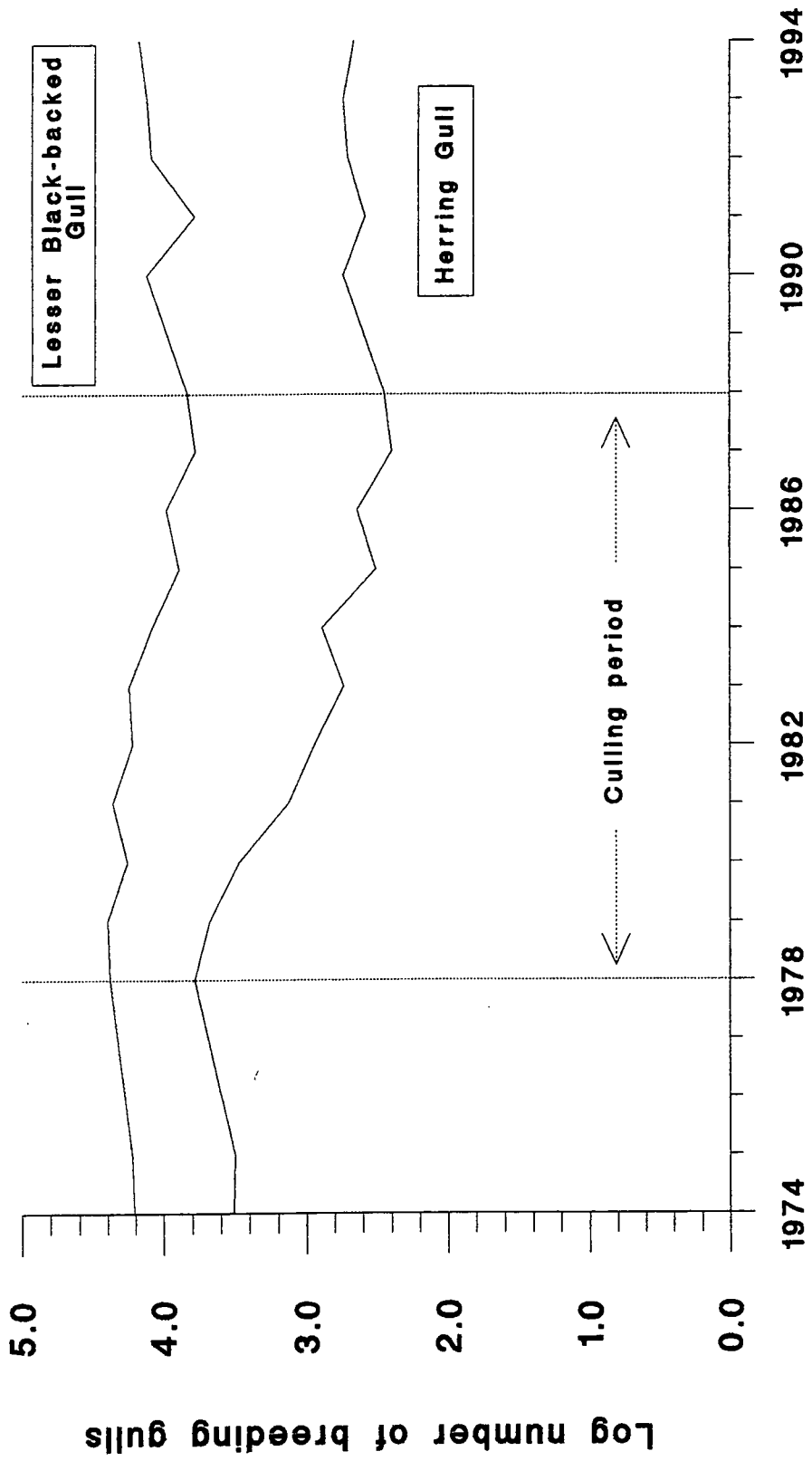


Figure 34. Log number of breeding Herring and Lesser Black-backed Gulls at the Tarnbrook Fell Gullery 1974-1994.



represent a fall from the 41,000 birds estimated in 1972 by headcounts. Numbers increased up to 1979 with a peak at just over 25,000 breeding gulls. Surprisingly this was the year after the first major cull at the colony, in which 23,000 adult birds were killed (see later). During the remainder of the culling period (last cull 1988), there was a progressive and significant reduction in the number of breeding Lesser Black-backed Gulls ($t=8.0$, 7 df, $p<0.01$) (Figure 35). The lowest recorded number was about 7,000 breeding gulls in 1988. The rate of decrease during this period was 34% *per annum*.

In 1974, there were an estimated 3,000 Herring Gulls at Tarnbrook Fell. As with the Lesser Black-backed Gulls, Herring Gull breeding numbers also peaked in 1979 at about 47,000 birds. During the culling period the number of Herring Gulls was progressively and significantly reduced with only 284 being recorded in 1988 ($t=7.8$, 7 df, $p<0.01$). This is equivalent to a reduction of 26% *per annum*. This is a significantly greater rate of decrease than the 15% experienced by Lesser Black-backed Gulls during the same period ($t=3.0$, 16 df, $p<0.01$).

The last cull of adult birds using α -chloralose occurred in 1988. No census of nests was conducted in 1989 but between 1988 and 1990, Lesser Black-backed Gulls increased from 7,099 to 13,697 breeding birds (+93%), and Herring Gulls from 284 to 463 breeding birds (+63%). However, between 1990 and 1994 there has been no significant increase in numbers of either species (Herring Gulls: $t=0.14$, 6 df, n.s.; Lesser Black-backed Gulls: $t=0.89$, 6 df, n.s.) (Figure 36).

5.3.5. The Walney Island gullery 1934-1994

The mixed Herring and Lesser Black-backed Gull colony on Walney Island (41km west of Tarnbrook Fell) was established in 1934, i.e. four years earlier than the Tarnbrook Fell Gullery. There was a significant increase in the number of breeding Lesser Black-backed Gulls from 1934 to 1974 ($t=13.2$, 5 df, $p<0.01$) equivalent to about

Figure 35. Log number of breeding Herring and Lesser Black-backed Gulls at the Tarnbrook Fell Gullery during the culling period 1978-1988.

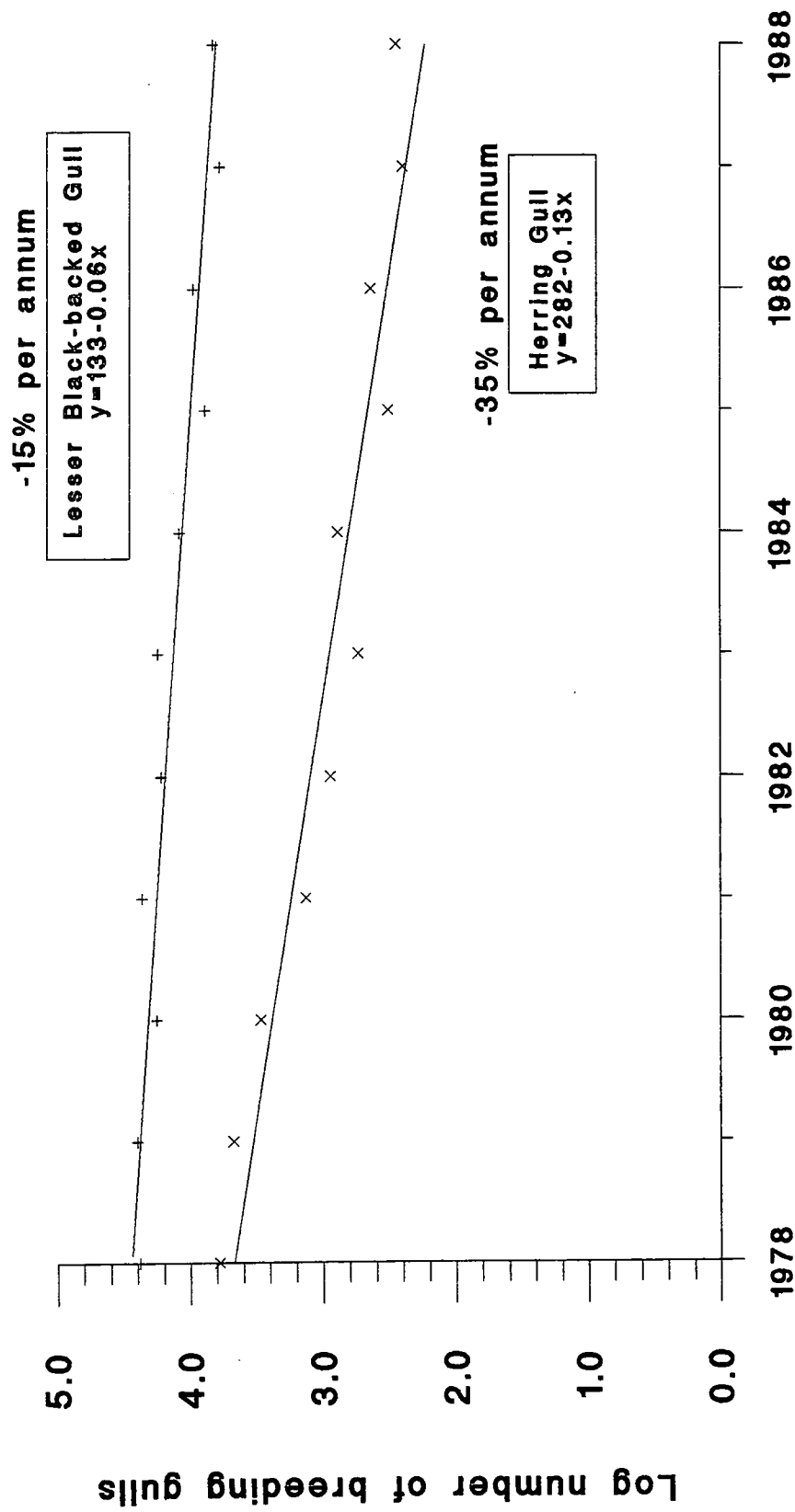


Figure 36. Log number of breeding Herring and Lesser Black-backed Gulls at the Tarnbrook Fell Gullery 1990-1994.

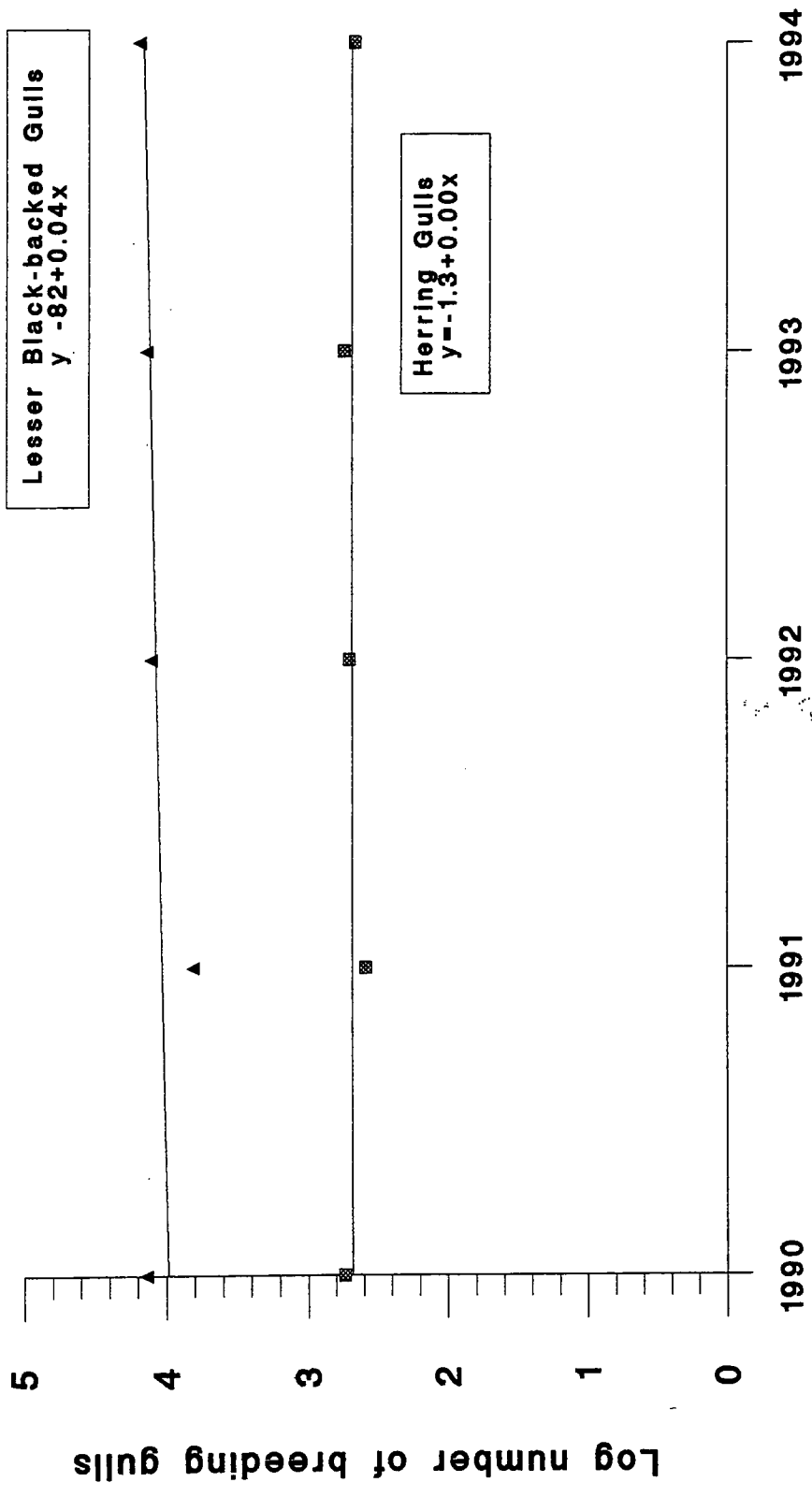
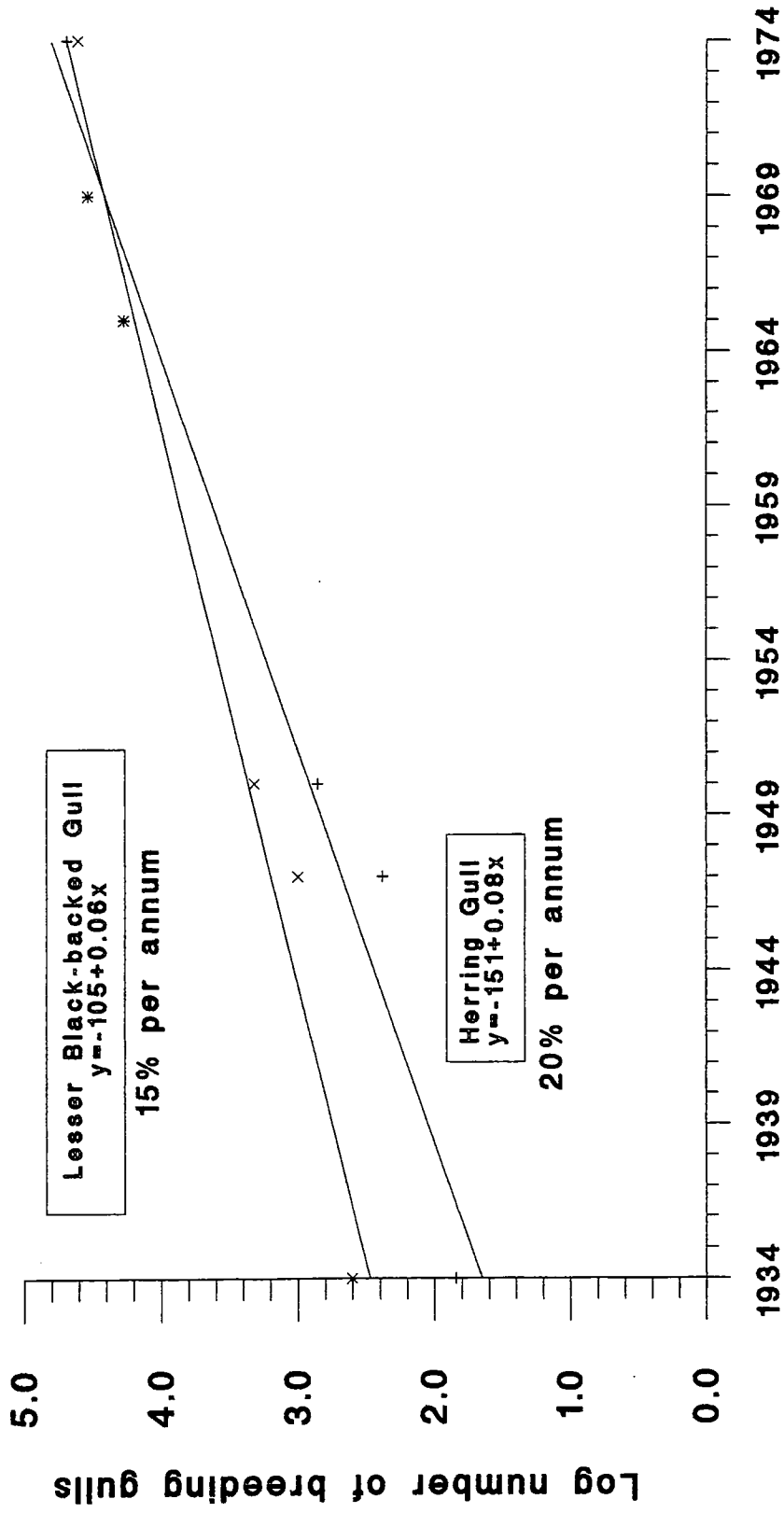


Figure 37. Log number of breeding Herring and Lesser Black-backed Gulls at the Walney Island Gullery 1934-1974.



annum (Figure 37). This is not significantly different to the rate of increase of Lesser Black-backed Gulls at Tarnbrook (26%) during their growth phase between 1938 and 1965 ($t=0.91$, 10 df, n.s.). The number of Herring Gulls at Walney also increased significantly at this time ($t=12.5$, 5 df, $p<0.01$) with a rate of 20% *per annum*. This is not a significantly different rate of increase compared to Lesser Black-backed Gulls at Walney Island ($t=3.2$, 10 df, $p<0.01$), but it is a significantly slower rate of increase compared to the Herring Gulls at Tarnbrook (44% *per annum*) during their growth period of 1951 to 1972 ($t=6.6$, 10 df, $p<0.01$). At both gulleries, the number of breeding gulls peaked around the mid to late 1970's and fell progressively thereafter. The culls at Tarnbrook Fell occurred just after this peak period and there was a significant reduction in breeding numbers until the end of the culls (see above). At Walney Island in 1974, there was an estimated 92,000 breeding gulls (both species combined) at the colony. By 1994 this had been reduced by 52% to 44,000 breeding Gulls (Figure 38). In 1994 there were 20,000 breeding Herring Gulls (a reduction of 7% *per annum* since 1974) and 24,000 breeding Lesser Black-backed Gulls (a reduction of just over 2% *per annum* since 1974). The annual rate of decrease of Herring Gulls at Walney is significantly higher than Lesser Black-backed Gulls ($t=2.9$, 6 df, $p<0.05$).

Only two surveys of the Walney Island colony were made during the culling period at Tarnbrook Fell: one in the first year 1978 and one in the last 1988. During this period, Herring Gulls at Walney Island fell from 44,000 breeding birds to 16,000 (64% reduction) and Lesser Black-backed Gulls fell from 38,000 breeding birds to 30,000 (21% reduction). The total reduction in the number of breeding gulls at Walney 1978-1988 was 36,000 birds. At Tarnbrook Fell, where 75,000 gulls were culled during the same period, the number of Herring Gulls fell by 95% and Lesser Black-backed Gulls by 71%. When both species are considered together, the fall in numbers between 1978 and 1988 at Tarnbrook Fell was 76% compared to 44% at Walney Island. The number of gulls at Walney has remained stable since 1988.

Figure 38. Log number of breeding Herring and Lesser Black-backed Gulls at the Walney Island Gullery 1974-1994.

