Modelling the feeding distribution of wintering Pink-footed geese (*Anser brachyrhynchus*) and Greylag geese (*Anser anser*) in central Scotland

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Submitted to

The Faculty of Natural Science, University of Stirling
(Date 10th January 2002)

For the degree of
Doctor of Philosophy

05/02

ABSTRACT

Pink-footed and Greylag geese winter in Britain and can cause damage to crops, resulting in a conflict with agriculture. An understanding of where geese are likely to feed would help to target suitable areas for goose management plans, aimed at relieving such conflict. The aim of this project was to create models to predict the feeding distribution of both Pink-footed and Greylag geese. Two separate approaches were taken to model goose feeding distribution from landscape characteristics. The first was a standard approach, logistic regression, which predicted the probability of a field being used by geese from the field's landscape characteristics. Models were based on goose distribution data from field surveys. The main factors affecting field choice by both species were distance from the nearest building and distance from the roost. The inclusion of autologistic terms did not improve the fit of the models. A second, more novel approach to predicting goose distribution was taken to see if more accurate predictions could be produced. This modelling technique involved simulating the movements of Greylag geese throughout the day. The rules constraining goose movement in the model were derived from analysis of radio-tracked geese. Flight direction was constrained by altitude or distance from the river while the probability of landing was dependent on the distance from buildings. The accuracy of the models in predicting goose distribution was tested both within the study area, Strathearn and Strathallan, and in another area, Loch Leven. Models based on animal movements have the theoretical advantage of incorporating barriers to movement, but the simulation model did not out-perform the logistic regression model. The models can be applied to other goose feeding areas relatively easily and can be used to identify areas where management plans for both Pink-footed and Greylag geese should be targeted.

DECLARATION

I declare that this thesis has been composed by me and that the work which it embodies is my own and has not been included in any other thesis. Where data from secondary sources have been used, they have been duly acknowledged.

Signed:

Christine D Urquhart

Date : 25th November 2001

ACKNOWLEDGEMENTS

Firstly I would like to thank the Department of Environmental Science, University of Stirling for providing the funding for this project and my principal supervisor Patrick Osborne for providing continuous support and intelligent comments.

I am indebted to Alan Lauder, who put in long and unsociable hours cannon netting my geese, without who's goose catching expertise the radio-tracking aspect of this project would not have been possible. Thanks must also go to Les, Brian, Jude, Richard, Patrick, Barbara, Claire, Kirsty, Christian and everyone else who helped with the cannon netting. Thank-you to Michael Aldridge and all the staff at Drummond Estate who allowed us to catch geese in the castle grounds and to farmers Donald Brown and John McLaren for allowing us to catch geese in their fields.

Discussion with Mike Bell, with his extensive knowledge of Pink-footed and Greylag goose feeding behaviour and distribution, has been of great help. Information and comments from other knowledgeable goosey people, Richard Hearn, Charles Connell, Edward Cruikshank, Francoise Desmontes, Jock McDonald, to name a few, have also been very useful. Many thanks to Ian Newton for keeping, finding and letting me use his data from Loch Leven collected in the 1970's and Bob Swann for providing information on sightings of collared Greylag geese. Historical goose count data for the study area were supplied by the Wetland Bird Survey (WeBs), a joint scheme of the British Trust for Ornithology, The Wildfowl & Wetlands Trust, Royal Society for the Protection of Birds and Joint Nature Conservation Committee (the last on behalf of the Countryside Council for Wales, Department of the Environment, Northern Ireland, English Nature and Scottish Natural Heritage). I would also like to express my thanks to Tracey Grieve for helping me battle with ARC-INFO in the early days, to Bill, Dave and John for technical support and Peter Hudson for his invaluable comments on earlier drafts of this thesis.

The jolly banter and smiling faces of all the department, in particular the ever the changing occupants of 4b108 has kept me going over the last three years, with special thanks to Michael, Helena, Christian, Susan, Erica, Steven and Amanda. Finally I would like to say a massive thank-you to Blair and James. Blair for supporting, radio-tracking, proof reading and generally being there and James for being an entertaining distraction from the laborious process of writing up.

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OVERVIEW AND AIMS OF STUDY

Overview

The numbers of Pink-footed geese *Anser brachyrhynchus* and Greylag geese *Anser anser* wintering in Britain have increased greatly since the 1960's (Hearn 2000). In Britain both species feed almost entirely on agricultural land, and goose grazing on certain crops can cause damage, and consequently economic loss to individual farmers (Edgell & Williams 1992), resulting in a conflict between geese and agriculture. Possible solutions to the goose-agriculture conflict are the creation of Alternative Feeding Areas (AFA's) for geese to reduce grazing pressure on the surrounding farmland (Owen 1977, Owen 1990, Jepsen 1991, Giroux & Patterson 1995) and the implementation of schemes to compensate farmers for losses due to goose grazing (van Eerden 1990, Percival *et al* 1997). A knowledge of where geese feed is required to enable goose management plans to be targeted effectively (Patterson & Fuchs 1992).

Pink-footed and Greylag geese roost on a relatively small number of water-bodies, where their numbers are well documented (Mitchell *et al* 1999, Mitchell & Sigfusson 1999), and feed on the surrounding farmland. A model that could predict which fields are likely to be preferred by geese would highlight areas where goose management plans could be targeted.

Studies of Pink-footed and Greylag geese have shown that a wide variety of factors influence their feeding distribution. Geese have preferences for certain crops (Newton & Campbell 1973, Forshaw 1983, Madsen 1984, Bell 1988, Patterson *et al* 1989, Giroux & Patterson 1995, Hearn & Mitchell 1995, Stenhouse 1996).

Depletion of food resources by con-specifics and other species will affect resource availability, and consequently influence goose feeding distribution. As geese fly out each day from a fixed point, roost location will influence their feeding distribution (Newton *et al* 1973, Bell 1988, Giroux & Patterson 1995, Keller *et al* 1997). The risk, or perceived risk, of disturbance and predation also affect where geese feed. While the actual rate of predation or disturbance is difficult to quantify, studies have shown that geese are less likely to feed close to features likely to cause disturbance, such as roads (Newton & Campbell 1973, Madsen 1984, Keller 1991, Gill 1994, Larsen & Madsen 2000). In addition, it as been shown that landscape features that prevent Pink-footed geese from having a clear view of potential predators tend to be avoided (Newton & Campbell 1973, Newton *et al* 1973, Madsen 1985b, Larsen & Madsen 2000).