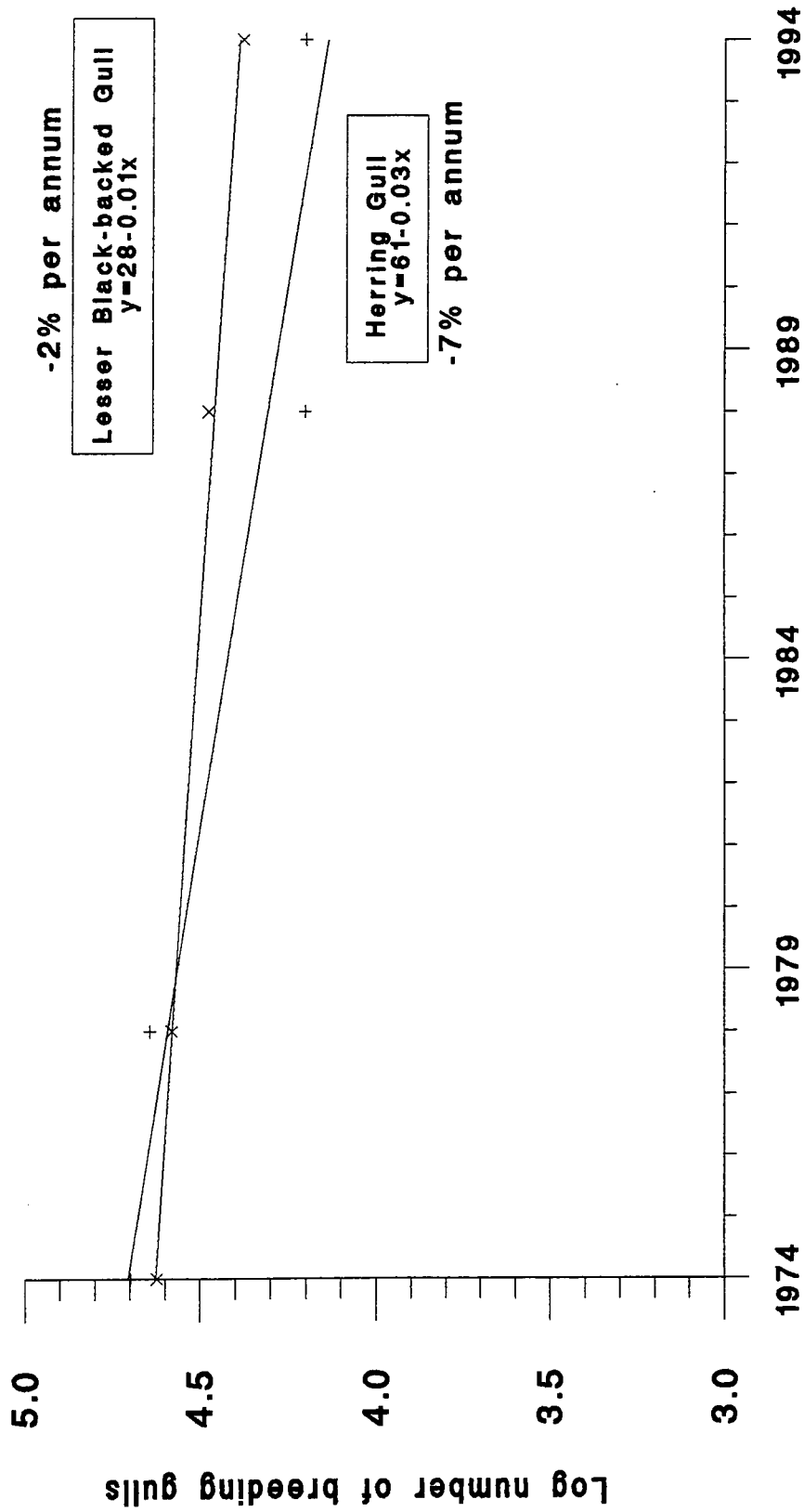
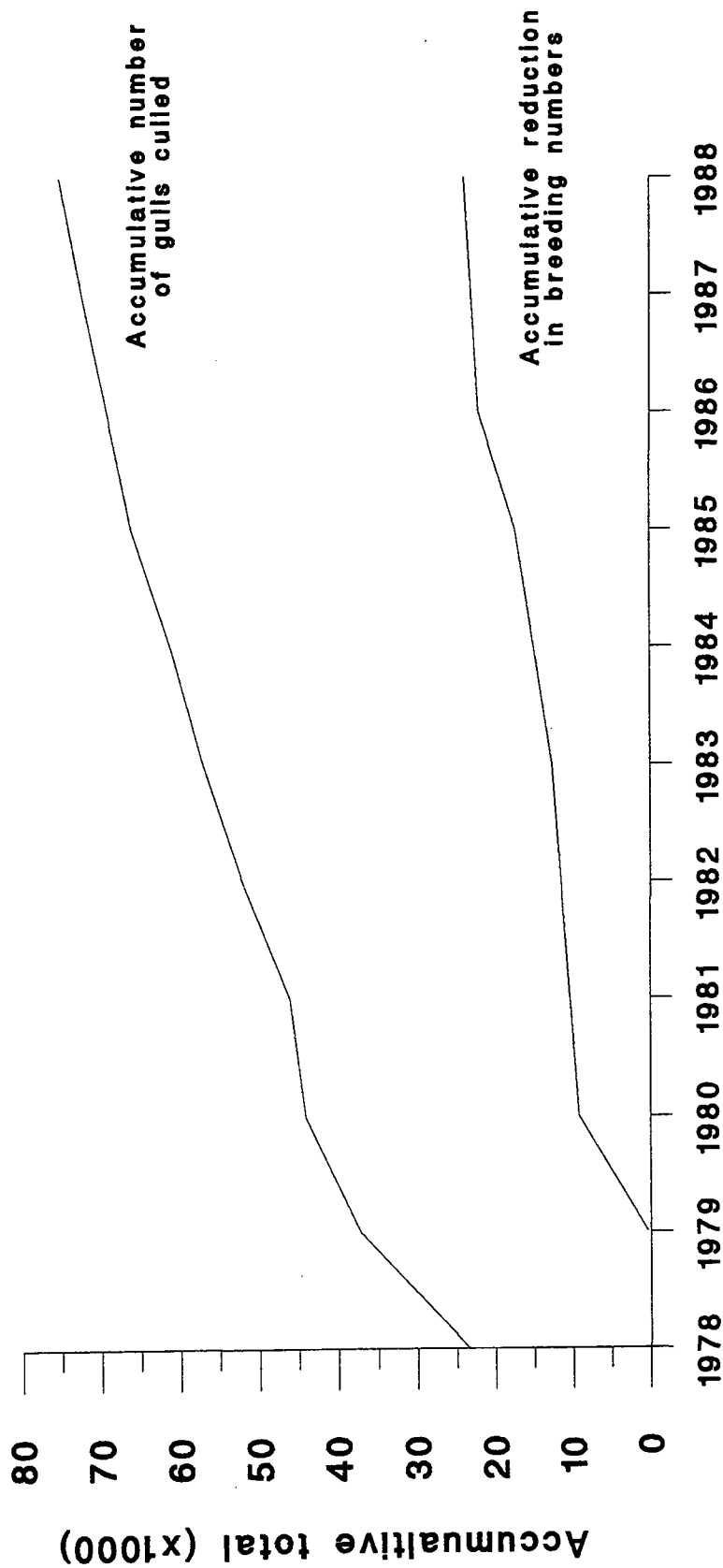


Figure 39. Accumulative total number of gulls culled at the Tarnbrook Fell Gullery 1978-1988, compared to the accumulative reduction in the number of breeding gulls.



5.3.6. Effects of culls at Tarnbrook Fell Gullery: 1978-1988

(a). Changes in the number of breeding gulls

During the eleven year culling period, approximately 75,000 gulls were killed by α -chloralose baiting. Table 33 shows the number of breeding birds culled in one particular year and the change in the number of breeding birds in the following year. During the culls, there was no relationship between the number of gulls culled and the change in breeding numbers the following season. After the first cull in 1978, when 23,000 gulls were reported killed, there was a fall of only 415 breeding birds in 1979. After the culls in 1983, 1984 and 1986, the fall in breeding numbers the following season was greater than the numbers killed. In all other years, the reductions were either smaller than the numbers culled or there was an actual increase in breeding numbers the following year. This occurred in 1980, 1982, 1985 and 1987 when there was thus a zero reduction in breeding numbers in the year following a cull. A regression (log transformed data) of the number culled in year (x) against the reduction in numbers in year (x+1) shows no significant relationship between the two variables ($t=0.01$, 8 df, n.s. $r^2<0.01$). The mean number of gulls culled per year during the culling period was 7241 ± 6558 . The mean reduction in breeding numbers was 2987 ± 3333 at this time. The difference is significant ($t=2.5$, 18 df, $p<0.02$).

The accumulative number of gulls culled during the ten year period compared to the accumulative reduction in the number of breeding gulls is shown in Figure 39. Although more than 75,000 adult gulls were killed between 1978 and 1988, the fall in breeding numbers by the end of the culls in 1988 was only 23,000 gulls.

(b). Survival and recruitment

Table 34 shows the effect of the culls on the survival rate of the gulls at the Tarnbrook Fell Gullery. The survival rate has been calculated by assuming that the survival rate of adults would have been 0.93 without the culls. The calculations are as follows:

$$\text{Survival rate after cull} = 0.93 \times (1 - \text{mortality due to culls})$$

By combining this with the number of breeding birds in any one year, the number of birds expected to return the following season can be estimated. The difference between this

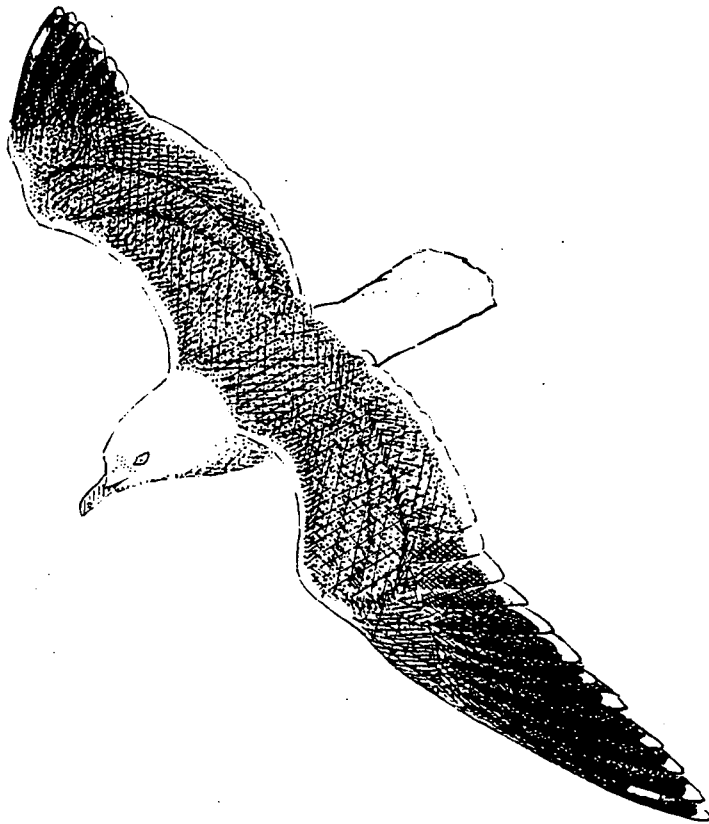


Table 33. Comparison of number of gulls culled in year (x) with the changes in numbers of gulls in year (x+1). Culling period at the Tarnbrook Fell Gullery: 1978-1988.

Year of cull	Number of breeding gulls culled in year (x)	Change in breeding numbers in year (x+1)	Reduction in breeding numbers in year (x+1)
1978	23,384 (77%)	- 415	415 (1%)
1979	13,830 (46%)	- 8,784	8,784 (42%)
1980	6,972 (33%)	+ 3,370	0
1981	2,000 (8%)	- 6,824	6,824 (39%)
1982	5,937 (34%)	+ 608	0
1983	4,967 (27%)	- 5,267	5,267 (41%)
1984	4,138 (32%)	- 4,768	4,768 (59%)
1985	4,899 (60%)	+ 1,872	0
1986	3,158 (32%)	- 3,707	3,707 (59%)
1987	3,129 (50%)	+ 831	0
1988	2,874 (40%)	No census in 1989	No census in 1989

Table 34. Survival rate and recruitment of gulls at the Tarnbrook Fell Gullery during the culling period (1978-1988).

Year	Number of breeding gulls	Adult mortality due to culls	Adult survival rate*	Number of breeding gulls expected from previous year	Number of recruits	Percentage recruits
1978	30,183	0.77	0.21	--	--	--
1979	29,768	0.46	0.50	6,338	23,430	78 %
1980	20,984	0.33	0.62	14,884	6,100	29 %
1981	24,354	0.08	0.86	13,010	11,344	47 %
1982	17,530	0.34	0.61	20,944	--	--
1983	18,138	0.27	0.68	10,693	7,445	41 %
1984	12,871	0.32	0.63	12,334	537	4 %
1985	8,103	0.60	0.37	8,109	--	--
1986	9,975	0.32	0.63	2,998	6,977	70 %
1987	6,268	0.50	0.47	6,284	--	--
1988	7,099	0.40	0.56	2,946	4,153	59 %

* Survival rate = $0.93 \times (1 - \text{mortality due to cull})$

figure and the actual number of breeding birds the following season, gives an estimate of the number of recruiting birds in each year of the cull. The number of recruits varied considerably in each year of the culling period. In three years (1982, 1985, 1987), no recruitment could be detected. This is not to say that it did not occur in these years, but the estimated number of adult gulls which had previously bred and were expected to return was greater than the actual number of breeding gulls in that year, and so no recruitment could be estimated. Considering only those years where an estimate of recruitment could be obtained, a regression (log transformed data) of the number of gulls culled in year (x) against the total number of recruits the following year showed no significant relationship between the variables ($t=1.53$, 5 df, n.s. $r^2=0.30$).

(c). Gulls recruiting into the breeding group.

An estimation of the number of birds born at the Tarnbrook Fell Gullery and showing natal philopatry was made from population estimates at the colony prior to and during the cull. The following assumptions were made in calculating the recruitment of Tarnbrook birds:

- (i) 30% of the gulls born at the Tarnbrook recruit in their fourth year, 40% in their fifth year and the remaining 30% in their sixth year.
- (ii) Survivorship was 0.80 in the first year of life and 0.93 thereafter.
- (iii) Productivity was 0.5 chicks fledged per breeding pair from 1974 onwards.
- (iv) Forty percent of the birds born at Tarnbrook (that survive to breeding age) will breed at their natal colony.

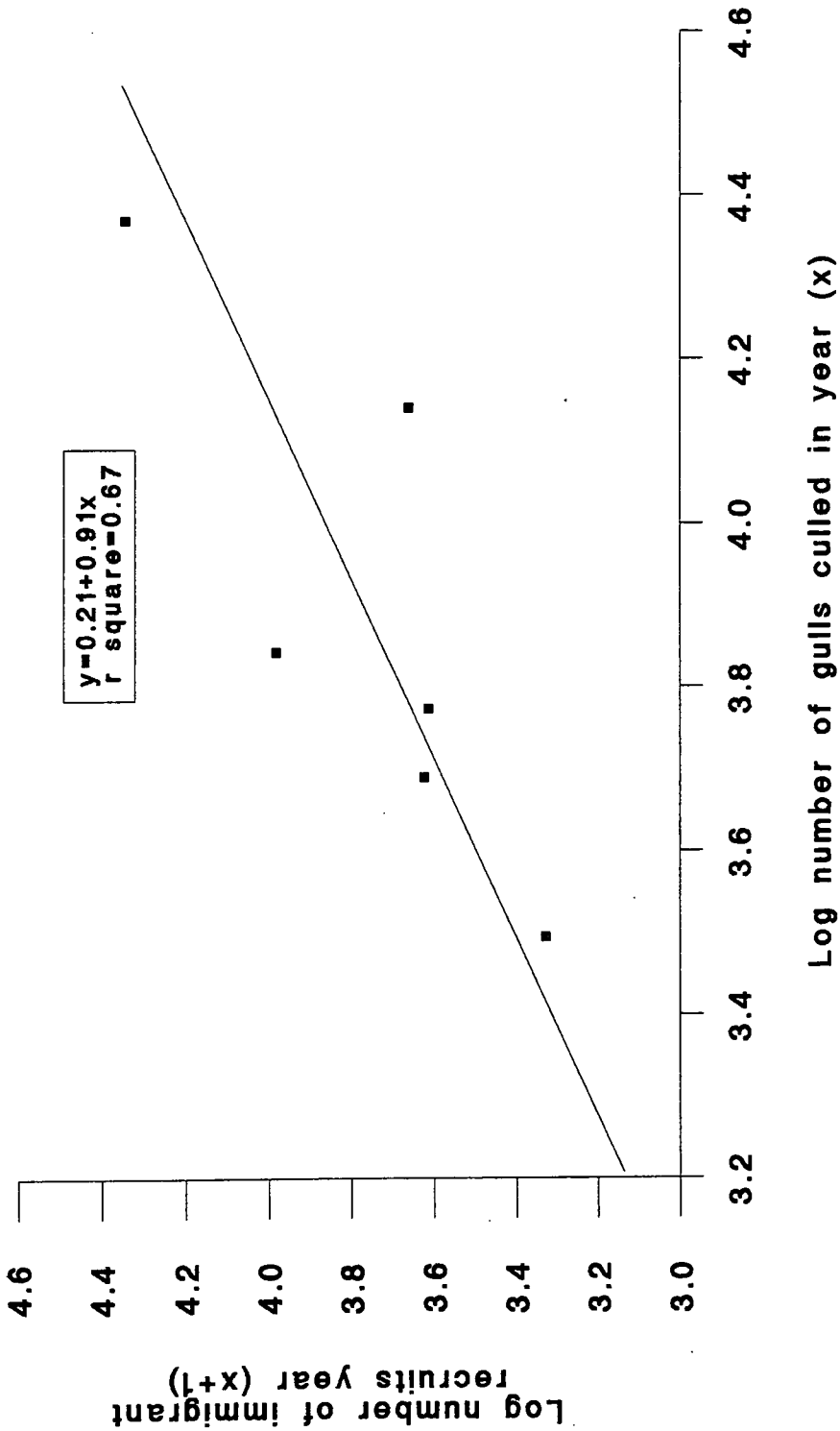
In those years where breeding numbers were higher than in the previous year i.e. there was no discernible recruitment, the birds that had been born at Tarnbrook and were 'available' as recruits were added to the recruits in the following year (after correcting

Table 35. Recruitment of gulls into the breeding group at Tarnbrook Fell Gullery during the culling period 1979-1988 for gulls born at the colony and immigrant recruits/adult non-breeders (see text for details).

Year	Number of breeding gulls	Total number of recruits *	Number of recruits born at Tarnbrook **	Number of immigrant recruits
1979	29,768	23,430	1,342 (6%)	22,088 (94%)
1980	20,984	6,100	1,512 (25%)	4,588 (75%)
1981	24,354	11,344	1,733 (15%)	9,611 (85%)
1982	17,530	0	---	---
1983	18,138	7,445	3,336 (45%)	4,109 (55%)
1984	12,871	537	---	---
1985	8,103	0	---	---
1986	9,975	6,977	2,780 (40%)	4,197 (60%)
1987	6,268	0	---	---
1988	7,099	4,153	2,025 (49%)	2,128 (42%)
	TOTALS	59,986	13,265 (22%)	46,721 (78%)

* See Table 34. ** Assuming 40% natal philopatry.

Figure 40. Relationship between the number of gulls culled in year (x) and the number of immigrant recruits in year (x+1) during the culling period at the Tarnbrook Fell Gullery 1978-1988.



mortality). Table 35. shows the percentage of birds recruiting during the culling period that were born at Tarnbrook. In 1979, the season after 23,000 adults were culled, a maximum of 6% of the recruits were chicks born at the colony and returning as first-time breeders. This means that an estimated 94% of the recruits were immigrants from other colonies. From 1980 to 1988 the percentage of immigrants varied between 51% and 75%.

The total number of recruits at Tarnbrook between 1978 and 1988 was 59,986 gulls, of which 13,265 (22%) were born at Tarnbrook. An estimated total of 46,721 (78%) therefore were born at other colonies.

(d). Culling and immigration

It was shown above that there was no significant relationship between the total number of recruits in year (x+1) and the numbers culled in year (x). However, a regression of the numbers culled against the number of immigrant recruits in the following year is significant ($t=2.8$, 4 df, $p<0.04$, $r^2=0.67$). The regression, using log transformed data, is shown in Figure 40. The results suggest that the more gulls that were culled, the greater the number of immigrant birds recruited into the breeding group the following year.

(e). Immigration and emigration rates

Assuming that natal philopatry is in the order of 40% at Tarnbrook Fell, the number of emigrants produced at the gullery between 1978-1988 was estimated as 19,898 gulls. The total number of immigrants at this time was 46,721 (Table 35). This means that for every emigrant produced at Tarnbrook Fell there were 2.3 immigrants during the culling period. The number of gulls born at Walney that survive to be potential recruits at other colonies during 1978-1988 can be estimated as described earlier for the gulls at

Table 36. Estimated number of emigrant gulls produced from the Walney Island Gullery compared to the number of immigrants at Tarnbrook Fell Gullery during the culling period 1978-88. See text for details.

Year	Estimated emigrant gulls from Walney Island Gullery	Estimated immigrant gulls to Tarnbrook Fell Gullery
1979	9,181	22,058
1980	8,924	4,588
1981	8,667	9,611
1982	8,374	--
1983	8,036	4,109
1984	7,665	--
1985	7,296	--
1986	6,926	--
1987	6,556	4,197
1988	6,186	2,128
TOTALS:	77,811	46,721

Tarnbrook Fell (see above). For the calculations, breeding success was assumed to be 0.5 chicks per pair. The actual figure is unknown for Walney and this is likely to be a minimum figure, and the number of emigrants from the colony may therefore actually be higher than the estimates presented. As with Tarnbrook Fell, natal philopatry was assumed to be 40%. The total number of emigrants is estimated to have been 77,811 gulls (Table 36). This is 66% greater than the number of immigrants recorded at Tarnbrook Fell (46,721) during the culling period, and therefore the immigration of gulls into Tarnbrook during the culling period, could easily have been supported by the output of emigrant birds from Walney Island. Rings recovered during the culls suggest that immigration of birds from Walney was indeed occurring (T. Dean personal communication).

5.3.7. Baiting efficiency 1982-1988

Between 1982 and 1988, there was a significant reduction in the baiting efficiency of the culls i.e. the percentage of the baits laid that were eaten by the gulls ($t=5.3$, 5 df, $P<0.01$) (Figure 41). In 1982, just under 60% of the baits were being taken. By the last year of the cull (1988), only 29% of the baits laid were eaten by the gulls. This is equivalent to reduction of 5% *per annum* (original data from Thomas and Tasker 1988).

5.3.8. Breeding success and productivity

(i) Inter-annual and inter-colony variation

The breeding success of gulls at Tarnbrook Fell (areas without egg pricking) and Ribble Marshes nature reserve in 1993 and 1994 is shown in Table 37. At Tarnbrook Fell, hatching success was significantly lower in 1994 (55%) than in 1993 (78%) ($\chi^2=14$, 1 df, $P<0.01$). Of the eggs that hatched, the percentage that gave rise to fledged

Table 37. Breeding success and productivity of Lesser Black-backed Gulls at the Tarnbrook Fell and Ribble Marshes Gulleries 1993-1994.

	Tarnbrook Sanctuary (no egg pricking)		Tarnbrook non-Sanctuary (egg pricking area)		Ribble Marshes (no egg pricking)	
	1993	1994	1993	1994	1993	1994
Number of study nests	109	167	105	133	54	60
Number of nests with clutches	45 (41%)	49 (29%)	53 (50%)	42 (32%)	51 (94%)	59 (98%)
Number of eggs laid	122	131	145	119	149	155
Number of eggs hatched	95 (78%)	72 (55%)	37 (26%)	34 (29%)	103 (69%)	3 (2%)
Number of chicks fledged	69	46	30	21	66	2
Percentage of eggs laid giving rise to fledged chicks	56%	35%	21%	18%	44%	1%
Percentage of eggs hatched giving rise to fledged chicks	73%	64%	81%	62%	64%	67%
Number of chicks fledged per clutch laid	1.53	0.94	0.50	0.57	1.29	0.03

young was not significantly different between the two years: 73% in 1993 and 64% in 1994 ($\chi^2=1.1$, 1 df, n.s.). Productivity (number of chicks fledged per clutch laid) at the gullery was 1.53 in 1993 and 0.94 in 1994. The significance of this difference will be discussed later in the chapter.

At the Ribble Marshes Gullery, 69% of eggs hatched in 1993 but because of unusually severe weather and high tides during incubation, only 2% hatched in 1994 ($\chi^2=148$, 1 df, $p<0.01$). In 1993, breeding success was 1.23 chicks fledged per clutch laid. This was considered an "exceptional" year for chick production (D. Lambert, personal communication). It was followed in 1994 by extremely low breeding success at the colony with an average of only 0.03 chicks per clutch.