There is a growing interest in large-scale ecology, dominated by modelling, not least because results are often directly relevant to environmental management (Ormerod & Watkinson 2000). Approaches to large-scale ecology are widely debated and, as classical ecological experiments are often practically impossible at large scales, alternative techniques are required to test hypotheses (Ormerod & Watkinson 2000). Geographical Information Systems (GIS) and remote sensing have greatly increased both the quality and quantity of information that can be incorporated into predictive models (Austin *et al* 1996, Cowley *et al* 2000, Corsi *et al* 2000). These systems have also enabled the development of alternative methods to tackling spatial modelling issues, for example cost-surface modelling for identifying the optimal (least-cost) paths across a landscape (Wadsworth &

Treweek 1999) and fuzzy logic mapping, which can be used to classify features which are not inherently discrete (Johnston 1998).

Models based on biological processes, such as con-specific and inter-specific competition (Gill 1994, Sutherland & Allport 1994), body condition, reproductive success and survival (Pettifor *et al* 2000) primarily focus on the biotic factors affecting goose distribution. In these models the landscape was considered to be fairly homogenous (e.g. intertidal mudflats), to enable modelling of depletion. For Pink-footed geese, Gill (1994) restricted modelling to one crop type. To extend such modelling techniques to predict the feeding distribution of wide-ranging goose species such as Greylag and Pink-footed geese in a heterogeneous agricultural landscape would be extremely complex and require very detailed information of the availability of food resources. This type of information is not generally available, except through detailed surveys of specific sites.

An alternative approach is to model the effect of abiotic factors, such as landscape characteristics, (e.g. Osborne *et al* 2001). Pink-footed and Greylag geese feed in a complex heterogeneous landscape, and previous have shown that their feeding distribution is affected by landscape characteristics (Newton *et al* 1973, Newton & Campbell 1973, Madsen 1984, Madsen 1985b, Bell 1988, Keller 1991, Gill 1994, Giroux & Patterson 1995, Keller *et al* 1997, Larsen & Madsen 2000). Therefore, for Pink-footed and Greylag geese a landscape based approaches, rather than a approach based on biological processed, were considered most appropriate for predicting feeding distribution. The landscape-based approach has the advantage that the landscape characteristics are permanent and can be derived from existent digitised data, with no need for field surveys. A predictive model based on permanent landscape characteristics provide predictions which do not alter considerably over time, unlike resource based models in an agricultural environment, and can be applied to other goose wintering areas relatively simply. The major disadvantage of such an approach, however, is that the effects of biotic factors, primarily resource competition, are not considered.

In this study two different landscape based modelling techniques will be used to predict the feeding distribution of wintering Pink-footed and Greylag geese. A standard approach, logistic regression, will be used to predict the chance of Pink-footed and Greylag geese using a field from the field's landscape characteristics. A second and more novel modelling technique will be used to predict the feeding distribution of Greylag geese. Movements of geese will be simulated, based on rules derived from analysis of radio-tracked goose movements, to predict where they are likely to feed. Modelling techniques will be compared to see which can most accurately predict goose feeding distribution.

Broad aims of study

The overall aims of this research are:

1. To predict the feeding distribution of Pink-footed and Greylag geese from landscape characteristics using logistic regression (Chapter 3).
2. To simulate goose movement, using decision rules from radio-tracked geese, to predict the feeding distribution of Greylag geese (Chapter 5).

3 To compare the predicted results from the two modelling techniques both within the study area and in another area used by wintering Pink-footed and Greylag geese (Chapters 6 and 7).

4 To draw conclusions about the suitability of the two modelling techniques for predicting the feeding distribution of geese (Chapters 6, 7 and 8).

5 To draw conclusions about the feeding distribution of Pink-footed and Greylag geese in Strathearn and Strathallan, and highlight areas of high predicted goose use which would be suitable for targetting goose management plans (Chapters 3, 5 and 8).

CHAPTER 1 – PINK-FOOTED AND GREYLAG GEESE: THEIR STATUS, DISTRIBUTION, BEHAVIOUR AND MANAGEMENT

1.1 INTRODUCTION

There is a relatively large amount of published information on the grey geese wintering in Britain. This chapter reviews the current knowledge of Pink-footed and Greylag geese, providing a background to the conflict between geese and agriculture, discusses the current knowledge about selection of feeding sites by geese, and consider possible solutions to the conflict. The majority of research to date has focused on Pink-footed geese, as reflected in this discussion, but information on Greylag geese has been included where available.

1.2 AIMS

The aims of this chapter are:

(i) To look at the status and spatial distribution of Pink-footed and Greylag geese wintering in Britain.

(ii) To discuss the effect of these geese on crops, providing a background to the goose-agriculture conflict.

(iii) To investigate the current knowledge on what affects where geese choose to feed, which provides a basic understanding of what factors could be used to predict goose distribution.

(iv) To consider some methods of managing wintering Greylag and Pink-footed geese to alleviate the goose-agriculture conflict, giving a insight into the practical applications of predicting goose distribution.

1.3 STATUS AND DISTRIBUTION OF PINK-FOOTED AND GREYLAG GEESE

1.3.1 Distribution

All Pink-footed geese overwintering in Britain are from the Icelandic population. Data from Pink-footed geese ringed in 1950-1954 by the Wildfowl Trust in both Britain and Iceland has shown that geese breeding in Iceland and Greenland winter in Britain, and show very little mixing from the geese breeding in Spitzbergen, which winter in Denmark, the Netherlands and Germany (Boyd 1956). Individual Pink-footed geese ringed in Britain have, however, been sighted on the continent (Fox *et al* 1989).

There are three populations of Greylag geese in Britain; a feral population which is non migratory and mainly confined to England and a few sites in central Scotland; a sedentary population in north-west Scotland; and a migratory population which breeds in Iceland and winters in Scotland (Fox & Madsen 1999). Ringing recoveries have confirmed that the Icelandic population of Greylag geese wintering in Britain show little mixing with other Greylag goose populations in the Western Palearctic (Mitchell & Sigfusson 1999). This study is concerned with Icelandic Greylag geese and subsequent reference to Greylag geese refers to this population unless otherwise stated.

Pink-footed geese arrive in Britain in late September and return to Iceland in late April and early May (Newton *et al* 1973). Greylag geese tend to arrive in Britain around a fortnight later and leave around a fortnight earlier than Pink-footed geese. Newton *et al* (1973) suggested that this is because Pink-footed geese breed in the highlands of Iceland where the summer is shorter than in the lowlands, where the Greylag geese spend the summer.

Once geese have arrived in Britain, before dispersing, they often congregate at well defined staging areas. For example, in September 1991 there were 57,500 Pink-footed geese at Dupplin Loch, Perthshire (Bell & Newton 1995). From their staging grounds in Scotland some Pink-footed geese disperse to Lancashire and Norfolk (Fox *et al* 1994). Resightings of Pink-footed geese marked in Loch Leven show that there is high turnover of geese in October, many of which were re-sighted further south later in the season, while geese marked from December to February were often re-sighted within the region, and very seldom elsewhere (Hearn & Mitchell 1995). This indicates that Loch Leven is a major staging ground for Pink-footed geese in autumn, but once passage has finished the geese have a tendency to remain in the area.