Table 40. Effect of egg pricking on the Abbeystead Estate 1993-1994 on the overall productivity at the Tarnbrook Fell Gullery (see text for details).

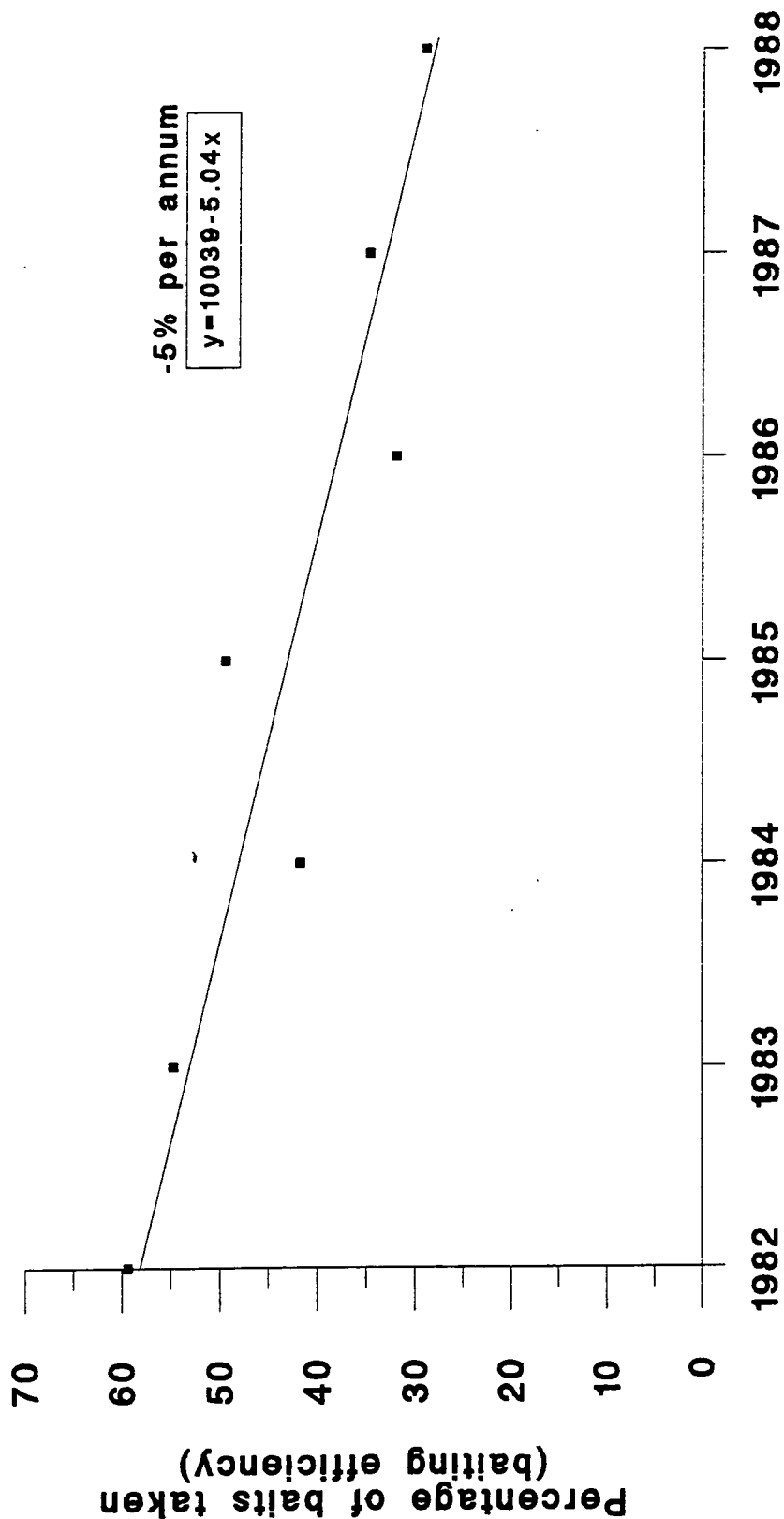
1993:

Egg pricking areas:	3016 clutches with 0.50 chicks per clutch	= 1508 fledged chicks
Undisturbed areas:	3170 clutches with 1.53 chicks per clutch	= 4850 fledged chicks
		Total = 6358 fledged chicks
With egg pricking:	6186 clutches with 6358 fledged chicks	Productivity (whole colony) = 1.03
Without egg pricking:	6186 clutches with 9464 fledged chicks	Productivity (whole colony) = 1.53

1994:

Egg pricking areas:	3040 clutches with 0.57 chicks per clutch	= 1733 fledged chicks
Undisturbed areas:	4245 clutches with 0.57 chicks per clutch	= 3990 fledged chicks
		Total = 5273 fledged chicks
With egg pricking:	7285 clutches with 5273 fledged chicks	Productivity (whole colony) = 0.78
Without egg pricking:	7285 clutches with 6848 fledged chicks	Productivity (whole colony) = 0.94

Figure 41. Baiting efficiency (percentage of baits laid that were taken by gulls) during the 1982-1988 culls at the Tarnbrook Fell Gullery.



(ii) The effect of egg pricking on breeding success

Table 38. shows the results of egg pricking on the Abbeystead non-Sanctuary area between 1992 and 1994. Egg pricking effort appears to have been reasonably similar in all three years. There was no significant difference in the percentage of eggs in the study plots that were pricked in 1992 (68%), 1993 (62%) or 1994 (69%) ($\chi^2=1.72$, 2 df, n.s.). Nor was there a significant difference in the percentage of clutches in which one or more eggs were pricked in the three years: 84% in 1992, 77% in 1993 and 71% in 1994 ($\chi^2= 2.7$, 2 df, n.s.). In each year of the study, some of the eggs that were pricked subsequently hatched. There was no significant difference in the percentage of pricked eggs that hatched in 1992 (9%), 1993 (16%) and 1994 (19%) ($\chi^2=4.8$, 2 df, n.s.). The average over the three years was 14%.

Table 38. Percentage of Lesser Black-backed Gull clutches and individual eggs that were pricked by estate workers 1992-1994 in the non-Sanctuary study plots.

	1992	1993	1994
Number of clutches studied	92	53	42
Number of clutches with 1-3 eggs pricked	77 (84%)	41 (77%)	30 (71%)
Number of eggs studied	205	145	119
Number of eggs pricked	139 (68%)	90 (62%)	82 (69%)
Number of eggs pricked that hatched	13 (9%)	14 (16%)	16 (19%)

The effects of egg pricking in the non-Sanctuary areas on breeding success in 1993 and 1994 compared to breeding success in the Sanctuary area where no egg pricking or disturbance occurred are shown in Table 37. In both years hatching success was significantly lower in egg pricking areas (26% in 1993 and 29% in 1994) compared to hatching success in the Sanctuary (78% in 1993 and 55% in 1994) ($\chi^2=71$ for 1993, and $\chi^2=17$ for 1994, 1 df, $p<0.01$). The percentage of eggs laid giving rise to fledged young was significantly lower in the non-Sanctuary areas (21% in 1993 and 18% in 1994) compared to the Sanctuary (56% in 1993 and 35% in 1994) ($\chi^2=35$ for 1993, and $\chi^2=8.8$ for 1994, 1 df, $p<0.01$). Of those eggs in the non-Sanctuary that were not pricked and managed to hatch, 81% gave rise to fledged young in 1993 and 62% in 1994. This was not significantly different to the 73% and 64% in the Sanctuary area in 1993 and 1994 (χ^2 for both years =0.1, 1 df, n.s.).

The number of egg/clutches that were pricked on the Abbeystead Estate 1992-1994 as a percentage of the total number of eggs/clutches produced in the colony is shown in Table 39. There was no significant difference in the percentage of clutches in the gully that had at least one egg pricked between 1992 (23%) and 1993 (25%) ($\chi^2=3.2$, 1 df, n.s.) or between 1992 and 1994 (23%) ($\chi^2=2.1$, 1 df, n.s.). The difference between 1993 and 1994 is significant ($\chi^2=7.2$, 1 df, $p<0.01$). Over the three years as a whole, 24% of all the clutches produced in the colony had one or more eggs pricked. In terms of the number of eggs that were pricked as a percentage of the total number of eggs in the whole colony, there was a significant difference between 1992 (19%) and 1993 (20%) ($\chi^2=5.4$, 1 df, $p<0.05$) and 1992 and 1994 (23%) ($\chi^2=51$, 1 df, $p<0.01$). The difference between 1993 and 1994 is also significant ($\chi^2=40$, 1 df, $p<0.01$).

In 1993, if breeding success without egg pricking had been the same in the whole colony as it was in the Sanctuary area (1.53), 9,464 chicks would have been produced in the gully. With egg pricking having taken place, an estimated 6,358 chicks were produced. There were 6,186 clutches produced in the colony, so egg pricking reduced breeding success in the entire gully from 1.53 to 1.103 chicks fledged per

Table 39. Percentage of the total number of Lesser Black-backed Gull clutches and eggs in the whole colony that were egg-pricked by estate workers, Tarnbrook Fell Gullery 1992-1994.

	Number of clutches in colony	Number of clutches where 1-3 eggs were pricked	Percentage of clutches where 1-3 eggs were pricked	Number of eggs in colony	Number of eggs that were pricked	Percentage of eggs that were pricked
1992	6,981	1,673	24 %	18,848	3,571	19 %
1993	6,186	1,567	25 %	16,702	3,328	20 %
1994	7,285	1,699	23 %	19,670	4,460	23 %
1992-94	20,452	4,939	24 %	55,220	11,359	21 %

clutch laid (Table 40). Using the same method for 1994, egg pricking reduced breeding success in the entire gullery from 0.94 to 0.78 chicks fledged per clutch laid.

5.3.9. Modelling the effects of lethal management on annual changes in numbers of breeding gulls

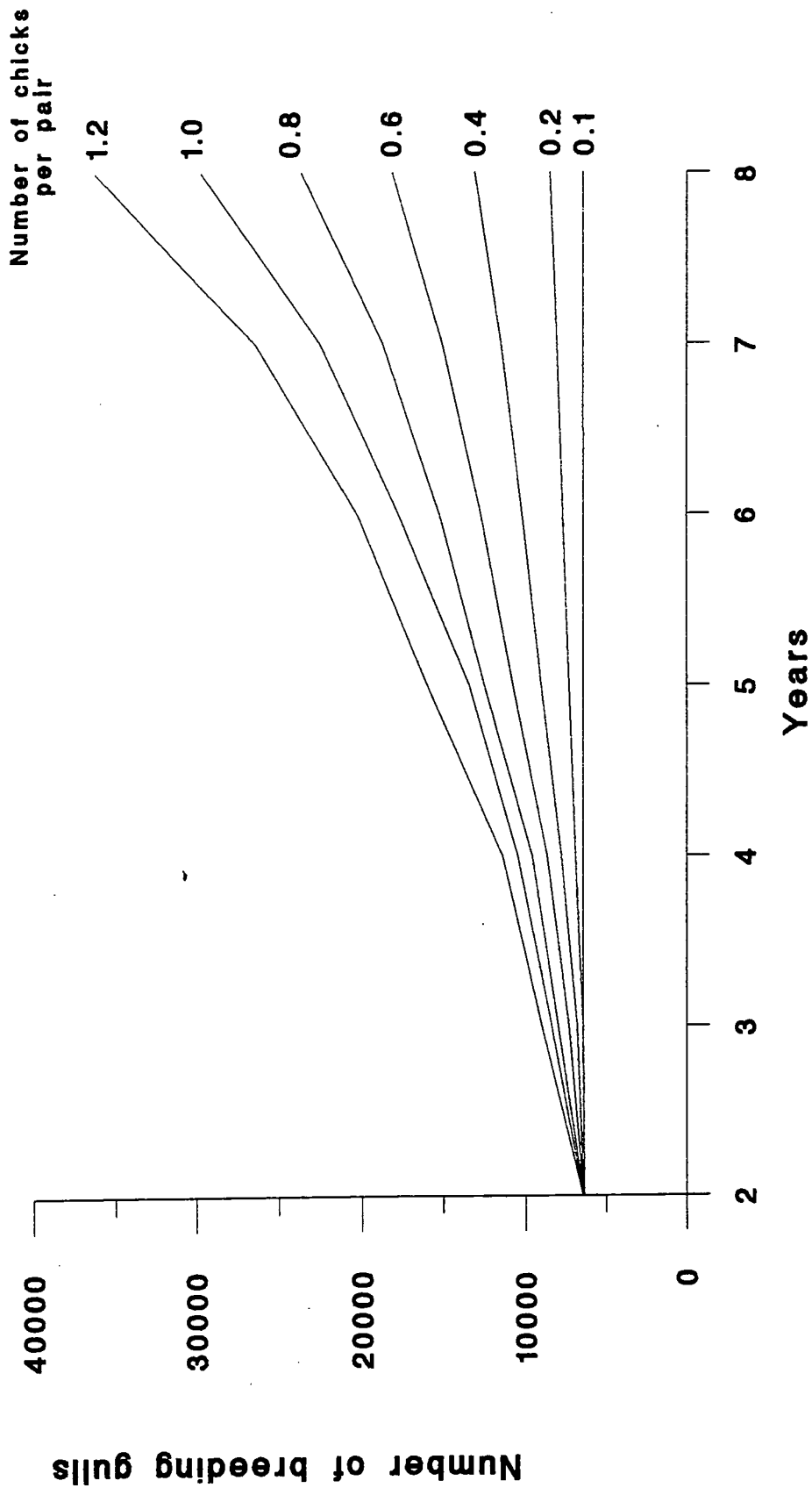
Egg pricking:

The primary reason for egg pricking is to reduce productivity, defined here as the number of fledged chicks per pair. Figure 42 shows a model of the annual changes in the number of breeding gulls in a colony that occur at different levels of fecundity. The model is based on the following breeding parameters:

- (i) Gulls do not breed in the first three years of life (Tinbergen 1961).
- (ii) First year survivorship is 0.80 after which all birds have a survivorship of 0.93 (Chabrzyk and Coulson 1976)
- (iii) The productivity of gulls attempting to breed in their fourth year is half that of older pairs (Thomas 1980).
- (iv) The starting population was 8,000 gulls of which 80% were breeding birds (Duncan 1978).
- (v) All the pre-breeding birds that emigrate from the gullery are replaced by gulls immigrating from other colonies i.e. emigration equals immigration.

In both models presented in this chapter, the starting population was 8,000 gulls. This number was chosen because the PASCAL programme used can not process integer levels produced by increases of a higher starting number of breeding birds with time. This also limits the number of years over which a model of a growing population can be run. Also, the model does not incorporate density dependent effects that might occur at

Figure 42. Model of annual changes in the number breeding gulls at different levels of productivity (number of chicks per pair). See text for assumptions.



higher population levels. For these reasons, the model had a starting population of 8,000 and was simulated for only eight years.

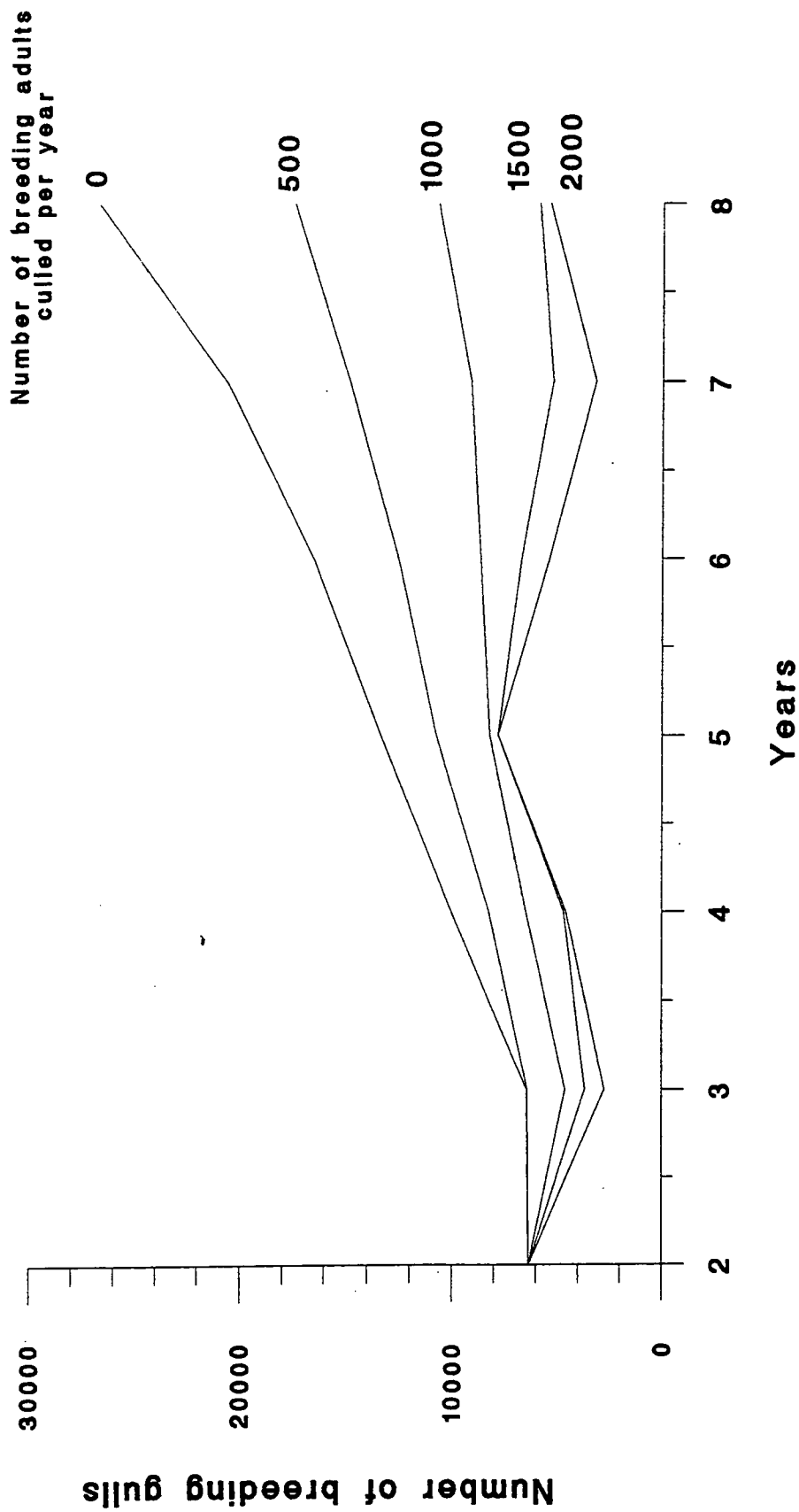
In the last section it was shown that egg pricking activities at Tarnbrook Fell reduced productivity over the entire gullery from 1.53 to 1.03 in 1993 and from 0.94 to 0.78 in 1994. At both these reduced levels of productivity, the model predicts continued growth in numbers of the breeding group. To be able to prevent an increase in the population by affecting productivity, egg pricking activities would have to reduce annual breeding success to 0.2 fledged chicks per clutch, or less. Given the high costs involved in egg pricking (the present activity on the Abbeystead Estate alone costs £15,000 per annum) and the topography of the colony, such a reduction is not feasible at Tarnbrook. It should also be stressed that the reductions shown in the models probably represent a 'best case' scenario. This is because the models assume a ratio of immigrants to emigrants equal to unity, whereas during the culls at Tarnbrook, the ratio was estimated to be approximately 2.3. immigrants to emigrants (see earlier).

Culling breeding adults

A similar model was constructed whereby adult survival was reduced as a result of culling breeding adult gulls. The results are shown in Figure 43. Productivity was assumed to be 0.94 chicks fledged per pair i.e. the same as found in undisturbed areas at Tarnbrook in 1994. Culling less than 1,000 adults per year reduces the speed of colony growth, but does not lead to a fall in breeding numbers. Only when more than 1,500 gulls per year were culled did a fall in breeding numbers occur. The survival rate of adult birds after each cull can be estimated from:

$$0.93 \times (1 - \text{mortality due to cull})$$

Figure 43. Model of annual changes in the number of breeding gulls after culling different numbers of adult birds (see text for assumptions).



The mean annual survival rate of adult gulls in the model is 0.44 ± 0.14 when 1,500 birds are culled per year (Table 41). Changing the number of breeding gulls in the model does not change the level of adult survivorship where a reduction in breeding numbers is achieved, it merely affects the number of adults required to be killed to achieve this survival rate. It has been shown that the required reduction in adult survivorship is possible to achieve at a colony like Tarnbrook Fell where, during the culling period, the mean annual adult survivorship after each cull was 0.56 ± 0.17 (see earlier). This is higher, but not significantly different to the 0.44 ± 0.14 predicted by the model to produce a fall in numbers. The fact that there was a higher survival rate at Tarnbrook during the culls and yet a reduction in numbers was still achieved, may be due to the fact that egg destruction also occurred at Tarnbrook during the culls of adult gulls, thus reducing fecundity as well as survivorship. The number of breeding birds at the Tarnbrook Fell Gullery and the rate of immigration from other colonies (see earlier) meant that an average of 7,000 gulls per year were culled to achieve a mean adult survival rate of 0.56 and the subsequent fall in numbers of breeding birds.

Table 41. Mean annual adult survivorship of gulls in culling model (see text).

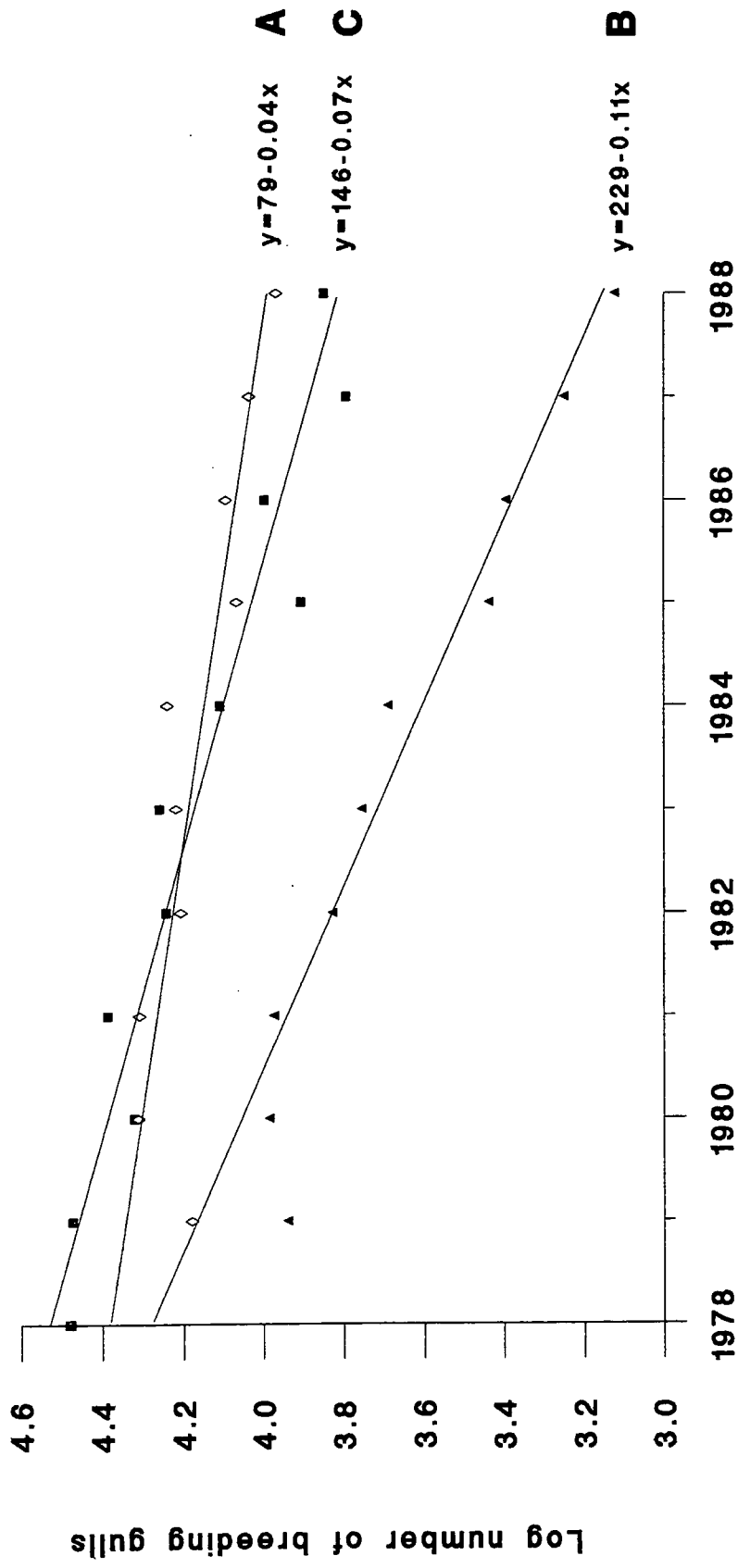
Number of breeding adults culled	Mean annual adult survivorship
No cull	0.93
500	0.83 ± 0.04
1000	0.70 ± 0.05
1500	0.44 ± 0.14
2000	0.21 ± 0.17

The model assumes that the ratio of immigrants to emigrants is unity. As shown earlier, this was not the case at Tarnbrook during the culling period, when there appears to have been 2.3 immigrants for every emigrant. This increased immigration would have the effect of lowering the level to which adult survivorship would have to be reduced in order to achieve a fall in the number of breeding birds. The fact that the culls at Tarnbrook managed to achieve a fall in breeding numbers by reducing adult survivorship to 0.56 may therefore be due to other 'pressures' on the population in addition to the culls (as well as the reduction in fecundity mentioned earlier). The population changes that occurred at Walney Island suggest that the number of gulls at Tarnbrook at the time of the culls may have fallen between 1978 and 1988, independently of the culling regime. During this period, the number of breeding gulls in the colony at Walney Island fell by 36,000 birds. At first sight, it would appear that this decline could have been caused by the Tarnbrook culls. However, as demonstrated earlier, a proportion of the chicks produced at Walney Island would not have shown natal philopatry and would not have bred at Walney whether the culls were taking place at Tarnbrook or not. This non-philopatric proportion of the chick production at Walney during the culling period, was at least as great as the number of immigrants to Tarnbrook at this time. The declines at Walney Island are therefore unlikely to have been caused by the culls at Tarnbrook, the latter merely acting as a 'sink' for non-philopatric chicks. The causes of the declines at Walney Island are not known, but it is possible that similar 'natural' declines would also have occurred at Tarnbrook had the culls not taken place. This may explain why the culls at Tarnbrook achieved a fall in the number of breeding birds despite adult survivorship not being reduced to levels at which the model predicted a population decline.

5.3.10. Models using data from the 1978-1988 culls:

Unfortunately, the ability of the model to accurately reconstruct the population changes that occurred at Tarnbrook during the culls can not be tested. The software allows 'harvesting' but does not permit the input of individuals from outside the breeding group (immigrants). In some years, the number of immigrant gulls outnumbered the birds culled and natural mortality and there was a net gain to the breeding group. This could not be entered into the model. However, useful information can be obtained by modelling a gullery with the same starting population as Tarnbrook in 1978 and then harvesting the same number of gulls as occurred during the culls. The only difference between the model and the real situation is that the model assumes immigration and emigration rates to be the same. Figure 44 shows the changes in the number of breeding birds produced by two such models compared to the changes that actually occurred at Tarnbrook 1978-1988. In model A, productivity is set at 0.5 Chicks per pair and in model B at 0.2 chicks per pair. Model A predicts a population decline of 10% *per annum*. This is significantly slower than the 17% *per annum* that actually occurred ($t=3.1$, 20 df, $p<0.01$). Had it been possible to incorporate an immigration rate into the model that was greater than emigration (the situation at Tarnbrook during the culls) the rate of decline would have been even slower. This suggests that productivity at Tarnbrook fell during the culling period was probably extremely low due to both the mortality of adult birds and to egg destruction. In model B, with productivity set at 0.2, a decline of 28% *per annum* is predicted. This is significantly faster than the actual decline of 17% ($t=5.9$, 20 df, $p<0.01$). Had it been possible to incorporate net immigration gains, the best fit of the model to the actual situation would therefore occur when productivity was set at these low values. The implications of low productivity during the culling period are that immigration levels may actually have been higher than the rates calculated earlier and that the population at Tarnbrook at this time must have been sustained largely through immigration.

Figure 44. Two models (A and B) of changes in the number of breeding gulls during the culling period at Tarnbrook Fell Gullery (1978-1988) compared to actual data from culls (C).



5.4. DISCUSSION

5.4.1. Population dynamics and culling:

In 1978, when the first culls were carried out at Tarnbrook Fell, it was believed that killing large numbers of gulls would rapidly reduce the size of the breeding group and that the colony could be removed from the area in a few years. No account was taken of the complex nature of gull population dynamics or the fact that gulleries are not 'closed' systems. Natal philopatry is probably displayed by only a minority of gulls in a colony and as a consequence there is an inter-change of individuals produced at different colonies. The culls at Tarnbrook fell, although achieving a reduction in the population, killed many more gulls than the number by which the breeding group declined. The culls were thus a 'sink' for birds from other colonies. Another important factor was that the greater the number of individuals culled, the greater the number of immigrants that were recruited at the gullery. This suggests that immigrant recruits attend the colony prior to breeding and are filling 'gaps' in the colony created by the culling of breeding adults. Much work remains to be done on the factors that influence pre-breeding gulls in the choice of the colony at which they ultimately breed. Duncan (1978) showed that medium density areas at a colony are more "attractive" to recruits because an inexperienced pair has a greater chance of establishing in these areas than in areas of higher breeding densities. Parsons (1976) showed that gulls breeding at lower nest densities, have lower clutch sizes and lower hatching and fledging success. Ironically, the culls at Tarnbrook, by 'thinning' out the breeding densities may have made the colony more attractive to recruiting birds and allowed them to become established breeders. This problem must be addressed when contemplating gull management and complete clearance of an area must be achieved to overcome it.

On the Isle of May during the culls of the 1970's, once the population approached about 3,000 pairs, it became increasingly difficult to further reduce breeding numbers

(Duncan 1978). Consequently, a minimum quota philosophy was adopted i.e. a small number of birds were culled each season to keep the population at a reduced level. Whether this could have been achieved at Tarnbrook remains academic because the licence to use α -chloralose was withdrawn in 1989. Shooting was not a viable alternative because the gulls have the ability to identify humans with guns and simply fly out of range until the danger has passed. The alternative to culling adults presently being used at the Gullery i.e. egg pricking, has been shown to be unlikely to have an appreciable effect on the present number of breeding gulls. In the light of this, the non-lethal management programme reported in earlier chapters would seem the more appropriate strategy.

5.4.2. Population models and management strategies:

Models of animal populations can be developed with a range of 'resolutions' i.e. different levels of complexity, incorporating more or less information on population parameters. For example, a low resolution model would be:

$$\text{changes in numbers} = \text{births} - \text{deaths} + \text{immigration} - \text{emigration}$$

whereas a high resolution model incorporates age specific productivity and mortality, density dependent effects, population age structures, and information on the rates of immigration and emigration. The models presented earlier in the chapter are thus of reasonably high resolution. Such models can be used in planning management strategies for a problem group of gulls by allowing predictions to be made of the relative effects of different management tools and the time scale over which they would have to be implemented in order to have an effect. This allows the most cost effective and humane

method to be developed. The models used in this chapter suggest that for the Tarnbrook Fell Gullery, management of either fecundity or survivorship will be long-term and financially costly and that non-lethal alternatives would be more appropriate. At other colonies where the breeding group is smaller, more accessible and isolated, it may be possible to prick 100% of the eggs each season at a low financial and time cost. In such cases, lethal management may be considered more appropriate. Similarly, there may be colonies at which culling adults may be a viable control method. Modelling the effects of management prior to the implementation of a cull, has the potential to eliminate financial waste, reduce the time-scale of the management programme and prevent the unnecessary slaughter of large numbers of birds in the problem group. In the case of the Tarnbrook Fell Gullery it would also demonstrate that alternative methods of control, such as complete clearance through disturbance, is a more effective strategy. The models presented in this chapter have demonstrated the potential value of modelling techniques applied to the process of managing problem species. It is important to note, however, that no account was taken of how changes in the magnitude of different parameters could affect the outcome of the model. This type of investigation, 'sensitivity analysis', could be particularly important for gull management, in the light of the wide variation in the published data on adult and immature survival rates and the fact that at most colonies immigration and emigration rates are unknown and are likely to be colony specific (see earlier). There are a wide range of methods that can be employed in sensitivity analysis, and these must be closely referenced to the type of the model used (Kleijnen *et al.* 1992, Brown and Rothery 1993). Techniques for investigating the relative influence of different parameters used in environmental data are reviewed by Caswell and Trevisan (1994), and Hamby (1994).

When deciding on the appropriate management strategy, consideration must be given to the role of individuals from other colonies in the dynamics of the problem group. The large discrepancy between the number of gulls killed at Tarnbrook and the fall in

breeding numbers was due to the culls acting as a 'sink' for gulls from other areas, almost certainly Walney Island and this aspect of population dynamics must be addressed before the culling of large numbers of individuals takes place.

Changes in public opinion about killing large numbers of animals and the problems that have been encountered by such programmes, mean that government agencies mandated to licence culling in Britain are unlikely to sanction large scale culls in the future. Culling of small numbers of gulls at nature reserves is still used at several sites, but for larger groups, alternative non-lethal management will have to be considered to ameliorate the problems that gulls can cause.

CHAPTER SIX

NEST SITE SELECTION AT TARNBROOK FELL GULLERY

6.1. Introduction

The morphological, physiological and behavioural make-up of a particular bird species will be influenced by and directly influence the evolution of preferences for certain habitats. Darwin, on his 'Beagle' voyages in the 1830's, recorded numerous examples of species that were segregated by their habitat preferences and realised the bearing that habitat selection could have on an animals ultimate fitness (Darwin 1836). In some bird species, habitat selection may involve relatively small areas where the individuals will breed and feed throughout the year. Others may have a preferred summer breeding habitat and then move elsewhere during the winter months. Many colonial nesting seabirds fall into this latter category, but have the summer habitats separated into distinct feeding and breeding areas i.e. most seabirds do not forage within the breeding colony. For larids, selection of breeding habitat occurs at three levels:

(i) Colony habitat.

Many gulls display a high degree of philopatry once a colony has been chosen, and so will only make this choice once in their lifetime. For highly social seabirds such as gulls, cues such as the presence, behaviour and density of conspecifics will be as important in colony selection as the nature of the physical environment. In some larids, very specific physical features are selected and different colonies will have very similar habitats. An example of this is Franklin's Gull *Larus pipixcans* of North America,

where all colonies are in areas with a specific mixture of reed species (*Scirpus*) and a high percentage of edge-open water interface (Burger 1991). Lesser Black-backed Gull colonies are selected from a wider range of habitats (Table 42).

Table 42. Range of habitats utilised as colony sites in Britain and Ireland.

Colony	Major habitat type associated with colony	Reference
Tarnbrook Fell	Blanket moorland (+450m)	Greenhalgh 1974
Walney Island	Coastal sand dunes with marram grass, pebbles and grass sward	Brown 1967
Orfordness	Shingle beach with some vegetation	Lloyd 1991
Bristol city centre	Flat or gabled roofs and chimney tops	S. Raven, personal communication 1994
Dounreay nuclear power station	Flat-top roofs and metal walkways on industrial site	As above
Ribble marshes nature reserve	Coastal marsh with brackish pools	D. Lambert, personal communication 1994
Isle of May	Rocky coastal island with dense summer growths of <i>Atriplex</i> sp. and <i>Rumex</i> sp.	Duncan 1978
Lough Erne	Grassy islands in centre of freshwater lake	Lloyd 1991

(ii) Territory habitat.

Within a colony there is often a range of available habitats at a smaller scale. For example, the Tarnbrook Fell Gullery is situated on blanket moorland, but within this major habitat type are smaller patches of several different types of vegetation, slopes, aspects and unvegetated areas of bare peat and rock. The selection of territory will incorporate both the physical and social context of a particular area. The territory must provide suitable sites for displaying, mate acquisition, defence and provide a suitable range of potential sites for the nest and hiding places for chicks. A high density of breeding conspecifics may mean a greater number of fights and disputes and may increase the risk of egg predation by neighbouring pairs. On the other hand, the risk of attack from predators other than breeding conspecifics may be reduced.

(iii) Nest site habitat.

After colony and territory selection, birds must decide on a suitable nest site within a territory. Physical cues play an important role in this part of the habitat selection process because the nest, eggs and incubating parent need protection from predators and the effects of bad weather. The distribution of nests can occur in three ways:

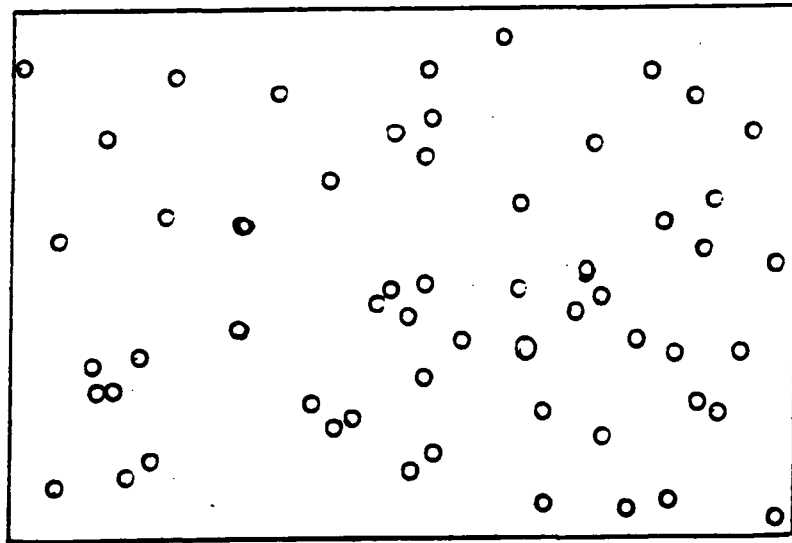
(a). Random distribution: If the presence of other gulls does not influence nest site choice and if the gulls have no preference for a particular vegetation type, each point in space within the colony will have an equal probability of being occupied. This leads to a random nest distribution (Figure 45).

(b). Aggregated or clumped distribution: This occurs when gulls display some degree of social cohesion when breeding together or if a particular vegetation type/physical

feature is favoured for the nest site. The nests then aggregate into certain areas with less dense or completely nest-free areas between the denser 'patches' of nests.

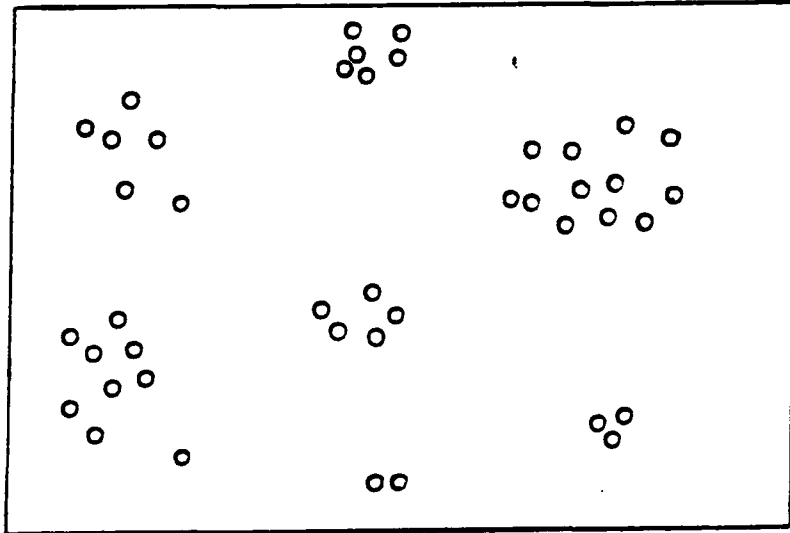
(c). **Regular distribution:** Regular or even spacing of gull nests occurs when each pair has a tendency to actively avoid the presence of other breeding pairs.

Figure 45. Three possible distribution patterns for gull nests within a colony.



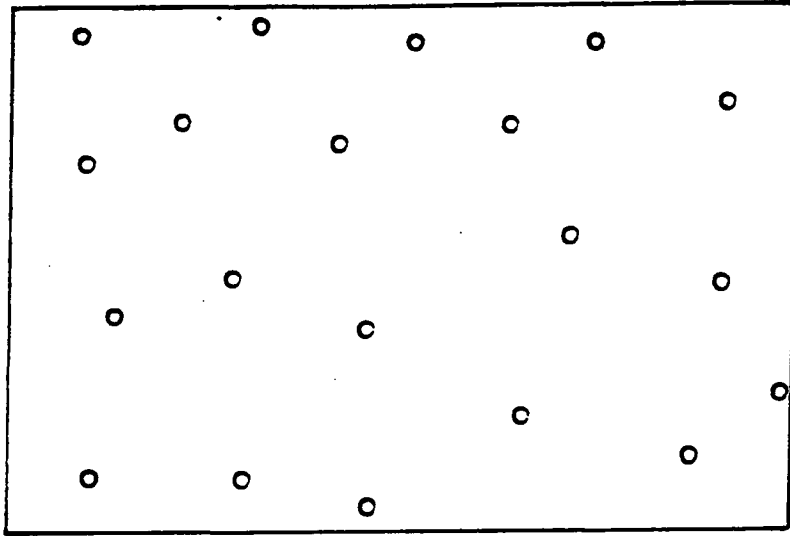
Random distribution

Variance: Mean = 1.0



Aggregated distribution

Variance: Mean > 1.0



Regular distribution

Variance: Mean < 1.0

6.1.2. Aims of the nest site selection study

There were three main aims in studying the nest site selection of gulls at the Tarnbrook Fell Gullery:

- (i) To investigate whether a non-random nest distribution exists at the colony.
- (ii) To investigate differences in usage and availability of different vegetation types within the gullery.
- (iii) To investigate how much of the variation in the number of nests in census quadrats can be explained by differences in vegetation types.

6.2. Methods

During the annual census of nests in the gullery (Chapter 5), 45 quadrats (0.5ha) were surveyed for nests and eggs. In 1994, in addition to nest contents, the vegetation within a circle of 1m radius around the nest was categorised and recorded. The following five categories of dominant vegetation were used:

- (i) Grass/Sedge: areas of *Nardus stricta*, *Deschampsia flexuosa*, *Molinia caerulea* and *Eriophorum vaginatum* usually cropped by sheep.
- (ii) Low heather: *Calluna vulgaris* <20cm height.
- (iii) High heather: as above but >20cm height.
- (iv) Bilberry: *Vaccinium myrtillus*.
- (v) No vegetation: areas of either bare peat or rock.

In most cases, nests were surrounded by only one type of vegetation and could be easily classified. Where this was not the case, the vegetation type comprising >50% of the total coverage was used to describe the nest site.

A χ^2 goodness of fit test was used to investigate differences in the observed nest density frequencies compared to the frequencies 'expected' if nests were randomly distributed. Empty nests and nests with clutches were analysed separately for both the Sanctuary and non-Sanctuary areas. The expected frequencies were generated using the Poisson formula:

$$P(x) = (e)^{-\text{mean}(x)} \frac{(\text{mean}(x))^x}{(x)!}$$

$$\text{Expected frequency} = P(x) n$$

where $P(x)$ = probability of (x) number of nests per sampling unit ($x = 1, 2, 3, 4, \text{etc.}$), mean (x) = mean number of nests per sample, (e) is the base of the natural logarithm (2.718), and n = number of sampling units (census quadrats).

To assess the availability of different vegetation types within each quadrat, 30 random 'non-nest' points were sampled and the vegetation within a 1m radius circle of each point was recorded. In the sanctuary area, 22 quadrats were surveyed giving 720 non-nest site points. In the non-Sanctuary, 32 quadrats were surveyed giving 960 non-nest site points. A χ^2 goodness of fit test was then used to investigate differences in availability and usage of the vegetation types. Where more than 20% of the cells in a contingency table had expected values of <5, adjacent cells were pooled with the appropriate loss of degrees of freedom.

To determine the effect of variation in vegetation types on the variation in nest densities, a Pearson correlation and a stepwise linear regression on transformed data

(SPSS for Windows) was used to investigate the relationships between the following variables:

(i) number of nests in a quadrat (dependent variable)

(ii) Grass/Sedge

(iii) Low and High Heather

(iv) Bilberry

(v) Areas with no vegetation cover

(vi) Distance of census quadrat from edge of the colony.