In the spring the geese return northwards to spring staging areas in Grampian and the Moray Firth (Fox *et al* 1994). The geese are thought to move north following the point of 55% frost-free days to get the maximum protein from newly grown grass (Fox *et al* 1994). Pink-footed geese show some year to year site fidelity. The return rate for Pink-footed geese ringed on Lancashire in subsequent years was 75% (Fox *et al* 1994). At present no papers have been published on the movements of marked Greylag geese, although marking schemes are currently being carried out in the Highland region by Bob Swann.

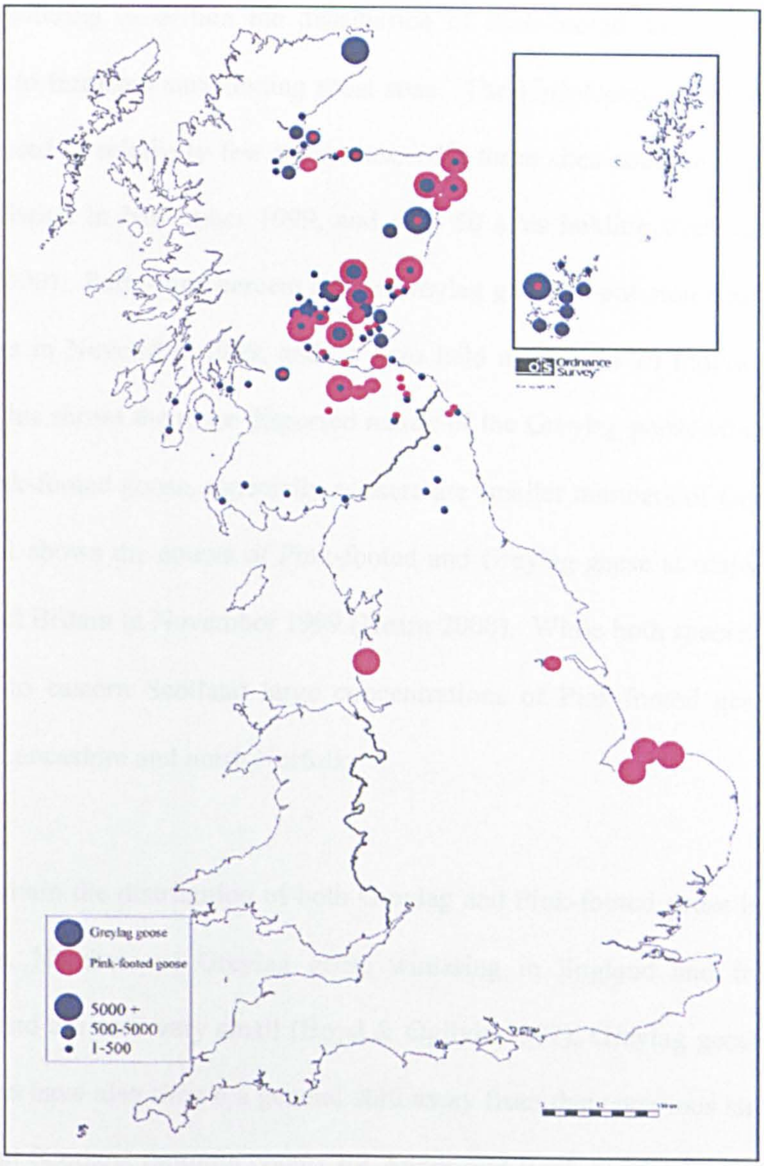

Figure 1.1 The distribution of Pink-footed and Greylag geese in November 1999 (from Hearn 2000).

Food availability appears to affect the wintering distribution of geese. In years with more potato and grain waste in east central Scotland larger numbers of Pink-footed geese winter in the area (Newton & Campbell 1973, Newton *et al* 1973) while years with little grain waste in Scotland result in large numbers of geese moving to Lancashire in early autumn (Forshaw 1983).

While wintering in Britain the distribution of Pink-footed and Greylag geese is confined to farmland surrounding roost sites. The Pink-footed goose population is concentrated in relatively few roost sites, with three sites containing over 40% of the population in November 1999, and only 50 sites holding over 10 individuals (Hearn 2000). Forty-nine percent of the Greylag goose population was held at four roost sites in November 1999, and 75 sites held more than 10 individuals (Hearn 2000). This shows the more dispersed nature of the Greylag goose when compared to the Pink-footed goose, especially as there are smaller numbers of Greylag geese. Figure 1.1 shows the counts of Pink-footed and Greylag geese at major roost sites throughout Britain in November 1999 (Hearn 2000). While both species are mainly confined to eastern Scotland large concentrations of Pink-footed geese are also found in Lancashire and north Norfolk.

Within Britain the distribution of both Greylag and Pink-footed geese has changed over time. Numbers of Greylag geese wintering in England and Ireland have declined and are now very small (Boyd & Ogilvie 1972). Greylag geese wintering in Scotland have also shown a general shift away from their previous stronghold in east central Scotland (autumn counts for Angus and Perth have dropped from over 30,000 – 40,000 in the late 1960's to less than 10,000 in 1999) to Orkney, Caithness and Ross & Cromarty (Boyd & Ogilvie 1972, Hearn 2000). This is a phenomenon known as 'short-stopping', where birds winter closer to their breeding grounds when conditions are suitable, and is well known on both sides of the Atlantic (Owen 1992).

Although the range of Pink-footed geese has not changed in recent years, the proportion of geese wintering in England has increased, with up to 18% of the British population now wintering in Lancashire (Mitchell 1997) and 41% in North Norfolk (Gill *et al* 1996*b*). Gill (1994) suggested that the increase in numbers of wintering Pink-footed geese in north Norfolk is due to a combination of:

- Goose preference for feeding on sugar beet remains, with knowledge of the food supply spread by cultural learning of geese, accounting for the delayed reaction to the increase in sugar beet production in the region;
- Overspill from traditional wintering sites due to increase in population size.