The relationship could not be investigated for the Sanctuary and non-Sanctuary areas separately, because the number of variables (7) was too great for the number of Sanctuary cases (22). The results thus refer to the colony as a whole based on data from the 45 quadrats of the large grid system (Chapter 5).

Paludan (1951) and Tinbergen (1961) described the 'edge' of gulleries as having lower nest densities than areas further away from the edge. The relationship between distance from the edge and nest density is unlikely to be a linear one and in order that distance could be incorporated in the regression analysis, quadrats less than 150m from the edge of the colony were assigned into category '0' and quadrats more than 150m from the edge into category '1'. It should also be noted that none of the census quadrats lie over the colony boundary i.e. are partially outside the colony area.

6.3. Results

6.3.1. Number of nests found

In the Sanctuary area, 293 empty nests and 198 nests with clutches were found during surveys of 22 quadrats. In the non-Sanctuary area, 273 empty nests and 172 clutch nests were found in 32 quadrats.

6.3.2. Nest distribution

(a). Sanctuary area.

Figure 46 and Figure 47 show the frequency distributions for empty nests and nests with clutches in the Sanctuary area (n=22 quadrats). Table 43 gives the variance to mean ratio of the observed frequencies and the percentage of quadrats whose nest density was outside 95% of the random distribution range. Both empty nests and nests with clutches had distributions significantly different to a random distribution. For empty nests the variance to mean ratio was 14.5 and $\chi^2=8.1$, 2 df, $p<0.05$. A total of 16 quadrats (73%) were outside the range of the random distribution. For nests with clutches, the variance to mean ratio was 8.6 and $\chi^2=16.3$, 2 df, $p<0.01$. A total of 11 quadrats (50%) were outside the range of the random distribution.

Figure 46. Frequency of number of Lesser Black-backed Gull nests in census quadrats (n=22) compared to a random distribution of nest numbers produced by Poisson formula (see text). Mean number of nests per quadrat =9.2 (sd=8.9). Data from 1994 census.

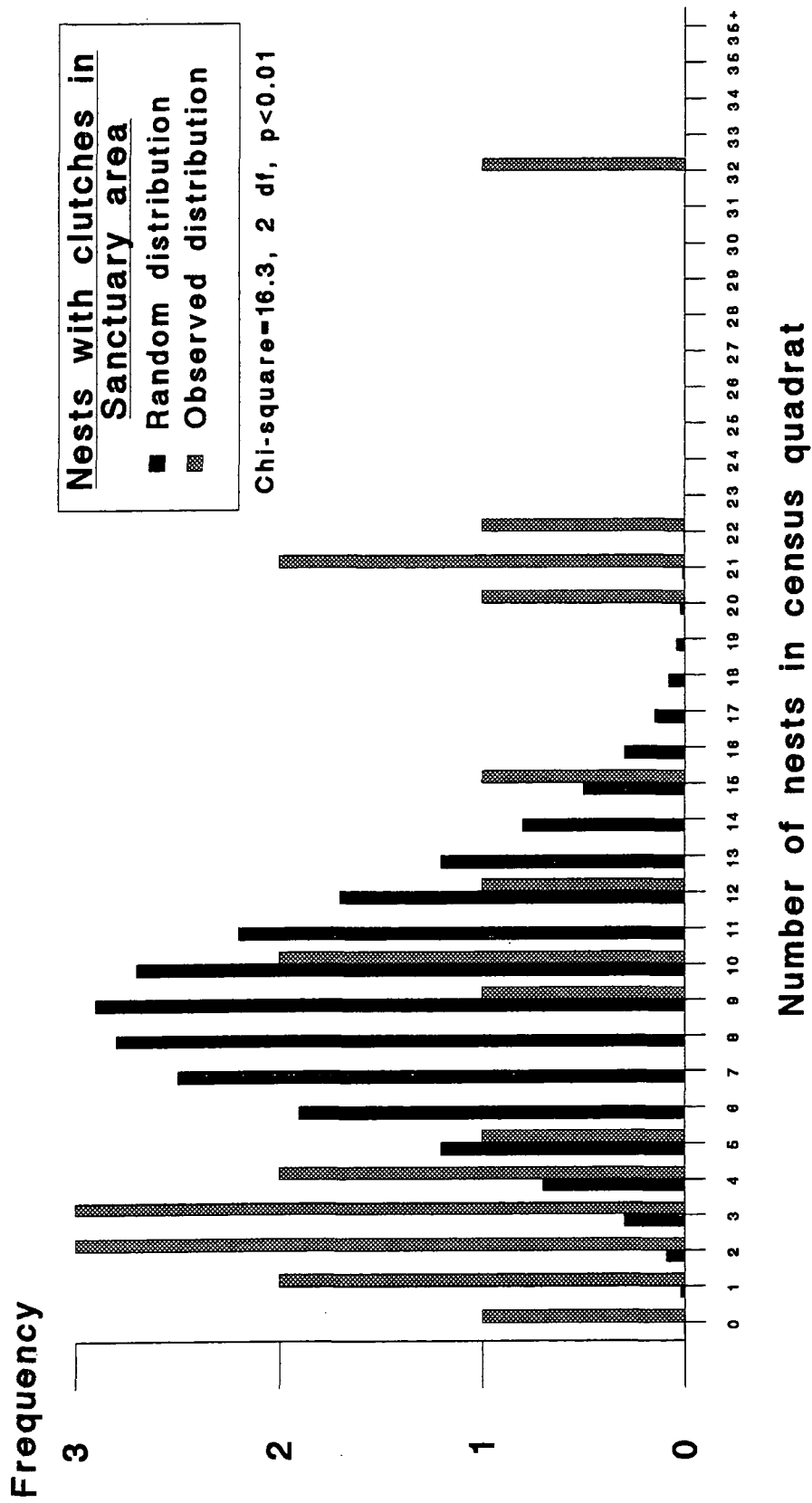


Figure 47. Frequency of number of Lesser Black-backed Gull nests in census quadrats (n=22) compared to a random distribution of nests produced by Poisson formula (see text). Mean number of nests per quadrat =11.8 (sd=13.1). Data from 1994 census.

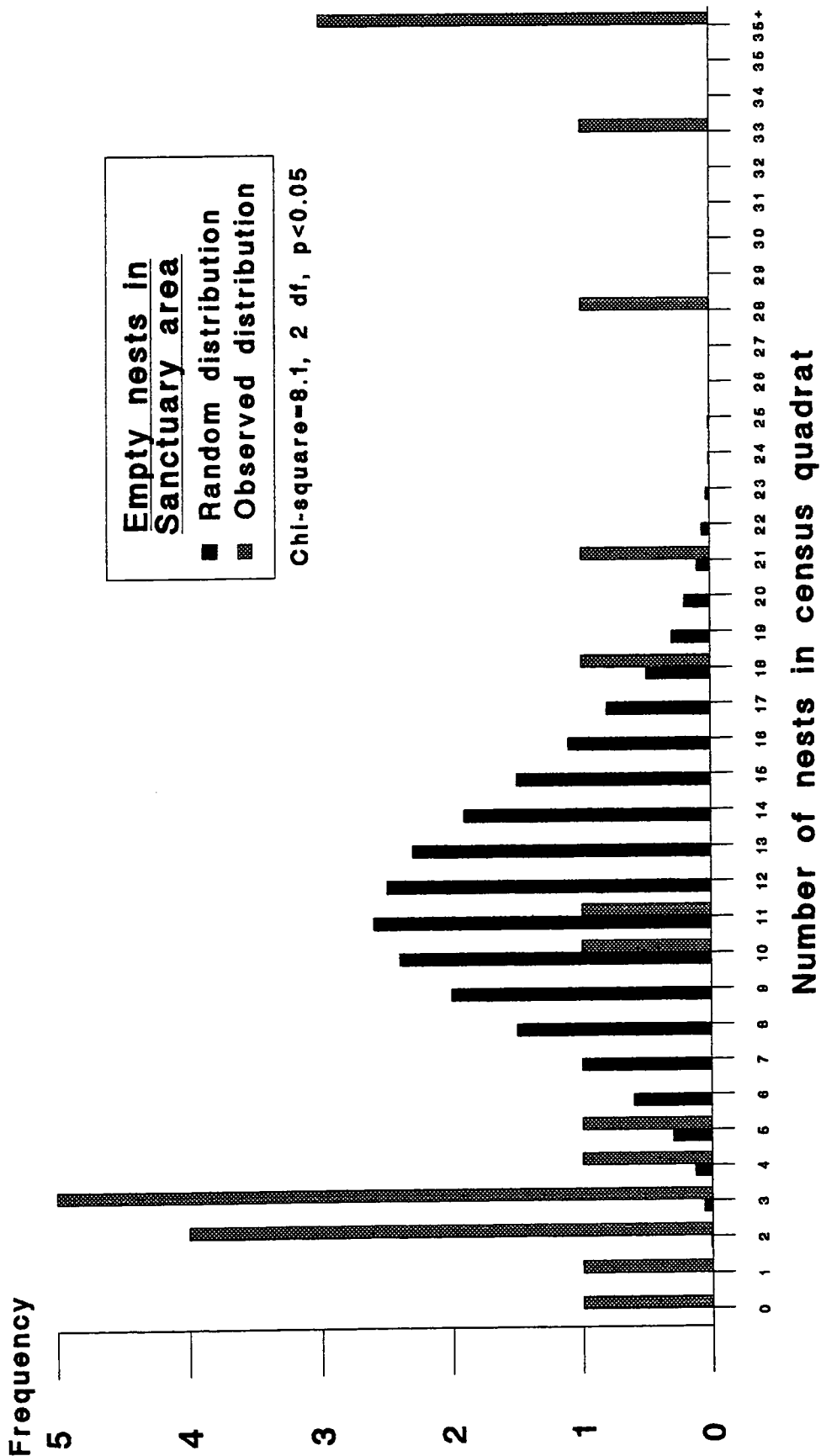


Table 43. Variance:mean ratios and number of quadrats outside the nest density range of a random distribution of nest density frequencies for empty nests and nests with clutches: Sanctuary and non-Sanctuary areas 1994.

	Number of nests	Number of quadrats	Mean number nests per quadrat	Variance	Variance:Mean	Number of quadrats with nest density outside 95% of random distribution
Non-Sanctuary: empty nests	273	32	8.3	34.8	4.2	5 (15%)
Non-Sanctuary: nests with clutches	172	32	5.4	13.0	2.4	None
Sanctuary: empty nests	293	22	11.8	171.6	14.5	16 (73%)
Sanctuary: nests with clutches	198	22	9.2	79.2	8.6	11 (50%)

The distribution for both empty nests and nests with clutches in the Sanctuary area was thus aggregated rather than random or regular.

(b). Non-Sanctuary area.

Figure 48 and Figure 49 show the frequency distributions for empty nests and nests with clutches in the non-Sanctuary area (n=32 quadrats). Table 43 gives the variance to mean ratio of the observed frequencies and the percentage of quadrats whose nest density was outside 95% of the random distribution range. For empty nests, the variance to mean ratio was 4.2 and $\chi^2=10.4$, 3 df, P,0.05. A total of 5 (15%) of quadrats had nests densities that fell outside the range of the random distribution. For nests with clutches, $\chi^2=5.2$, 3 df, (not significant) and no quadrats had a nest density that fell outside the random distribution. This suggests that empty nests had an aggregated distribution but nests with clutches had a distribution not significantly different to a random distribution. The result of the goodness of fit test should, however, be treated with caution as the variance to mean ratio for nests with clutches was 2.4 which does indicate an aggregated distribution.

6.3.3. Availability of vegetation types

The percentage availability of the five vegetation classifications for the Sanctuary and non-Sanctuary areas are shown in Figure 50. There was no significant difference in the availability of Grass/Sedge between the two areas (29% in Sanctuary, 26% in non-Sanctuary, $\chi^2=1.8$, 1 df, n.s.). Significantly more Heather was available as a nest site for the gulls in the non-Sanctuary (29%) than in the Sanctuary (13%) ($\chi^2=55.4$, 1 df, $p<0.01$). For high Heather the situation was reversed with significantly more available in the Sanctuary (28%) compared to the non-Sanctuary (17%) ($\chi^2=27.7$, 1 df, $p<0.01$). In the Sanctuary, Bilberry made up 8% of the available vegetation. This was significantly lower than the 15% in the non-Sanctuary ($\chi^2=20.1$, 1 df, $p<0.01$). A

Figure 48. Frequency of number of Lesser Black-backed Gull nests in census quadrats (n=33) compared to a random distribution of nest numbers produced by Poisson formula (see text). Mean number of nests per quadrat=5.4 (sd=3.6). Data from 1994 census.

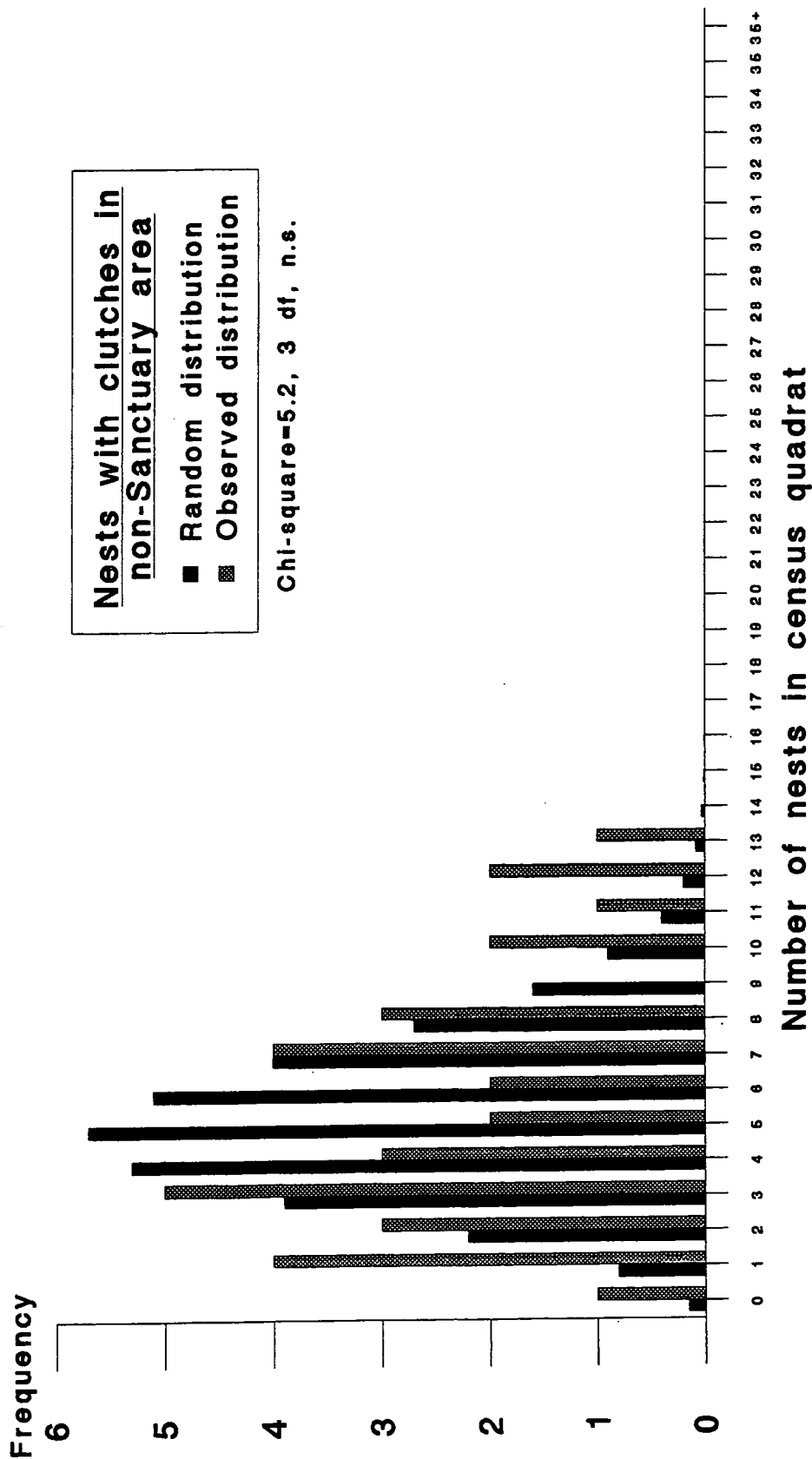


Figure 49. Frequency of number of Lesser Black-backed Gull nests in census quadrats (n=33) compared to random distribution of nest numbers produced by Poisson formula (see text). Mean number of nests per quadrat=8.3 (sd=5.9). Data from 1994 census.

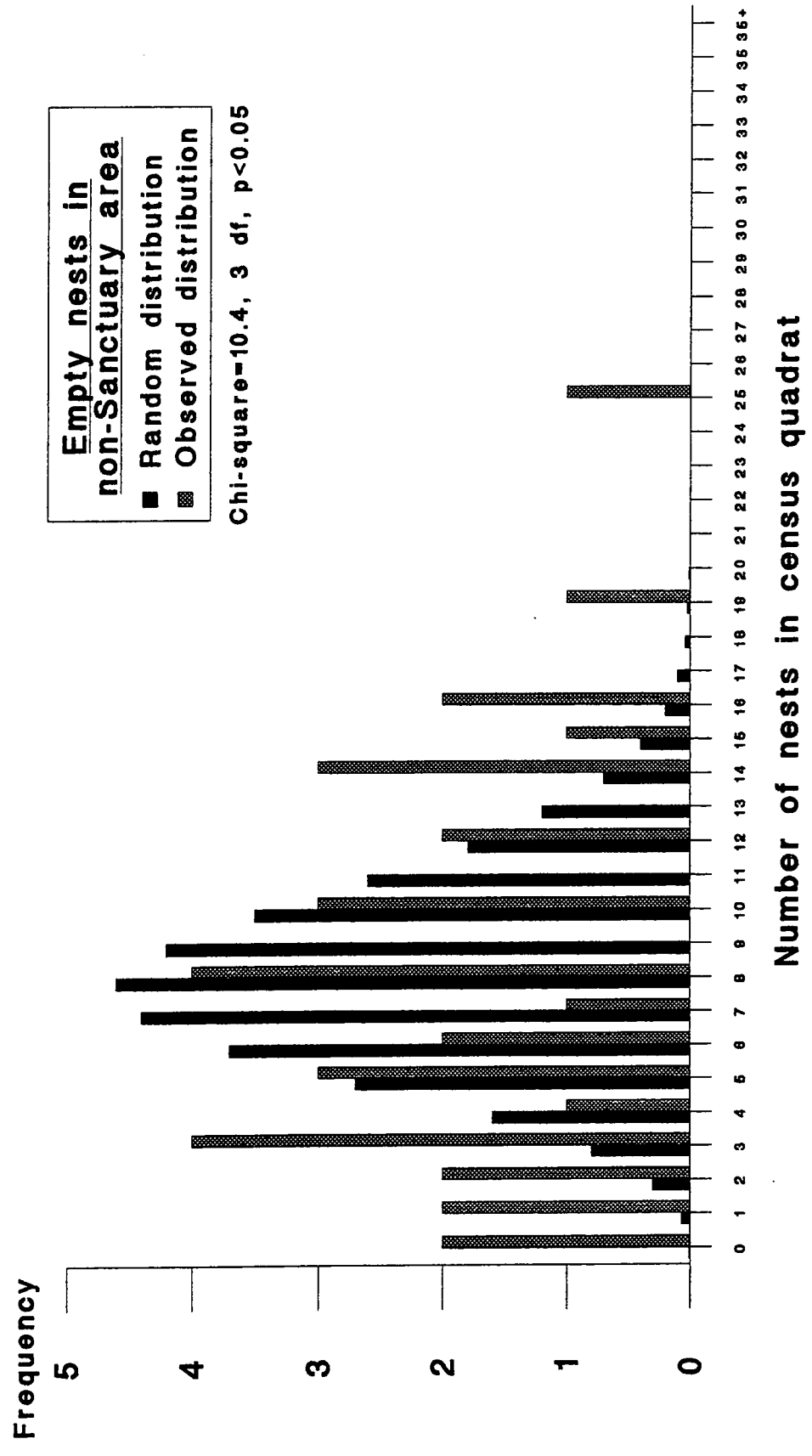
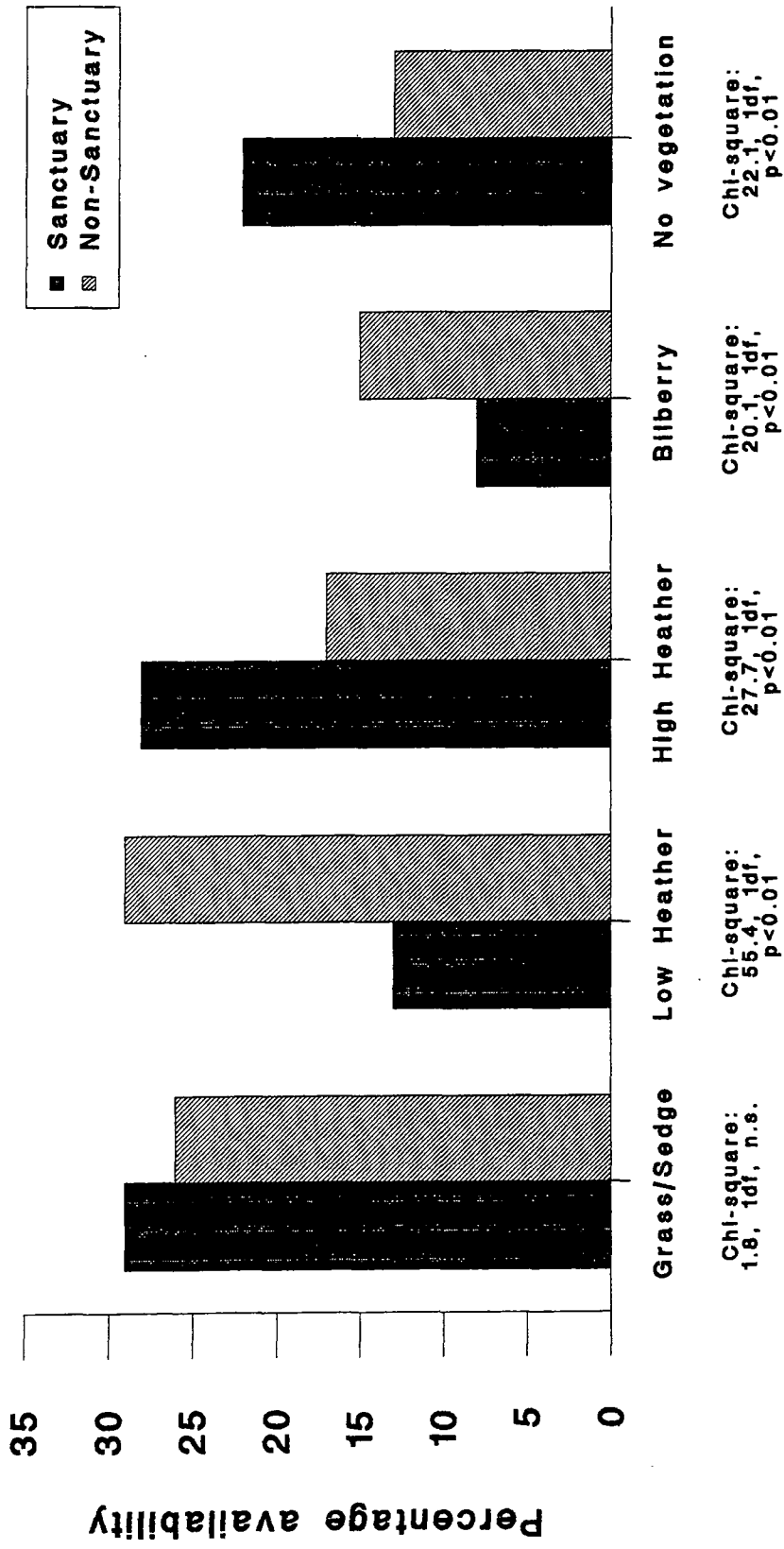


Figure 50. Percentage availability of vegetation types in the Sanctuary area (720 random points in 24 quadrats) and the non-Sanctuary area (960 random points in 32 quadrats). Tarnbrook Fell gully 12-19 May 1994.



greater percentage of the Sanctuary comprised areas of outcropping rock or exposed peat on which there was no vegetation (22%) compared to the non-Sanctuary (13%) ($\chi^2=22.1$, 1 df, $p<0.01$).

6.3.4. Nest site selection in the Sanctuary area

(a). Empty nests and availability of vegetation types.

Figure 51 shows the percentage availability of the five vegetation classifications compared to the percentage of empty nests found in each vegetation type. Seventy six percent of the empty nests in the Sanctuary area were built in Grass/Sedge which made up only 29% of the available vegetation. The difference is significant ($\chi^2=182$, 1 df, $p<0.01$). The percentage usage of low Heather (6%) and high Heather (16%) as sites for empty nests in the Sanctuary was significantly lower than expected from their percentage availability: low Heather = 13%, $\chi^2=10.4$, 1 df, $p<0.01$; high Heather = 28%, $\chi^2=14.9$, 1 df, $p<0.01$. Only 3% of the empty nests were found in Bilberry which comprised 8% of the available vegetation ($\chi^2=15.7$, 1 df, $p<0.01$). Areas without vegetation cover made up 22% of the Sanctuary area but contained only 3% of the total number of empty nests ($\chi^2=66.1$, 1 df, $p<0.01$).

(b). Nests with clutches and availability of vegetation types.

Figure 52 shows the percentage availability of the five vegetation classifications compared to the percentage of nests with clutches found in each vegetation type. As with the empty nests in the Sanctuary, the percentage of nests with clutches in Grass/Sedge (57%) was significantly higher than expected from the percentage availability of this vg type (29%) ($\chi^2=51.2$, 1 df, $p<0.01$). There was no significant difference in the percentage of the total number of nests with clutches built in low

Figure 51. Percentage availability of vegetation types within census quadrats (720 random points in 24 quadrats - see text), compared to percentage utilised as Lesser Black-backed Gull nest sites (n=293 empty nests). Tarnbrook Fell Gullery 1994.

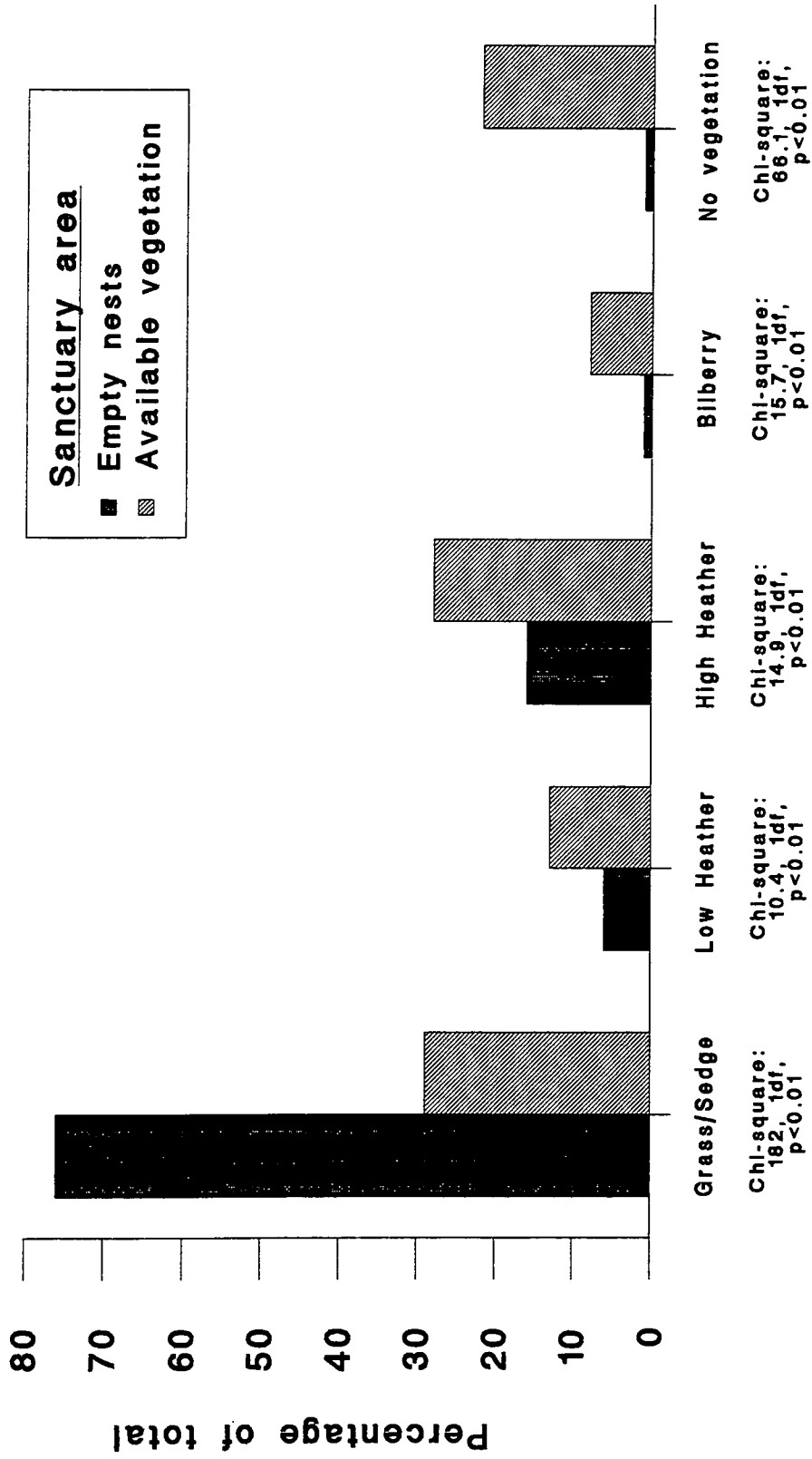
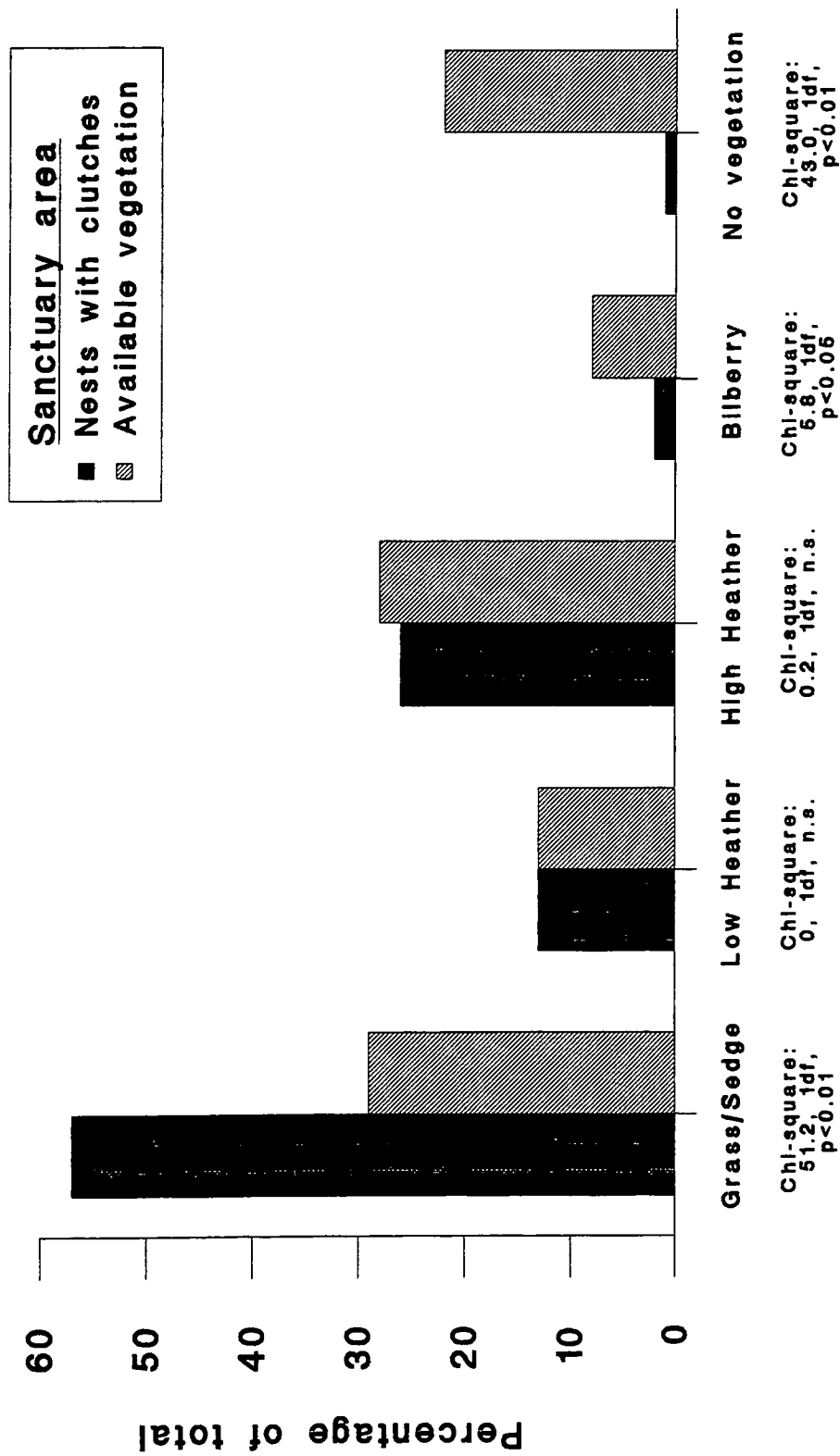


Figure 52. Percentage availability of vegetation types within census quadrats (720 random points in 24 quadrats - see text), compared to percentage utilised as Lesser Black-backed Gull nest sites (n=198 nests with clutches). Tarnbrook Fell Gullery 1994.



Heather (13%) or high Heather (26%) compared to the percentage expected from the availability of these vegetation types: low Heather = 13%, $\chi^2=0$, 1 df, n.s.; high Heather = 28%, $\chi^2=0.2$, 1 df, n.s.. Bilberry made up 8% of the available vegetation but only 2% of nests with clutches were built in this vegetation ($\chi^2=5.8$, 1 df, $p<0.05$). Bare rock or exposed peat made up 22% of the Sanctuary area but only 1% of nests with clutches were sited in these areas ($\chi^2=43$, 1 df, $p<0.01$).

(c). Empty nests and nests with clutches.

When comparing the percentage of the total number of empty nests found in each vegetation type with the percentage of nests with clutches in each vegetation type (Figure 53), there was a significantly greater percentage of empty nests (76%) built in Grass/Sedge compared to nests with clutches (57%) ($\chi^2=18.2$, 1 df, $p<0.01$).

Significantly fewer empty nests were built in low Heather (6%) than nests with clutches (13%) ($\chi^2=6.2$, 1 df, $p<0.05$). The same was true for high Heather with 13% of empty nests and 26% of clutch nests sited in this type of vegetation ($\chi^2=6.4$, 1 df, $p<0.05$).

Bilberry was used as a nest site for only a small percentage of the total nests: 1% of empty nests and 2% of nests with clutches. The difference is not significant ($\chi^2=0.9$, 1 df, n.s.). The situation was similar for areas without vegetation which contained only 1% of the total number of both empty nests and nests with clutches ($\chi^2<0.1$, 1 df, n.s.)

6.3.5. Nest site selection in the non-Sanctuary

(a). Empty nests and availability of vegetation types.

Figure 54 shows the percentage availability of the five vegetation classifications in the non-Sanctuary compared to the percentage of empty nests found in each vegetation type. Grass/Sedge made up 26% of the total vegetation and contained 23% of the total number of empty nests. The difference is not significant ($\chi^2=1.2$, 1 df, n.s.). Nor was there a significant difference in the percentage availability of low Heather (29%)

compared to its percentage usage as a site for empty nests (32%) ($\chi^2=1.0$, 1 df, n.s.). High Heather however, made up only 17% of the non-Sanctuary vegetation but 44% of empty nests were built in it ($\chi^2=86$, 1 df, $p<0.01$). As in the Sanctuary area, Bilberry was not favoured as a site for empty nests <1% of total in this vegetation which comprised 15% of the total vegetation ($\chi^2=39.7$, 1 df, $p<0.01$). Bare rock or exposed peat made up 13% of the non-Sanctuary but <1% of empty nests were sited in these areas ($\chi^2=35.7$, 1 df, $p<0.01$).

Table 45. Results of stepwise multiple regression of total number of Lesser Black-backed Gull nests in census quadrats (n=45) with five vegetation classifications (see text) and distance of quadrat from edge of colony. Tarnbrook Fell Gullery 1994.

Dependent variable: number of nests in quadrat
 Multiple R: 0.49
 R square: 0.24
 S.E. of R: 0.30

Variables in equation:

	Slope	S.E. Slope	Regression coefficient	t value	Significance
Grass\Sedge	0.46	0.18	0.36	2.55	p=0.01
Low Heather	-0.25	-0.11	0.30	2.13	p=0.04
Constant	0.89	0.21		4.29	p<0.001

Analysis of variance:

	Degrees of freedom	Sum of squares	Mean square
Regression	2	1.13	0.56
Residual	42	3.50	0.09

F = 6.27 Significance $_{2,42} = 0.004$

Variables not in equation:

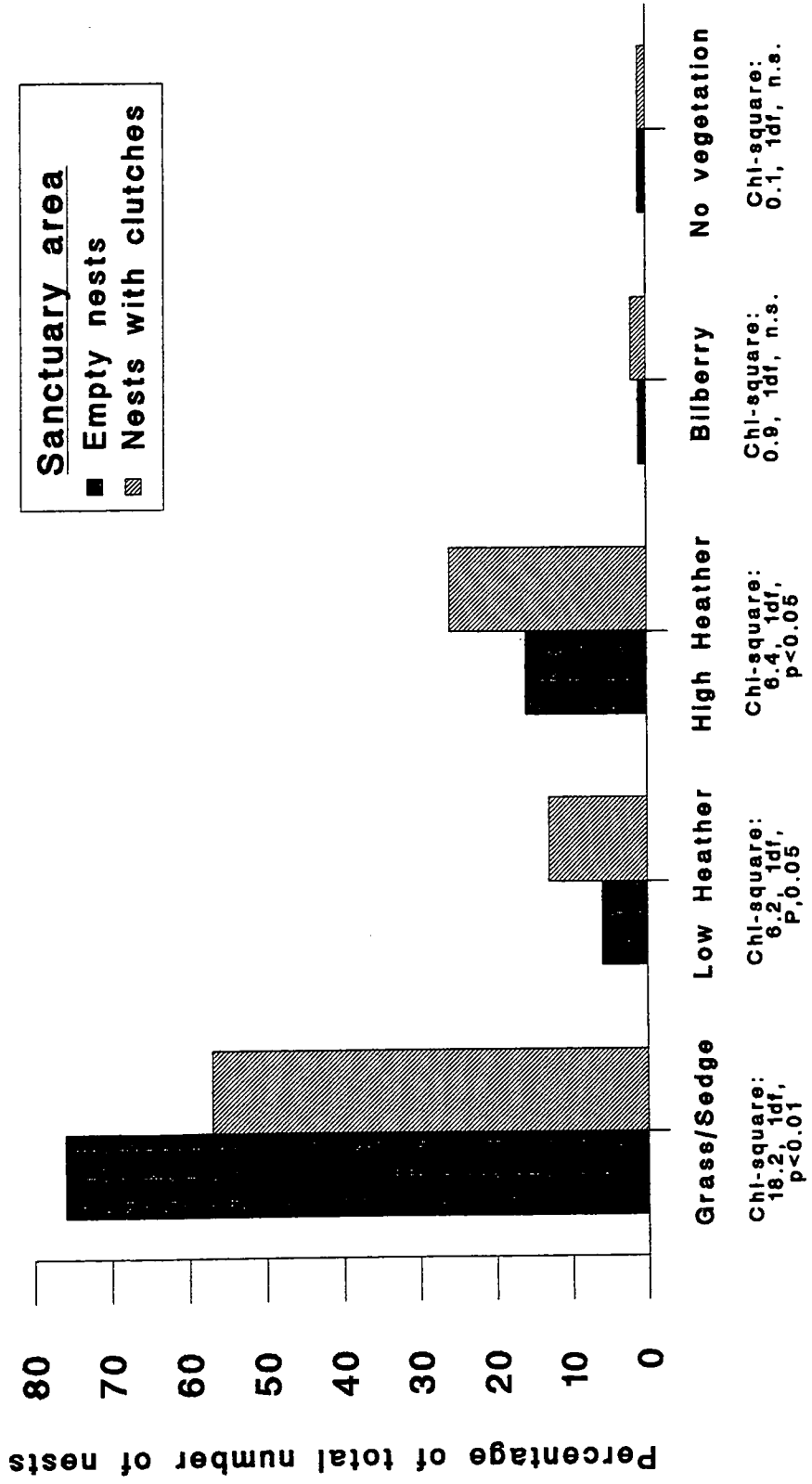
	Regression coefficient	t value	Significance
Bilberry	-0.22	1.55	p=0.13
High Heather	0.22	1.08	p=0.29
No vegetation	-0.01	0.01	p=0.99
Distance from edge of colony	0.01	0.01	p=0.99

Regression equation:

Number of nests in quadrat = 0.46 Grass/Sedge - 0.25 low Heather + 0.89

with the two independent variables (Grass/Sedge and low Heather) explaining 24% of the variation in the dependent variable (number of nests in the census quadrats).

Figure 53. Comparison of total number of empty Lesser Black-backed Gull nests (n=293) and nests with clutches (n=198) built in Sanctuary vegetation types. Tarnbrook Fell Gullery 1994.



(b). Nests with clutches and availability of vegetation types.

Figure 55 shows the percentage availability of the five vegetation classifications compared to the percentage of nests with clutches found in each vegetation type. There was no significant difference in the percentage of nests with clutches built in Grass/Sedge (20%) compared to its percentage availability (26%) ($\chi^2=2.9$, 1 df, n.s.). Thirty eight percent of the nests with clutches in the non-Sanctuary were built in both low and high Heather compared to 29% availability for low Heather ($\chi^2=5.8$, 1 df, $p<0.05$) and 17% availability for high Heather ($\chi^2=38.0$, 1 df, $p<0.01$). Bilberry comprised 15% of the total non-Sanctuary vegetation but only 3% of nests with clutches were found in this vegetation ($\chi^2=15.6$, 1 df, $p<0.01$). Bare rock and exposed peat made up 13% of the non-Sanctuary although only 1% of nests with clutches were built in these areas ($\chi^2=21.6$, 1 df, $p<0.01$).

(c). Empty nests and nests with clutches.

There were no significant differences in the percentage of the total number of empty nests built in the vegetation types in the non-Sanctuary area, compared to the percentage of the total number of nests with clutches. The percentages and χ^2 values are given in Figure 56.

6.3.6. Variation in the number of nests per quadrat

(a). Variables entered into the regression equation.

The number of nests in a quadrat was positively correlated with coverage of Grass/Sedge ($r=0.39$, 43 df, $p=0.01$) and negatively correlated with low Heather ($r=-0.34$, 43 df, $p=0.03$) and so both of these variables were entered in to the correlation matrix shown in Table 44. Correlation between independent variables

Figure 54. Percentage availability of vegetation types within census quadrats (960 random points in 32 quadrats - see text), compared to percentage utilised as Lesser Black-backed Gull nest sites (n=273 empty nests). Tarnbrook Fell Gullery 1994.