1.3.2 Status

The size of the British population of Pink-footed geese, estimated from capture-recapture were calculated as *c*.34, 000 in November 1952, and *c*.50, 000 in November 1953 (Boyd 1956). This method of calculating the population size is expensive and unsatisfactory due to sampling problems, especially the inability to catch geese in proportion to their regional abundance. In November 1960 the Wildfowl Trust (now the Wildfowl and Wetlands Trust, WWT) began annual counts of Pink-footed and Greylag geese, with a large team of observers counting the number of geese at every roost in the country on a co-ordinated weekend (Boyd & Ogilvie 1969). autumn counts have shown that the population of Pink-footed geese wintering in Britain has increased from *c*.50, 000 in 1960 to *c*.215, 000 in 1999 (Boyd & Ogilvie 1969, Hearn 2000). The number of Greylag geese wintering in Britain increased from *c*.26, 000 in 1960 to *c*.110, 000 in 1985 (Boyd & Ogilvie 1972, Owen *et al* 1986). However, numbers of Greylag geese have since declined to *c*.76, 000 in autumn 1999 (Hearn 2000), and the British population is one of only two goose populations in the Western Palearctic that is know to be in decline (Fox & Madsen 1999). Figure 1.2 shows the change in the number of Pink-footed and Greylag geese wintering in Britain since the 1960's.

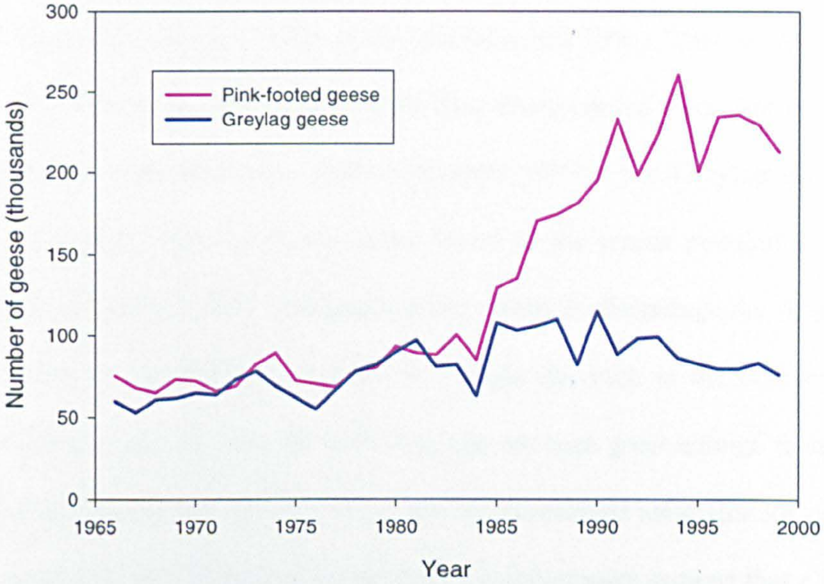

Figure 2.2 Five year moving average of the November counts for Greylag geese at Drummond Pond. Data from the WWT National Census of Pink-footed geese and Greylag geese in Britain and Ireland.

There have been no long-term trends in productivity in either species (Mitchell *et al* 1999, Mitchell & Sigfusson 1999) and population increases have been attributed to changes in adult survival (Ebbinge 1985, Fox *et al* 1989, Owen 1990). In January 1968 restrictions were placed on shooting and the sale of dead wild geese was banned. Both Greylag and Pink-footed geese are legal quarry species but they are protected in the closed season by Schedule 2 of the Wildlife and Countryside Act 1981, which allows shooting in the closed season only by special licence in vulnerable areas. These protection measures have resulted in the lowering of mortality rates in both Pink-footed and Greylag geese which, together with the improved feeding conditions in the wintering grounds (with more barley, potatoes and improved grassland), have resulted in an increase in population size (Ebbinge 1985, Fox *et al* 1989, Owen 1990).

In 1994 the Icelandic government bought in legislation that required all holders of a shotgun license to complete a bag record card (Mitchell 1996). This revealed that in 1995 *c.* 35,000 Greylag geese and *c.* 8,000 Pink-footed geese were shot in Iceland, and figures for 1996 were very similar (Mitchell 1997). For Greylag geese such heavy annual loss seems to be the major factor in the recent population decline (Mitchell & Sigfusson 1999). Although recent efforts to discourage the shooting of Greylag geese in Iceland have resulted in a slight decrease in the numbers shot, census estimates indicate that this reduction has not been great enough to stem the population decline (Hearn 2000). There are no comparable estimates for numbers of grey geese shot in Britain, but results from a questionnaire suggest that *c.*16, 000 Pink-footed geese, and a similar number of Greylag geese are shot in Britain each year by BASC members (Harradine 1991).

1.4 THE EFFECT OF GOOSE GRAZING ON CROPS

1.4.1 Introduction

Geese can feed at very high densities. Observations by Gill *et al* (1996) showed that individual sugar beet fields have been recorded supporting over 2000 goose days per hectare. This does not always result in damage, and it as been suggested by Kear (1970) that geese feeding on harvested potatoes and spilt grain can be beneficial to farmers, as cleaning up prevents carryover of pests such as cereal mildews, potato eel worms, weed seeds and roots.

1.4.2 Damage to grass

The effect of goose grazing on 'early bite' spring grass results in direct competition with livestock (Owen *et al* 1986) and can reduce the silage yield on the first cut (Kear 1970, Groot Bruinerink 1989, Ernst 1991). Trampling by geese may also cause puddling and waterlogging, especially in areas with heavy soils (Owen *et al* 1986). With intensification of farming, especially dairy farming, this is becoming an increasing problem (Groot Bruinderink 1989). Groot Bruinderink (1989) compared grazed grass with grass within 'goose free' enclosures to look at the effect of grazing, treading and manuring by a mixture of species of grey geese with respect to sward height, dry mass, and Gross Leaf Area Index. He concluded that goose grazing in winter and early spring in areas of goose dropping densities of 5 - 44 droppings per m^2 resulted in dry-matter (DM) loss at first cut or grazing of 335-1100 kg ha^{-1} depending on grazing pressure and time. Similarly Ernst (1991) found that grey geese, feeding at 3000-6000 goose days per hectare reduced the first cut by 310-560kg DM ha^{-1}, a 10-20% loss of yield. Patton & Frame (1981) found that grazing by Greylag geese feeding at high densities in west Scotland resulted in an average herbage loss of 1.51 tonnes DM ha^{-1}. This is equivalent to an 8 tonne loss of silage, or 90 days of grazing for a cow or the silage part of a cow's winter diet. Goose grazing had no effect on species composition and density of shoots, and defecating and treading had no effect on chemical or physical soil factors (Groot Bruinderink 1989). The resultant decrease in area that can be mown for silage may result in farmers having to purchase supplementary feed. However, it may be possible to increase the first cut in grazed fields by increasing the nitrogen dose (Groot Bruinderink 1989). The cost of damage to grass by goose grazing has been estimated from information on the March and April weather and the grazing pressure (Ernst 1991).