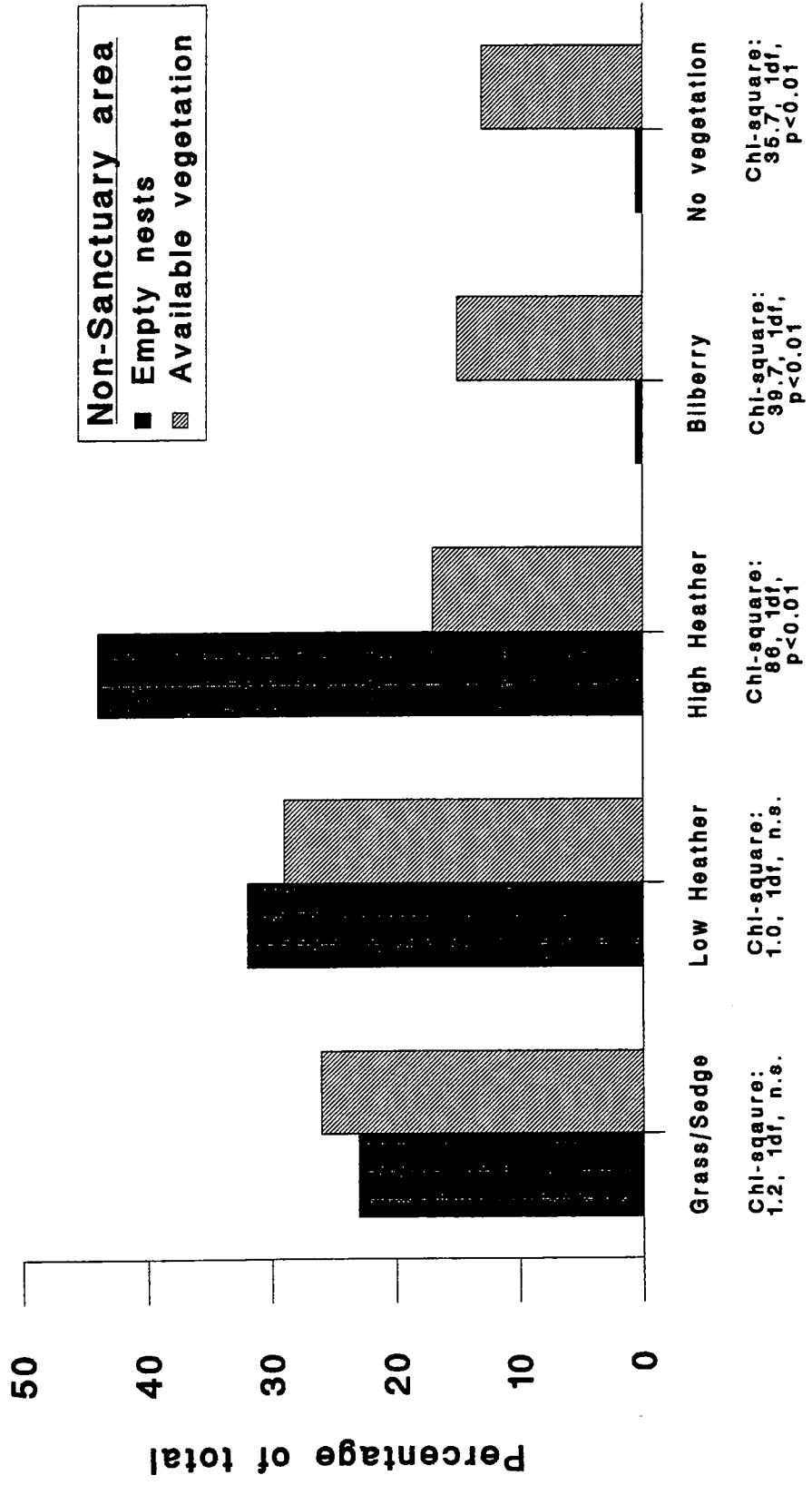


Figure 55. Percentage availability of vegetation types within census quadrats (960 random points in 32 quadrats - see text), compared to percentage utilised as Lesser Black-backed Gull nest sites (n=172 nests with clutches). Tarnbrook Fell Gullery 1994.

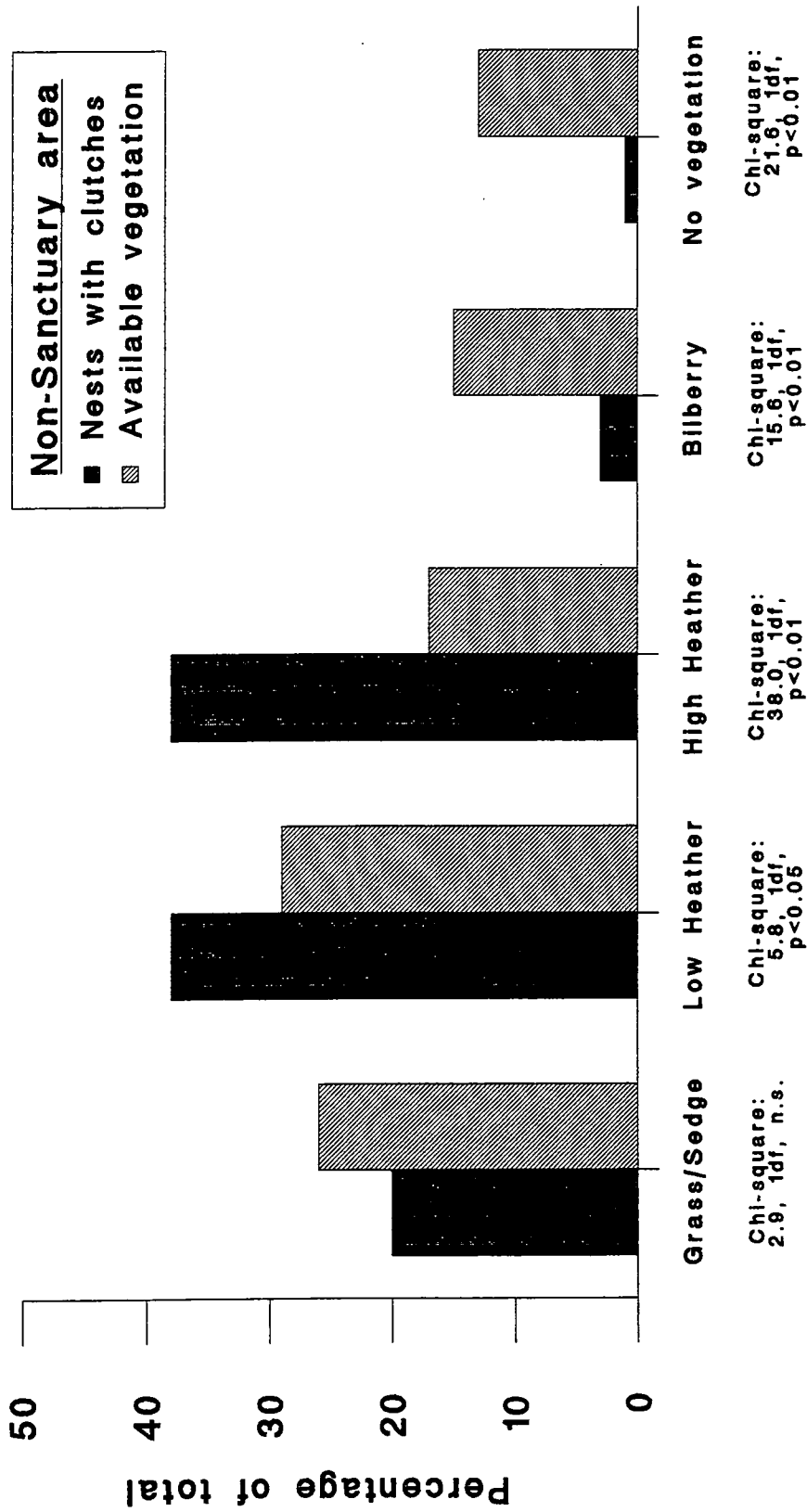


Figure 56. Comparison of percentage of total number of empty Lesser Black-backed Gull nests (n=273) and nests with clutches (n=172) built in non-Sanctuary vegetation types. Tarnbrook Fell Gullery 1994.

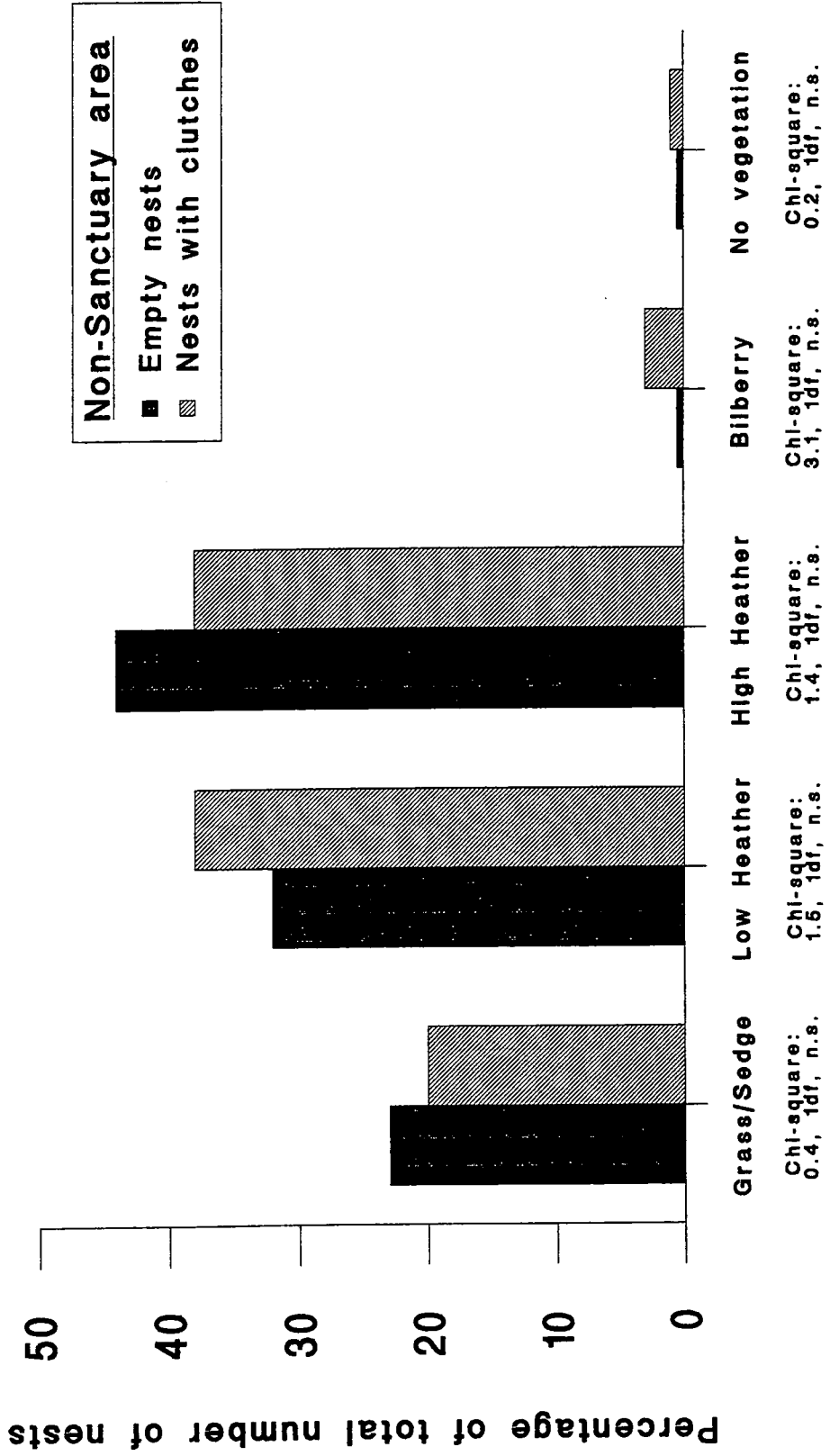


Table 44. Pearson correlation coefficient matrix showing relationship between total number of Lesser Black-backed Gull nests in 45 census quadrats, vegetation type, and distance of census quadrat from edge of colony. Tarnbrook Fell Gullery 1994.

	Bilberry	Grass/Sedge	High Heather	Low Heather	No vegetation	Distance	Number of nests in quadrat
Bilberry	--	-0.16 p=0.31	-0.12 p=0.46	0.07 p=0.66	-0.30 p=0.05	-0.04 p=0.80	-0.28 p=0.06
Grass/Sedge		--	-0.63 p<0.01	-0.12 p=0.44	-0.23 p=0.15	0.29 p=0.07	0.39 p=0.01
High Heather			--	-0.30 p=0.05	0.04 p=0.80	0.04 p=0.79	-0.04 p=0.82
Low Heather				--	-0.31 p=0.04	-0.47 p=0.02	-0.34 p=0.03
No vegetation					--	0.14 p=0.36	0.01 p=0.95
Distance						--	0.23 p=0.13
Number of nests in quadrat							--

Degrees of freedom for all correlations = 43. Significant correlation coefficients shown in bold type.

was also found for distance and low Heather ($r=-.47$, 43 df, $p=0.02$) and so distance was also used in the regression. The remaining three variables (Bilberry, high Heather and no vegetation) were also entered into the regression analysis because Bilberry was negatively correlated with no vegetation ($r=-0.30$, 43 df, $p=0.05$) and High Heather was negatively correlated with both Grass/Sedge ($r=-0.63$, 43 df, $p<0.01$) and low Heather ($r=-0.30$, 43 df, $p=0.05$).

(b) Regression analysis.

The results of the stepwise multiple regression are shown in Table 45. At the end of the analysis, Grass/Sedge and low Heather were the only significant variables that remained in the equation. These two variables were not auto-correlated ($r=-0.12$, 43 df, $p=0.44$) and the r^2 value = 0.24 i.e. the variation in the amounts of these vegetation types explained 24% of the variation in the number of nests in the census quadrats.

6.4. Discussion

6.4.1. Selection of breeding habitat

Selection of a favoured vegetation type, creates a disproportionate number of nests within a particular vegetation type compared to its percentage availability. This in turn leads to an aggregated, non-random distribution of nests within the colony as a whole (Borgiano 1970; Montevecchi 1978; Burger and Lesser 1980). Non-random nest site selection by gulls suggests that nest sites can be ranked in terms of their suitability and that suitability is related to presumed correlates of fitness such as breeding success or

survivorship (Bernstein *et al.* 1991). Prior to nest site selection, a territory must be acquired that is suitable for display, defence and contains potential nest sites that will protect the nest, eggs, chicks and incubating parents from predation and inclement weather. Selection of suitable habitat at this stage of the breeding season therefore has consequences for individual breeding success. Fretwell and Lucas (1970) proposed two ways in which animals become distributed amongst habitats. The first, "despotic distribution", occurs when habitats can be ranked in suitability and animals that settle first in the area will do so in the most suitable habitats. Late breeders or 'poorer' competitors will only be able to settle in less suitable habitats i.e. habitats in which there is the probability that their breeding success or survival will be reduced. The second, "Ideal free distribution", assumes that the higher ranking habitats will have a reduced suitability as the density of animals increases. At higher densities, the top ranking habitat will thus have a similar suitability to lower ranking habitats at low densities. When this point is reached, new settlers will settle equally in the two areas and individuals cannot improve their fitness by moving from one area to another. In gulls, group breeding presumably evolved because it conferred some fitness advantage to those breeding in denser groups over those breeding in less dense groups or in isolation. At very high densities, however, these advantages can be lost through increased social pressures and predation by conspecifics. In a gullery, habitat suitability is a function of both physical structure and the density of breeding conspecifics i.e. at higher breeding densities, habitats with physical characteristics that would normally enhance fitness may be reduced in their suitability and thus an ideal free distribution will occur.

Once the gulls have acquired a territory, a suitable nest site must be selected. Different types of vegetation and their varying heights means that there is both vertical and horizontal stratification within a gulls territory (Cody 1991). In both the Sanctuary and non-Sanctuary areas, Bilberry was not favoured as a nest site probably due to its stiff, interwoven stem structure. Why the gulls in the Sanctuary should be selecting Grass/Sedge areas to a greater extent than the non-Sanctuary birds remains unclear. One possible explanation is that topographical features in the non-Sanctuary mean that the Grass/Sedge areas are more prone to becoming saturated for longer spells during the regular periods of wet weather, a feature that might be selected against when constructing a nest. Although the ground in the Sanctuary area does appear to be generally drier throughout the season this has not been properly investigated and is only a subjective assessment. In the Sanctuary, a significantly greater proportion of empty nests were sited in Grass/Sedge. This may simply be a result of the ease with which this vegetation type can be pulled up to construct a nest compared to the tougher stems of Heather and Bilberry. During courtship, 'choking' displays occur at several sites over a period of time until one site is chosen where the nest that will eventually contain eggs is built. Empty nests appear to be the result of choking displays that are taken through to actual nest building (Chapter 4) and vegetation that is easy to remove from the ground or that facilitates 'scraping' may be favoured for empty nests. While gulls in the Sanctuary selected for Grass/Sedge, the birds in the non-Sanctuary area selected for Heather, particularly the High Heather. Again, topographical differences between the two areas that were not investigated during this study (e.g. slope, aspect, drainage and the frequency of deep channels dissecting the area) may account for these differences. More speculatively, the fact that Sanctuary gulls preferred Grass/Sedge and the non-Sanctuary gulls tall Heather, may be due in part to the differential management currently used on the two areas. In the non-Sanctuary, where gulls are disturbed, shot and have their eggs pricked, selecting for higher vegetation may give protection to adults, eggs and chicks compared to nesting in the more exposed shorter vegetation types. In the Sanctuary where the birds are free to breed without disturbance, the need to conceal the

nest may not be so important. There are no data to support this theory or to suggest that breeding success is higher in certain types of vegetation. Nor are there data available on the proportion of eggs that area pricked in each of the vegetation classifications.

However, the small proportion of nests on bare ground (which comprised 13% of the non-Sanctuary and 22% of the Sanctuary area) is perhaps another indication that nest site selection is based on the need to 'protect' the nest, eggs and incubating parent.

6.4.2. Causes of variation in nest density

Nest density within the Tarnbrook Fell Gullery varies greatly (Chapter 5) ranging from 0 to 89 nests per 0.5 ha census quadrat. Only 24% of the variation in the number of nests in a quadrat could be explained by certain vegetation types (Grass/Sedge and Low Heather). The extensive culling programme at the colony between 1978 and 1988 (Chapter 5) may provide further explanation of the variation. The culls achieved a reduction in the total number of birds breeding in the colony but failed to reduce the area over which the gulls breed i.e. the breeding density within the gullery was reduced. The topographical and vegetational make-up of the gullery area means that some parts of the colony are more difficult to gain access to than others. This coupled with the possible shielding effect of certain vegetation types and heights (see above), will have meant that past culling regimes will have been more effective in some parts of the colony than in others. This would have produced a patchwork of high and low nest densities within the colony. Once the removal of breeding birds stopped at the end of the cull, social cohesion will have meant that new recruits will tend to attempt to occupy areas where surviving gulls were at medium or high nest densities (Duncan 1978). In other words, the patchwork of nest densities created by the culling programme will have been maintained by recruiting birds. Large variations in nest density will therefore presumably be a feature of the Tarnbrook Fell Gullery while the total number of breeding gulls remains at lower levels than when the cull started.

CHAPTER 7

GENERAL DISCUSSION

7.1. Approaches to the control of problem species

Prior to the early 1960's, most pest control programmes were based on a 'maximum kill' philosophy, aimed at destroying the largest possible numbers of the pest in question (Kogan 1986). It gradually became apparent after the failure of many of these programmes, that new strategies would have to be developed and the concept of 'integrated pest management' grew in favour with agencies mandated to control pests (Horn 1988). The new philosophy used 'ecological' principles based on detailed knowledge of the species' biology, ecology and behaviour, and to simultaneously use a wide spectrum of techniques to achieve pre-stated aims. This approach has been successfully used in the latter half of the 20th century to reduce the economic or life threatening problems caused by some pests from a wide variety of taxa (Flint and van den Bosch 1981).

Since the advent of modern control practices, management strategies have generally been based on the following (Burgess 1990):

- (i). a survey of the nature and scale of the problem,
- (ii). a plan of the programme with a clear set of aims,
- (iii). the execution of the programme,
- (iv). a scientific evaluation of the efficacy of the programme.

7.2. An ecological approach to gull management

For many agricultural pests, particularly invertebrates, simple cost:benefit ratios have been used to assess the usefulness of management policies (Ordish 1952). Such assessment can be used to give a broad overview of the proposed strategy but Cherrett (1971) urged some caution with this approach for two reasons. Firstly, the ratio is based on assessments of past damage and future damage can be difficult to predict, and secondly, the ratio may be less than unity for a single occurrence of a problem, but greater than unity if the problem re-emerges at a later date. For gulls, the costs and benefits of control measures are particularly difficult to assess. Unlike many agricultural pests, many of the problems caused by gulls are 'potential' threats such as faecal contamination of water, or 'subjective', such as noise in the urban context.

In the preface to a recently published proceedings of a symposium on bird conservation it was stated that:

"Wildlife conservation needs a basis of sound science; it requires an understanding of the ecology of organisms and of the principles governing the responses of species and populations to habitat loss and other threats.

A strong theoretical framework is essential to effectively plan conservation strategies, manage land for wildlife and fight threats."

(Eds.Coulson and Crockford 1995)

It is perhaps ironic that many of the ideas behind this statement are equally applicable to the management of gulls, and agencies seeking to control numbers will be required to ask similar questions to those seeking to enhance them:

- What are the species' habitat requirements and when does it occupy breeding sites ?
- Is the species more sensitive to changes in adult or juvenile survivorship ?
- How does the species react to disturbance ?

- How are the numbers of individuals naturally regulated ?
- What are the levels of productivity and survivorship for different age classes ?
- What effect does breeding density have on productivity and survivorship ?
- What are the levels of immigration and emigration from the breeding group ?
- How can the changes brought about by management be evaluated ?

Drury and Nisbet (1969) were early proponents of the idea of using an ecological approach to control gull numbers and realised the importance of inter-colony dispersal to management strategies. The realisation that this sort of approach was likely to be more effective than killing large numbers of individuals *ad hoc*, also occurred during many years of attempting to control one of the worlds major avian pests, the Red Billed Quelea (Horn 1988). Early attempts at control in the 1950's and 1960's, were based on the strategy of simply locating as many concentrations of the birds as it was possible to find and destroying them by whatever means were available (Ward 1972). No significant reductions in either the numbers of individual birds or the cost of the damage caused was achieved despite the annual culling of tens of millions of birds. A temporary decline in numbers in South Africa was later attributed to low rainfall in certain areas, and only when an ecological approach was attempted were damage and control costs lowered (Ward 1979). The strategy used was to alter crop phenology along the birds' migration route and only destroy individuals when newly fledged young were the cause of damage. Another important factor in this strategy, was that it was aimed to give local relief wherever a problem occurred in contrast to the 'total population reduction' strategies of earlier years. Although deemed desirable, this latter course proved both impractical and financially costly. Quelea remain a serious pest and the ecological approach was never conceived as a panacea to all of Africa's pest problems. It has,

however, prevented continuing wastage of time, money and life, and for the first time brought relief from the problem in some local areas.

A 'total population reduction' strategy as a solution to the 'gull problem' would be equally impractical, and problems will have to be dealt with on a site-by-site basis. This can of course present its own problems. Just as loafing or feeding gulls displaced from one area of an airport can merely be moved to another area, breeding gulls displaced from a site such as Tarnbrook Fell Gullery have the potential to create the same problems in new areas. The displaced birds may, of course, move to areas where they do not come into conflict with humans and are therefore not considered as pests. Also, the problems caused by gulls are hardly comparable to the impact of Red Billed Quelea on human life in Africa, and from a moral standpoint a total reduction' strategy for gulls is untenable. Site-by site control of gulls using a sound scientific rationale is both a practical and morally defensible approach. It is important that decisions about management strategies should not become divorced from the moral aspect of gull control, particularly where lethal management is suggested. Consideration must be given to an objective assessment of the severity of the 'problem', how many people it affects, and how many gulls will have to be killed to achieve the desired aims of the control programme. The moral aspect of gull control is perhaps made more apparent today when we have adequate knowledge of the ecology of many species to prevent the unnecessary killing of animals through the use of inappropriate culling regimes and 'knee-jerk' reactions to problems at a local level. The problems at Tarnbrook provide a good example of this. The proposed solution to the "potential" health threat posed by the gullery was to attempt to kill as many gulls as possible. Many more gulls were culled compared to the actual fall in numbers of gulls breeding at the colony, and no reduction in the area of the gullery was achieved (Chapter 5). Also, no consideration was given to alternative strategies such as completely clearing catchment areas for the water intake pipes or temporary pipe closure when contamination levels were highest. Given our present knowledge of the effects of culling large number of gulls, and that

non-lethal methods have been demonstrated to be a viable alternative, large-scale culls such as the ones that occurred at Tarnbrook 1978-1988 could not be justified today.

7.3. Declines in gull numbers and recent trends in urbanisation

Two relatively recent changes that will be of relevance to future workers in the field of gull management are the reduction in national Herring gull numbers and the increased urbanisation of both Herring and Lesser Black-backed Gulls. Herring Gull numbers in Britain have reduced by 50% since the mid 1970's (Lloyd *et al.* 1991). The causes of these declines are not known and it remains unclear why they should not also be affecting Lesser Black-backed Gulls, whose numbers have increased in some areas over the same time period. Several suggestions have been forwarded for the declines. Furness *et al.* (1988) associated the declines with changes the size of offal discards brought about by legislation on fish-net sizes. Others have linked the declines with outbreaks of bacterial infections within local groups of gulls, particularly *Clostridium botulinum* that can cause a fatal condition known as botulism. Outbreaks of botulism can kill large numbers of gulls (6,000 in one incident in Scotland; Lloyd 1976) and may be severe enough to have an adverse effect on local numbers of gulls (Bell 1985; Buckley and O'Hallrohan 1986; Sutcliffe 1986; Dobson and May 1991; May 1994). Despite these declines, the Herring Gull remains a numerous bird in Britain. The national survey in 1985-1987 (Lloyd 1991) suggested about 360,000 breeding birds in Britain. Even at much lower numbers, the range of problems they cause would still exist. Understanding the reasons behind the changes will be one of the challenges to future workers in this field and will provide useful insights into the root causes of gull problems and how current management strategies might be improved.

There are now in excess of 10,000 pairs of Herring Gulls and 3,000 pairs of Lesser Black-backed Gulls utilising urban or industrial sites in Britain (S. Raven, personal communication). The first major investigation of the use of these sites by breeding gulls

was made by Monaghan and Coulson (1976). Since then the number of Herring Gulls involved has increased at 10% *per annum* and Lesser Black-backed Gulls by 18% *per annum* (S. Raven, personal communication). The increased urbanisation of gulls will undoubtedly increase the incidence of human-gull conflicts and many local government agencies will be faced with the problem of how to deal with these problems. The ecological approach to finding solutions to gull problems in towns is identical to the approach taken at Tarnbrook Fell i.e. the gulls' breeding biology, demography and behaviour should form the basis on which controls strategies are based. However, the increased urbanisation of gulls will necessitate new investigations of practical solutions to the problem because the visual, audio and human disturbance that was successful at Tarnbrook are unlikely to be sanctioned or of great value in an urban context.

7.4. Previous investigations of gull exclusion and disturbance

Some success has already been achieved in managing problems with urban gulls. Blokpoel and Tessier (1984) successfully eliminated a problem with gulls utilising Toronto City Hall, Canada. Stainless steel wires and monofilament lines were used to exclude the gulls from sensitive areas, and exclusion is undoubtedly a useful tool in this context. Other attempts using overhead wires both in towns and at reservoirs have also been successful (Amling 1980; Forsythe and Austin 1984; McClaren 1984; Morris *et al.* 1992). Broadcasting distress calls has also been used at reservoirs, although their main use seems to have been at airports (review in Blokpoel 1976). The main problem with distress calls is that they are very effective if there is a large turnover of gulls but repeated playing to the same group results in rapid habituation (Bridgman 1980; Aubin 1990). This effect was seen during the experiments with distress calls conducted at the Tarnbrook Fell Gullery (Chapter 3). "Cocktail" methods, i.e. where a suite of methods are used simultaneously or in succession, have also been used successfully (Blokpoel

and Tessier 1989) and the success of this method when used at Tarnbrook, suggests that it should be considered as a priority in planning gull management.

7.5. Limiting factors in gull management

The results of all work in deterring birds from sensitive areas are limited by three important factors:

(i). the motivation of the group to utilise a particular area and the availability and proximity of alternative sites (Brough 1969; Spanier 1980; Ostergaard 1981),

(ii). the numbers of problems birds involved and the area over which they cause a problem (Spaans *et al.* 1991),

(iii). the resources available to the agents of the management policy (Spaans and Blokpoel 1991).

The success of the Tarnbrook Fell disturbance work was similarly affected by these factors. The motivation of the breeding gulls to utilise the site is high, evidenced by their extreme tenacity in the face of widespread disturbance. Some of the gulls will have bred at the site for many years and it is in their interest to be site faithful (Chapter 3). At loafing sites there may be less advantage to them staying in the area if disturbed, and so the same disturbance regimes can have different effects at the two sites. The size of the Tarnbrook colony presents a problem in that methods such as monofilament enclosures will only cover a fraction of the total area of the gullery. The presence of grazing sheep is also a problem, as they can become entangled or damage the enclosure by rubbing against the support posts. Creating disturbance over a large area was also a major problem because of the number of birds involved and the resources available to the study. This is being overcome by completely clearing smaller areas and providing

the gulls with alternative sites. This of course, increases the time over which disturbance has to occur and increases the costs of the work.

7.6. Density dependence and non-breeders

Two inter-related factors that will continue to challenge those involved with managing gull problems are density dependent effects and the presence of non-breeding birds. Most authors agree that density dependence plays a role in limiting seabird numbers (see Croxall and Rothery 1991 for review) and that food, breeding space and predation are the important factors (Chapter 2). Density dependant effects occur within the colony area, through competition for breeding space, territory defence and increased predation of eggs and chicks. There are also density dependant effects operating away from the colony, particularly at feeding sites. Competition for food resources between individuals of several colonies can occur when their foraging ranges overlap. Thus density dependant effects can be a function of colony size and distance from other colonies, as well as the density of birds within the breeding area. When culling of adults is deemed necessary, its effects can be enhanced if timed to be additive to the effects of density dependence acting within the colony i.e. after natural density dependent effects have occurred. Reducing density too early in the season can make the site more 'attractive' to recruiting birds and increase the breeding success of surviving birds. In other words, it is possible for the culls to relieve the effects of density dependence and induce compensatory effects in remaining birds, and this has the potential to reduce the effectiveness of the culling programme (Chapter 5). Related to this, is the presence of a 'pool' of potential recruits that can replace culled birds when density dependent effects are relieved. The 'pool' of recruits can be made up of young birds who in the absence of the culls not be able to establish in the higher density colony (Chabrzyk and Coulson 1976), or birds that have taken a period of time out of breeding for one reason or another (widowed, divorced, failed late breeding or poor body condition). The presence

of a pool of non-breeding birds is often difficult to show but has been successfully demonstrated by removal experiments for a variety of species (Hensley and Cope 1951; Krebs 1977; Pedersen 1988). Several authors have attempted to quantify the non-breeding proportion of seabird groups (Duncan 1978; Coulson *et al.* 1982; Croxall *et al.* 1990) but Clobert and Lebreton (1991) urged caution with this sort of work as it is based on the distribution of ages when birds were first seen to breed for the first time, without correcting for variations in survival rates and catching effort. Nevertheless, there is undoubtedly a surplus of gulls associated with many colonies whose recruitment, induced by culling, would tend to reduce the effectiveness of the culls. Further research is needed in this area and consideration of these effects must be made when planning gull management strategies.

SUMMARY

CHAPTER 1.

During the twentieth century, several gull species have undergone large scale increases in numbers. These have been accompanied by expansions both in geographical distribution and the range of habitats utilised as breeding sites. Increased legislative protection of seabirds at the turn of the century, and the ability of gulls to exploit increasing amounts of a variety of anthropogenic food sources, have contributed to the increases in gull numbers. There have been a wide variety of conflicts with humans as a result of these recent changes in numbers. These have been placed under the umbrella term the 'gull problem'. Areas of conflict include: strikes with aircraft, public health, damage to property and detrimental effects on other, more sensitive species of birds.

During the past fifty years a variety of methods have been used in attempts to ameliorate gull problems, ranging from attempts to move birds away from sites by scaring methods to nest destruction and killing of breeding adults. Few of these attempts have resulted in the original aims of the management programmes being achieved.

CHAPTER 2.

In common with several other gull species, the Lesser Black-backed Gull has increased in numbers during the twentieth century. The British breeding group also appears to have changed its winter migratory pattern since the mid 1950's. Most adults now winter in the English midlands rather than moving southwards to the Mediterranean, southern Spain, Senegal and Mauritania as was formerly the case.

In 1938, the first pair of Lesser Black-backed Gulls bred at Tarnbrook Fell on the western slopes of the Pennine region known as the Forest of Bowland. No attempts

were made to control the gulls in the early stages of the gullery, and it grew both in terms of the number of breeding birds and the physical extent of the colony. In the early 1970's, there were around 48,000 gulls breeding over some 6.5km². Herring gulls first bred in the colony in 1951 and now make up 5% of the breeding group.

The gulls at Tarnbrook have come into conflict with humans in several ways. The area is managed for Red Grouse, and the three shooting estates on which the gullery lies have expressed concern that the gulls are having a detrimental effect on grouse numbers by predation and exclusion. Evidence for the effect of gulls on grouse remains anecdotal. If predation of grouse does occur, it may involve grouse that were already sick and dying when predated. Exclusion of grouse from breeding sites by the presence of gulls is also difficult to prove, and most territory and mate acquisition behaviour has occurred by the time the gulls fully occupy the colony in mid March.

The faecal contamination of water supplies has been one of the major areas of human-gull conflicts on a national scale and this problem has also occurred at Tarnbrook Fell. Gulls can be carriers of pathogenic bacteria and contamination of water supplies occurs when gulls defecate into rivers or reservoirs from which potable water is drawn. Circumstantial evidence also suggests that gulls are vectors of pathogens to sheep and cattle. In 1978, a study by the North West Water Authority drew attention to a potential health hazard posed by the Tarnbrook Fell Gullery, after contamination of a water supply used to provide drinking water to Lancaster city was demonstrated during the breeding season. In 1993, water analysis showed that although breeding numbers of gulls at Tarnbrook are 70% lower than in 1978, faecal contamination is still occurring at levels where the water authority is mandated to increase chlorine levels in the potable supply.

In addition to feeding at human waste sites, food sampling of birds at Tarnbrook revealed they also regularly utilised earthworms obtained from agricultural fields with 5km of the colony. Research into the effect of food availability on seabird numbers has been largely correlative and inferential, and the relative importance of availability in the

breeding and non-breeding seasons remains speculative. Nevertheless, the wide variety of food sources available to the gulls at Tarnbrook and their ability to successfully exploit them, has undoubtedly contributed to the success of the colony. In addition to this, grouse management has meant that the numbers of predators such as foxes and stoats are controlled at Tarnbrook, and this may also have benefited the gulls.

Circumstantial evidence exists that the presence of gulls at Tarnbrook has reduced the number of 'native' breeding species. Only four other bird species breed within the gullery area although fourteen breed in similar areas adjacent to the colony.

CHAPTER 3.

In the absence of control measures that were able to reduce the numbers of breeding birds at Tarnbrook Fell or the physical extent of the colony, a series of experiments were conducted between 1992 and 1994 designed to entirely clear specific areas of the colony by the disturbance of breeding birds. The experiments were based on the following rationale: gulls at the edge of the colony are easier to displace from breeding sites than birds toward the centre of the colony; complete clearance of the selected disturbance area is essential; an area of the colony should remain undisturbed to act as a control against which the disturbance experiments could be evaluated and to provide a 'sink' area for birds displaced by the disturbance. To facilitate this, a 'Sanctuary' area of 1.6km² was established in 1990 in which gulls were free to breed without disturbance or egg-pricking.

Disturbance took place in 2.25ha plots on the Abbeystead Estate. A variety of regimes and methods were used to evaluate their efficacy in excluding gulls during the breeding season and to prevent breeding from taking place. Two control plots, on which no disturbance occurred were used to quantify the effects of each type of disturbance. Propane gas guns, distress calls played through an amplifier, flags, monofilament lines and human disturbance were investigated. Comparisons of early and late disturbance was also made, as well as the relative efficacy of disturbance at the edge or centre of the

colony. On all the plots, some of the gulls habituated and progressively returned to the area after a variable period of total exclusion. Breeding was completely prevented on only two of the plots, and on both of these, two disturbance tools were used at the same time. On the other plots, some of the gulls were excluded from the plot during and after the disturbance and there was no evidence that excluded gulls moved onto the plot once disturbance had ended. A disturbance period of nine weeks was required to clear gulls from breeding sites and human disturbance was shown to be a useful management tool. In the season following a disturbance programme, the area needs to be 'guarded' from tenacious gulls and those that may have taken a year off from breeding and so missed the disturbance.

The disturbance work resulted in the clearance of approximately 1,900 gulls from 75ha of the gullery. This has reduced the total area of the colony by about 11%, and the gull areas on the Abbeystead Estate by 23%. No other control method used at the gullery has successfully reduced the extent of the colony. Circumstantial evidence from the annual census of gulls at Tarnbrook Fell, suggests that the disturbance work had an effect on breeding gulls beyond the limits of the disturbance site and that at least some of the birds displaced moved into the Sanctuary area.

CHAPTER 4.

In many bird species, a single nest structure is constructed to facilitate the incubation of eggs. In 1993, a study of nests was made at Tarnbrook where since 1980, 55% (s.d.±3%) of the nests found during the annual nest census have been empty i.e. nests that were built but not subsequently laid in. Out of 62 territories established on the study area, 26% of the pairs built a single nest and laid a clutch in it, 47% built between one and four nests and laid in one of them, and the remaining 27% of pairs built one to four nests but failed to lay a clutch. Empty nests were therefore not built exclusively by pairs that failed to produce clutches but were also a feature of successful breeding pairs.

In terms of the date of building, there were no significant differences between empty nests and nests with clutches, or between nests on territories where a single nest was constructed compared to those where multiple nests were built. When multiple nests were built on the same territory, the first nest built was not more likely to be laid in than subsequent nests. Once a clutch had been laid on a territory, no further nests were built and no territories contained two nests with clutches. No relationship was found between nest density and the proportion of empty nests in an area.

Gulls that failed to produce clutches attended their territories significantly less and achieved significantly fewer mountings than pairs that produced clutches.

In the past, calculations of the number of breeding gulls in the colony assumed that one nest represented one pair. This assumption was shown not to be true and a correction factor of 0.61 must be applied to the total number of nests found to estimate the total number of breeding pairs.

The empty nest study quantified the behaviour but more work is needed to explain why it occurs in the first place. Consideration must be given of why it does not occur at other colonies, why it is so constant from year to year and why only some of the gulls at Tarnbrook build empty nests.

CHAPTER 5.

The assumption that killing large numbers of individuals of a pest species will have the immediate effect of substantially reducing their numbers has been shown to be mistaken in the case of a variety of serious avian pests. Compensatory effects in the breeding parameters of surviving birds can reduce the overall effectiveness of the cull.

Demographic modelling can provide useful information on changes in bird numbers *per se* and also the processes that contribute to changes in breeding numbers. They also allow predictions to be made of the likely demographic effects of a particular management strategy.

The first Lesser Black-backed Gull bred at Tarnbrook Fell in 1938 and their numbers increased at 26% *per annum* up to 1965. The number of this species peaked in 1972 at 41,000 birds. The first Herring Gulls bred at the colony in 1951, and their numbers increased at 44% *per annum* up to 1972 when numbers peaked at about 7,000 birds. Similar rates of increase for these two species were recorded at the Walney Island during the same period. Between 1978 and 1988, some 75,000 gulls were culled at Tarnbrook fell but this resulted in a fall in breeding numbers of only 23,000 birds. In the first year of the cull, 23,000 (77%) of the breeding birds were culled but the reduction in breeding numbers was only 415 in the following year. No relationship was found between the number of gulls culled in one year and the reduction in the number breeding in the following year, but there was a significant relationship between the number of gulls culled and the number of recruits in the following year. During the culls, the number of gulls at Tarnbrook was reduced by 76%, although no reduction in the extent of the colony boundary was achieved. At Walney Island Gullery, where no culling took place, there was a reduction in the number of gulls of 44% between 1978 and 1988. The reasons for the decline at Walney are unclear, but during the culling period at Tarnbrook Fell, the number of emigrant birds hatched at Walney Island was greater than the number of immigrant recruits at Tarnbrook. The productivity of the gulls at Tarnbrook during the culling period was insufficient to sustain the levels of recruitment at this time. The culls were thus acting as a 'sink' for gulls emigrating from other colonies. There is no evidence that the sink effect was the sole 'cause' of the 44% reduction in the number of breeding gulls at Walney Island between 1978 and 1988. This is because the number of recruits produced at Walney that would not have been philopatric, whether culls had occurred or not, exceeded the number of immigrants culled at Tarnbrook.

Since 1988, no large scale culling has been licensed at Tarnbrook, but pricking of eggs has occurred on the Abbeystead Estate since 1991. Between 1992 and 1994 inclusive, 21% of the total number of eggs in the whole gullery have been pricked. Productivity in

the whole colony has been reduced by these activities from 1.53 chicks per pair to 1.03 in 1993, and from 0.94 to 0.78 chicks per pair in 1994.

High resolution modelling of gull numbers demonstrated that at a colony such as Tarnbrook Fell a control strategy aimed at reducing adult survivorship would be more effective than one directed toward productivity in the longer term. However, compensatory effects such as increased immigration as a result of the culls, reduced baiting efficiency, increased productivity in surviving gulls, the costs involved in such management programmes, and the fact that a licence for large scale culling no longer exists at the gullery, renders lethal management an unsatisfactory strategy at Tarnbrook Fell. Non-lethal management by disturbance has been shown to be an effective tool in completely clearing gulls from specific areas and is a viable alternative to lethal methods.

CHAPTER 6.

In Larids, selection of breeding habitat occurs at three levels: colony, territory and nest site. In 1994 a study of nest site selection was made at the Tarnbrook Fell Gullery. Both nests with eggs and empty nests showed an aggregated rather than random or regular distribution. Gulls breeding in the Sanctuary area disproportionately selected grass/sedge areas as nest sites compared to the available vegetation types, and in all areas of the colony birds avoided areas bare of vegetation and Bilberry. Nest density within the gullery varied from 1 to 89 nests per census quadrat (0.5ha). Multiple regression analysis showed that only 24% of the variation in the number of nests in a quadrat could be explained by the vegetation available within that quadrat. Differential culling effort in certain areas of the colony during the culling period 1978-1988, due to access problems and topographical features, may further explain the patchwork of high and low nest densities found within the gullery.

CHAPTER 7

Prior to the 1960's, most pest control was based on 'maximum kill' strategies. Later, integrated pest control philosophies were brought into efforts to control pests. These encouraged the employment of a range of management tools and regimes based on ecological knowledge and principles. In seeking to manage gull problems, many of the questions faced by agencies mandated to effect the management, will be similar to questions arising when efforts are made to conserve a species. 'Total population reduction' strategies have been shown to be ineffective and impractical in the case of a wide variety of pests. Similar strategies for controlling gulls are equally impractical. In planning gull management, the moral issues involved in such work must not be divorced from the planning process. In the light of current ecological knowledge, and the failures of past attempts at control, large-scale culling at Tarnbrook Fell is neither a practical nor morally justifiable method of management. The role of natural population mechanisms is an important issue in gull management and further research should be conducted into the causes of declines in Herring Gull numbers over the past twenty years, and the reasons why Lesser Black-backed Gull numbers have remained stable during this period. The increased use of urban and industrial areas in Britain will bring gulls into further conflict with humans in the future and require innovative practical solutions based on sound ecological principles. The success of many gull management programmes is often dictated by the motivation of the birds in question, the numbers involved and the resources available to the programmes designed to control them. Density dependence and the presence of a 'pool' of potential recruits play important roles in the management of gulls. Further research into both areas is required and planners must incorporate these factors in management strategies.

APPENDIX 1: Membrane filtration technique for water analysis

Pre-sterilised Gelman membranes were used in the analysis of water for *E. coli* and *Salmonella*. They were 47mm in diameter with a pore size of 0.45 μ m. Samples were shaken prior to preparation for filtration, to re-mix any sediment settled during transport. For *E. coli*, 10ml of water was mixed with 90ml of quarter strength Ringers solution and filtered through the cellulose ester membranes with the aid of a vacuum pump. The filtered sample was then mixed with a growth medium (Membrane Lanyl Sulphate Broth) on petri dishes and *E. coli* enumerated by counting the resultant colonies (bright yellow).

Salmonella organisms was be isolated using the membrane filtration technique, but a diatomaceous filter aid was required to bind with the *Salmonella* and retain them on the filter pad. Also, 1 litre of sample water was required for the analysis and after filtration the water was enriched using Rappoport broth. The samples were then transferred to a confirmatory agar (Xylose Lysine Desorycholate) which showed *Salmonella* colonies as pink or pink and black, after 24 hours of incubation at 37°C.

APPENDIX 2: disturbance tool specifications
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Propane gas-guns	<p>Model</p> <p>Manufacturers/suppliers</p> <p>Phone</p> <p>Trade price</p>	<p>Multi-bang</p> <p>Richard L Grant and Carter Ltd. 44 Station Road, Surfleet, Spalding, Lincs. 0775-85346 310.00 (inc VAT)</p>
Sound system: distress calls	<p>30W waterproof horn speaker</p> <p>25W Amplifier MPA250 mkII</p> <p>Cassette player: Aiwa HSP103</p>	<p>Maplin Professional Supplies. P.O. Box 777, Rayleigh, Essex.</p> <p>Sound Lab. Unit 2, Victoria Street Industrial Estate, Leigh, Lancs.</p> <p>Dixons Stores Group, 29 Farm Street, London.</p>

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