1.4.3 Damage to cereals

Damage can also occur when geese graze on winter cereal. Kear (1970) performed trials that involved putting very high numbers of domestic geese onto both winter wheat and spring cereals, and found no evidence of damage. In contrast Patterson *et al* (1989) found that goose grazing could damage autumn sown cereal. The difference between these results and that of Kear (1970) could be as that Patterson *et al* (1989) worked in Scotland, which is close to the northern limit of autumn sown barley, and therefore under more stress than cereal grown further south where Kear (1970) performed the experiments (Patterson *et al* 1989). Patterson *et al* (1989) measured goose use of field by dropping counts throughout the winter, which were correlated to the percentage of leaves grazed. They found that grazed cereal was shorter, even until the end of June, and unevenly grazed fields caused an uneven development of the crop. Grazing by geese also caused a decrease in grain yield and straw yield, and resulted in an increase in numbers of weeds. The yield, however, was very variable, and no correlation was found between yield and the extent of goose grazing due to confounding factors such as soils, topography, husbandry, severity of the winter and spring growing conditions (Patterson *et al* 1989). Simulated goose damage to winter barley showed similar reduced plant height until late June, grain yield and straw yield and increased weed cover with grazing (Abdul Jalil & Patterson 1989). A reduction in mean weight of individual stems was found that would tend to weaken the stem, leaving the grazed crop more vulnerable to flattening in rainy and windy conditions, an effect sometimes attributed to goose grazing (Abdul Jalil & Patterson 1989). The results from the simulated grazing also suggested that goose droppings had no effect on straw or grain yield, and that the loss of yield was much more affected by amount of damage, rather that the timing (between March and April). Summers (1990) concluded that high densities of Brent geese (*Branta bernicla*) grazing on winter wheat reduced grain yield by 6-10%. A local Perthshire farm owner found that when he left fields for Greylag geese to feed freely, he lost 1/2 a tonne of winter wheat per acre (C. Connell, pers. comm.). Goose grazing of winter cereals before February is not considered to have a major impact on the crop (E. Cruikshank, pers. comm.). The results from Patterson *et al* (1989) suggested that winter wheat is more susceptible to damage from goose grazing than winter barley. Farmers, however, feel that more damage occurs when geese feed on winter barley, and this may be because winter wheat is a tougher plant, and has a lower growing point, which is less likely to be grazed out (M.V. Bell, pers. comm.).

1.4.4 Damage to other crops

Both Greylag and Pink-footed geese sometimes feed on root vegetables, usually harvested remains, but Greylag geese also feed on turnips provided for livestock food and are therefore in direct competition with the livestock (Owen *et al* 1986). There are also occasional reports of geese ruining root crops. In Lancashire in 1973-74, Pink-footed geese were said to have ruined a whole crop of carrots; Greylag geese can also ruin crops of unharvested swede (Owen *et al* 1986). There are no reports in the literature of Pink-footed or Greylag geese feeding on oil-seed rape, but very occasionally Greylag geese have been known to feed on this crop causing extensive damage (E. Cruikshank, pers. comm.).

1.4.5 Economic loss due to goose grazing

Although the effect of goose grazing on the economic loss to farming as a whole is probably limited, individual farmers can suffer serious losses (Patterson *et al* 1989, Edgell & Williams 1992, SOAEFD 1996). Unfortunately, the extent of damage to crops and the resultant economic loss caused as a result of goose grazing is very hard to estimate, especially for cereal crops. This is because many factors such as time of grazing, spring weather and crop growing conditions affect yield as well as number of geese grazing (Patterson *et al* 1989, SOAEFD 1996).

1.5 ECONOMIC ADVANTAGES OF GEESE

Goose grazing can cause localised damage to crops and can result in financial loss to individual farmers. On a national level, however, geese are financially advantageous. Reduction in yield due to goose grazing decreases surplus grain and therefore lessens spending on EU support, even when taking into account the cost to farmers (Edgell & Williams 1992). In addition geese can prove a major visitor attraction and therefore increase tourist-related income; for example, Barnacle geese on Islay (Edgell & Williams 1992) or Pink-footed geese at Loch Leven. Wildfowling is very popular in Scotland and can provide an attractive income to some farmers who can receive £35 -£65 per gun per flight. It is estimated that 1,220 full time jobs are supported in the UK by game and wildfowl shooting (excluding grouse) and wildfowlers in Britain spend an estimated £5.7 million on their sport (SOAEFD 1996, Mitchell *et al* 1999).

1.6 FIELD SELECTION BY PINK-FOOTED AND GREEYLAG GEESE

1.6.1 The pattern of field use by geese

Geese have been shown to have a preference for feeding in certain areas (Newton & Campbell 1973, Giroux & Patterson 1995, Hearn & Mitchell 1995, Mitchell *et al* 1995, Keller *et al* 1997). It has frequently been observed that there are large sections of the feeding area that the geese rarely visit although conditions appear suitable (Forshaw 1983, Bell 1988). For Pink-footed geese various studies have shown that around 70% of all goose days observed were within only 22.5% - 32.8% of the goose feeding area (Forshaw 1983, Giroux & Patterson 1995, Mitchell *et al* 1995, Keller *et al* 1997). Pink-footed geese were found to centre their feeding in clusters of fields separated by areas where geese were never seen (Keller *et al* 1997), and these main centres of activity remained the same between years, although only 49% of fields used in one year were used the next. Certain fields are often visited repeatedly; in the late 1960s Newton and Campbell (1973) found that 75% of fields that geese were seen on were visited more than once, and if geese were seen feeding on a field twice there was a 90% chance of them returning. Work on the same feeding area in 1995 (Hearn & Mitchell) showed that not only were the centres of activity very similar to those in 1973, but the same figures were obtained for flocks of geese revisiting fields. Radio-tagged Pink-footed geese revisited 1 km^2 cells on average 1.8 times, and 51% of the time this was within a 3 day period (Giroux & Patterson 1995).

Many factors influence where geese choose to feed. These include:

- Distance from the roost
- Distance from other suitable feeding areas

- Food type
- Disturbance levels

1.6.2 Site Fidelity

Site fidelity has been recorded for many different goose species, although to differing extents. Greenland White-fronted geese *Anser albifrons flavirostris* have been shown to have very high site fidelity, to the extent that even when conditions deteriorate the geese still return to the area. Site fidelity is thought to be the explanation for some flock extinction's in this species (Wilson *et al* 1991). Some individually marked Pink-footed geese showed a strong preference for certain fields (Hearn & Mitchell 1995), but whether the feeding distribution of either Pink-footed geese or Greylag geese is due to site fidelity and tradition or habitat suitability is as yet unknown.

1.6.3 Distance from the roost

Whether geese feed in an area will be dependent, in part, on the proximity to the nearest goose roost. In north-east Scotland observations of flocks (Bell 1988, Keller *et al* 1997) and radio-tracked Pink-footed geese (Giroux & Patterson 1995) found that Pink-footed geese fed a mean distance of 4 - 5 km from the roost. In this area Greylag geese flew further, flying a median distance of 10.7 km (Bell 1988). However in east central Scotland Pink-footed geese flew further from the roost than the Greylag geese; 90% of Greylag feeding grounds lay within 5 km of the roost, while only 66% of the Pink-footed geese feeding area did (Newton *et al* 1973). Gill (1994) found no significant effect of distance from the roost on field selection by

Pink-footed geese 3 to 10 km from the roost, but the order of field use was significantly related to distance from roost.

1.6.4 Movements throughout the day

Movement of geese once they have started feeding is relatively restricted. Excluding flights to and from the roost, Pink-footed geese were found to move on average 7 times per day (Giroux & Patterson 1995), and moved a mean distance of 0.8 km per move. Similarly Keller *et al* (1997) found that in north-east Scotland that the mean length of stay in a field was 3.33 hours, and geese visited an average of 4.22 fields a day, moving a mean distance between fields of 1.13 km. This resulted in geese covering a mean area of only 1.1 km^2 (Giroux & Patterson 1995). Individual geese did not use the whole range; each bird used an average of 47% of the range, and geese had their own individual centres of activity (Giroux & Patterson 1995).

1.6.5 Crop type

Geese show definite preferences for certain crop types. In autumn both species of geese concentrate their feeding on harvested cereal fields where they feed on the spilt grain (Newton & Campbell 1973, Forshaw 1983, Madsen 1984, Bell 1988, Patterson *et al* 1989, Giroux & Patterson 1995, Hearn & Mitchell 1995, Stenhouse 1996). Between December and February the spilt grain is depleted, either by geese or other animals (Newton & Campbell 1973). The geese progressively move onto grass, especially improved grass and ley grass (which is under 2 years old) (Newton & Campbell 1973, Forshaw 1983, Madsen 1984, Bell 1988, Patterson *et al* 1989, Giroux & Patterson 1995, Hearn & Mitchell 1995, Mitchell *et al* 1995, Stenhouse

1996). Analysis of droppings confirms these seasonal changes (Patterson *et al* 1989).

Where available, geese show strong preference for remains of root vegetables, especially potatoes, in mid winter (Newton & Campbell 1973, Forshaw 1983, Bell 1988, Giroux & Patterson 1995, Hearn & Mitchell 1995, Mitchell *et al* 1995). Greylag geese, which have larger and stronger beaks, spend more time feeding on root crops than Pink-footed geese and also feed on turnips left out for sheep (Newton & Campbell 1973). Spring sown cereal was shown to be a minor food source (Newton & Campbell 1973, Bell 1988), although in Denmark it is important in April (Madsen 1984). The increase in the planting of winter wheat and winter barley in Scotland, particularly between 1979-1982 has resulted in a new source of food for the geese (Patterson *et al* 1989). Geese appear to use winter cereals less than (Forshaw 1983, Madsen 1984, Patterson *et al* 1989), or equal to (Mitchell *et al* 1995) that expected from the crop area available, although around the Moray Firth Greylag geese showed a preference for germinating winter cereal in autumn (Stenhouse 1996). Giroux and Patterson (1995) observed that Pink-footed geese show a preference for winter barley later in the winter, but an aversion for winter wheat, while Mitchell *et al* (1995) found that Pink-footed geese mainly fed on winter cereal in the months of December and January, when over one third of geese fed on this crop type.

Harvested potatoes and cereal stubble held larger flocks of Pink-footed geese, and geese feeding on these fields flew further from the roost than geese feeding on other crops (Giroux & Patterson 1995), suggesting a strong preference by Pink-footed geese for stubble and potatoes than other crops. The proportion of geese feeding on stubble and winter cereals was inversely related, and dependent on the timing of harvest, with late, "dirty" harvests resulting in much greater use of the stubble by geese (Patterson *et al* 1989).

In north Norfolk Pink-footed geese concentrate feeding on the remains of sugar beet, a crop that is not widely available in other parts of the wintering range (Gill 1994). The preference for sugar beet remains is suggested to be due to a combination of the reduced disturbance in beet fields (as the geese are causing no damage), and the high carbohydrate content of the food source (Gill 1994).

The amount of food available does not appear to be a major factor in determining where the geese feed. Gill (1994) found no significant effect of biomass after harvest and mean root mass on field selection by Pink-footed geese. Experimental manipulation of the density of sugar beet remains in fields also showed no significant difference in numbers of goose droppings with differing densities of food, or with the age of the food (Gill 1994). Similarly the amount of spilt grain in stubble fields and density of potatoes did not determine the extent of use of the field by geese (Newton & Campbell 1973).

1.6.6 Disturbance

Increasingly, disturbance is being considered as an important factor affecting bird distribution, and especially so for birds feeding in flocks (Hill *et al* 1997, Madsen 1998*a* & 1998*b*). Disturbance has been shown to be a major factor influencing the choice of feeding area by geese (Newton & Campbell 1973, Newton *et al* 1973, Madsen 1984, Belanger & Bedard 1989, Gill 1994). In north-east Scotland 58% of goose take off followed disturbance (Giroux & Patterson 1995).

The main cause of disturbance of Pink-footed geese is farm vehicles, which cause 31.8 - 35.6% of observed disturbances (Forshaw 1983, Gill 1994); other causes of disturbances were aircraft, pedestrians, birdwatchers and pheasant shooters. The extent to which fields were exploited was negatively related to disturbance rate (Gill 1994). An increase in deliberate scaring by farmers has been observed for fields where crops are susceptible to damage, for instance winter sown cereals (Giroux & Patterson 1995)

Both Icelandic Greylag and Pink-footed geese are shot heavily throughout their wintering range in Britain during the open season. BASC members shoot approximately 16,000 geese of each species per year (Harradine 1991). Disturbance from shooting is therefore likely to affect goose behaviour. The flight distances of wintering flocks of both White-fronted geese *Anser albifrons* and Bean geese *Anser fabalis* decreased from around 500m to 200m following a ban on shooting, and therefore resulted in an expansion of goose feeding grounds (Gerdes & Reepmeyer 1983). Madsen (1985b) also attributed seasonal differences in flight distance of Pink-footed geese to differences in shooting disturbance before and after the end of the shooting season. Grey geese avoid fields or roosts where shooting has occurred for a few days after the shoot (Newton & Campbell 1973), showing a more local and short term effect of shooting. It remains unknown whether shooting has a longer-term effect on feeding distribution of geese, and the number of geese an area can support.

Roads result in an increased level of disturbance. Gill (1994) found that there was a significant relationship between the frequency of disturbance events and distance from the nearest road. The presence of roads is known to depress goose use of fields nearby (Newton & Campbell 1973, Madsen 1984, Keller 1991, Gill 1994). Work by Keller (1991) showed that both Pink-footed and Greylag geese wintering in north-east Scotland did not feed within 100m of roads, or in fields with centres closer than 100m from roads. Similarly in Norfolk the fields where Pink-footed geese fed had a significantly greater distance from the centre of the field to the nearest road than the average, and geese never fed within 35m of the road (Gill 1994). In Denmark Madsen (1984) found roads with traffic volumes of 20-50 cars per day had a serious depressing effect of goose use within 500m of the road, and even tracks with fewer than one car per day had a depressing effect on goose utilisation. The greater effect of roads in Denmark is probably a result of lower overall disturbance rate in Denmark that in Britain. The presence of roads affects not only whether the field is used, but also the extent of crop depletion. Gill (1994) concluded that the extent of depletion of fields can mainly be accounted for by distance to nearest road and, in addition, the number of days the field was used varied with distance to the road.

Geese prefer to feed in fields with an open view, so that potential predators can be seen (Newton & Campbell 1973, Newton *et al* 1973, Madsen 1985b). If a field is enclosed by an object that will obstruct the view on more than one side, utilisation of the field by Pink-footed geese will be affected (Madsen 1985b). Windbreaks also depressed goose utilisation within 150m (Madsen 1985b, Larsen & Madsen

2000). However, neither Gill (1994) nor Stenhouse (1996) found a significant effect of the proportion of field surrounded by hedge. Small fields have reduced visibility and field size is recognised as a factor affecting field use by geese (Newton & Campbell 1973). In north Norfolk Pink-footed geese were found never to use fields smaller than 6 ha in area (Gill 1994). Madsen (1985b) found that Pink-footed geese in Denmark never use fields less than 500m wide. Other landscape characteristics that have been shown to depress Pink-footed goose use are wind turbines and power-lines (Larsen & Madsen 2000), although the effect of these may not be the result of disturbance.

Disturbance has been shown to have a detrimental effect on geese. Disturbance of staging Greater Snow geese (*Chen caerulescens atlantica*) affects their feeding activities and their subsequent use of the area (Belanger & Bedard 1989). In Greenland the time budget of Pink-footed geese was strongly affected by disturbance by helicopters carrying out oil exploration work (Mosbech & Glahder 1991). The Pink-footed geese spent less time resting and feeding and more time swimming and it was concluded that their energy intake was affected. However, disturbance will be detrimental to geese only if it reduces energy intake so much that it cannot be compensated for either by increasing rate of food intake while there is no disturbance or by night-time feeding. In Greater Snow geese increased disturbance did not result in an increase in food intake rate during the day and therefore up to a 32% increase in night-time feeding may be needed to compensate for energy losses (Belanger & Bedard 1989). Disturbance from shooting has been shown to affect the extent of night-time feeding. Night-time feeding has been shown to increase when geese are subject to increased predation, for example while mounting (and therefore flightless) (Kahlert *et al* 1996) or during the hunting season (Newton & Campbell 1973).

Abdominal profile indices (which have a linear relationship to weight) of Pink-footed geese were significantly lower in areas and years when farmers initiated a scaring campaign against geese in their staging grounds in north Norway (Madsen 1995). Disturbance also affected the subsequent breeding success of the geese, with geese staging in undisturbed areas having 46% breeding success, while geese feeding in the disturbed areas having a breeding success of only 17% (Madsen 1995). Therefore disturbance can have a detrimental effect on goose populations, and may explain why geese choose to feed in areas with reduced disturbance levels.

Most of the work on disturbance has been on Pink-footed geese. Greylag geese are less wary and less demanding with regard to field size (Newton *et al* 1973, Madsen 1984 & 1985a). Pink-footed geese feed in larger and tighter flock than Greylag geese, and depression of utilisation of fields near roads is more apparent in Pink-footed geese than Greylag geese (Newton and Campbell 1973).

1.6.7 Order of field use

The order of field use by Pink-footed geese in Norfolk was found to be related to distance from roost only, and not to root biomass, field area, mean root size or risk of disturbance (Gill 1994). This suggests that there are certain fields acceptable to the geese and that when they are depleted, the geese will travel further, as opposed to feeding in substandard fields, although closer.

Gill (1994) built a model to predict to what extent Pink-footed geese would use beet fields. The model was based on the following variables:

Distance from roost

Distance from road

Harvest and ploughing dates (availability)

Field size

Amount of food consumed (Standard intake x no of geese on roost)

The model ran on a daily basis for one winter, and results correlated strongly with field results, suggesting that the element of tradition on feeding location of these geese was slight, if an influencing factor at all.

1.7 POSSIBLE SOLUTIONS TO THE GOOSE-AGRICULTURE CONFLICT

1.7.1 Introduction

Both Pink-footed and Greylag geese are protected under European legislation (African/Eurasian Waterbird Agreement (AEWA) under the Bonn Convention, Annex III of the Bern Convention and Annex II of the EU Birds Directive) and are listed in the UK's Action Plans for Biodiversity (HMSO 1995). As the British government has a responsibility to conserve these geese it is necessary to find solutions that will reduce economic loss to farmers while conserving the geese. The goose-agriculture conflict could be alleviated by reducing the density of geese feeding on vulnerable crops by one of a number of ways:

- Simple changes in farm management
- Creation of alternative feeding areas for geese
- Compensation payments to farmers for losses

- Dispersing the geese
- Managing the geese populations at lower levels that at present

1.7.2 Farm management practices

There are some steps that farmers can take to reduce damage to crops. One of the ways of keeping geese off crops where damage can occur is to encourage them to feed in fields where they are causing no harm. Decreasing disturbance of geese feeding in fields where crops cannot be damaged (i.e. cereal stubbles and remains of sugar beet), leaving ploughing as late as possible and putting livestock in fields which are not favoured by geese will all encourage geese (Gill 1994). Increasing the amount of spring-sown cereal will result in more sugar beet and stubble remains being left overwinter, as early ploughing is not required (Gill 1996). One farmer in Norfolk reduced all unnecessary farm traffic in the vicinity of fields where geese fed on sugar beet remains, and this resulted in an increase in the percentage of geese feeding on the sugar beet from 80% to 97% and a corresponding decrease in the amount of geese feeding on winter sown cereals (Cross 1993, Gill 1996).

If the palatability of different varieties of cereal is tested, those with a higher fibre content and less protein may be less favoured by geese, and more suitable for planting in areas where goose grazing is a problem (Owen 1990).

1.7.3 Alternative Feeding Areas

Major goose roosts are often protected by legislation (e.g. as Sites of Special Scientific Interest (SSSI), Specially Protected Areas (SPAs) or Ramsar sites). There is rarely, however, protected feeding areas for Pink-footed and Greylag geese

(Mitchell *et al* 1999). Creating and managing 'alternative feeding areas' (AFAs) to concentrate feeding geese could reduce grazing pressure on local farmland and has been suggested by many conservationists to be the best way of alleviating conflict between farmers and geese (Owen 1977, Owen 1990, Jepsen 1991, Andrews & Rebane 1994, Giroux & Patterson 1995). AFAs could be managed either by conservation bodies (e.g. reserves) or by farmers (e.g. by incorporating into a set-aside scheme) (Owen 1990, Patterson & Fuchs 1992, Giroux & Patterson 1995).

A range of management prescriptions have been suggested to encourage geese to AFAs. Disturbance should be kept at a minimum, with no shooting (Fox & Madsen 1997), and they should be sown with crops that are more attractive than those in nearby farmland. Suitable crops include cut but unharvested or partially harvested cereals (Giroux & Patterson 1995), improving grasslands through fertilisation (Owen 1975, Jepsen 1991, Patterson & Fuchs 1992, Giroux & Patterson 1995) and managing sward height (Patterson & Fuchs 1992, Andrews & Rebane 1994). In Denmark management measures include the daily provision of supplementary grain in the most vulnerable season (spring) as well as improved pasture (Jepsen 1991). Reseeding pasture can increase Barnacle goose feeding density by 60-135%, and fertiliser application increased time spent by geese on the grass by 17-42% (Percival 1993).

The size suggested for management areas varies Giroux and Patterson (1995) suggest the creation of small management units of 1 km^2 scattered throughout the 100 km^2 feeding range at Loch Strathbeg, as Pink-footed geese tend to concentrate their daily feeding in a 1 km^2 area (Giroux & Patterson 1995). Andrew and Rebane

(1994) advise that two to three managed fields of 10 ha, 500m apart can hold 1,000 geese, while Jepsen (1991) suggests an area of 100 ha of improved grass and 'lure grain' can support 14,300 Pink-footed geese over 30 days in spring (when they are staging in Denmark). If possible, areas already favoured by geese should be chosen as AFAs (Owen 1990, Patterson & Fuchs 1992).

Where alternative food areas are available, scaring and shooting of geese from areas where they are causing damage will reduce numbers and concentrate the geese in the refuges (Owen 1990, Leito 1991, Andrews & Rebane 1994). Objects for scaring geese such as sacks on poles, barrels or gas guns have a minimal effect and work for only a short time before geese become accustomed to them (Hearn & Mitchell 1995). Vickery and Summers (1992) have shown that the only cost effective form of scaring Brent geese *Branta bernicla* from cereal fields is to employ a human scarer to shoot at the birds each time they land on the fields. Studies on the management of Barnacle geese *Branta leucopsis* on Islay have shown that intensive, deliberate human disturbance can decrease the number of geese feeding in an area by 50%, mainly by moving the geese to refuges (Percival *et al* 1997). Owen (1990) suggests that Pink-footed and Greylag geese should be shot outside the managed areas throughout the year, unless numbers drop to below 100, 000 (as they now have for Greylag geese) in which case the general licence should be withdrawn and specific licences should only be granted for known incidences of damage in vulnerable areas.

At Loch Strathbeg a scheme was set up by Scottish Natural Heritage (SNH), running from 1994 to spring 1996, in which farmers who were heavily affected by

Pink-footed geese were encouraged to enter into a management agreement. Farmers provided refuge areas for the geese, and in these payment rates were made depending on goose use, which was assessed by the density of goose droppings. Outside the refuge area goose scaring was encouraged. Farmers received £50 to £80 per hectare, and the annual cost was around £27,000 (SOAEFD 1996). The Loch Strathbeg scheme was the only management scheme for Pink-footed geese operated by SNH, and no such schemes operate at present for Icelandic Greylag geese (Mitchell *et al* 1999, Mitchell & Sigfusson 1999). There is potential for payments from SOAEFD through the Environmentally Sensitive Area (ESA) Scheme and the Countryside Premium Scheme (CPS) to fund such management plans (Patterson & Fuchs 1992, SOAEFD 1996). The CPS has already been used to fund the provision of grazing for Brent geese (Patterson & Fuchs 1992).

1.7.4 Compensation payments

Alternatively, specific payments can be made to farmers to compensate for their loss of yield. In Islay farmers receive £9.50 per goose in compensation for the damage caused by Barnacle geese. This method of management is costly, although no more than the cost of using a human scarer to scare these geese onto refuges (Percival *et al* 1997). In Canada the federal government buys any crops damaged by geese (Owen *et al* 1986). In Europe the Netherlands is the only country with a nationwide compensation payment scheme (van Roomen & Madsen 1992), made by the Ministry of Agriculture and Fisheries, through the Game Fund (van Eerden 1990). Other countries, however, make compensation payments in local situations (van Roomen & Madsen 1992). In the Netherlands an average of £167 per hectare is given for damage by geese to arable land, £35 per hectare for damage to grassland, resulting in a total cost of up to £758, 000 in severe winters (van Eerden 1990). As compensation payments are increasing at a rate exceeding the increase in goose numbers, however, the government may be unwilling to pay ever increasing compensation (van Eerden 1990). Vickery *et al* (1994) carried out an economic analysis on solutions to the problem of damage to agricultural land by Brent geese and found that the best solution for society was to create AFA's. However, the best solution for farmers was compensation for damaged crops.

1.7.5 Goose redistribution

Meire and Kuijken (1991) suggest that instead of concentrating geese in protected areas, it would be preferable to use shooting as a method of dispersing the geese and therefore diluting the problem of damage. Patterson *et al* (1989) suggests that significant damage to winter cereals could be avoided by dispersal of the geese by scaring, so that they use more fields at lower grazing pressures, preferably below 5, 000 goose hours ha^{-1}. Geese which are more dispersed will be less vulnerable than large proportions of the population concentrated in very restricted areas (Meire & Kuijken 1991). Mooij (1991) questioned shooting as a method of regulating goose damage, as it will only be effective if there are undisturbed areas for geese to feed. Shooting also injures non-target geese, if a goose is shot at 35m, on 37% of occasions other geese will get hit by some of the pellets (Mooij 1991). When x-raying geese, 60% of adult geese and 30% of juveniles had lead pellets in them (Owen *et al* 1986), although the effect of stray pellets on geese is unknown.

1.7.6 Population management

Population management involves reducing the numbers of geese and maintaining them at a desirable level (Owen 1990). Reducing numbers of geese through population management may reduce the level of conflict between farmers and geese (SOAEFD 1996). This can be achieved by the following methods:

- Extending the shooing season for quarry species from the existing 1 September to 31 January (inland) (SOAEFD 1996)
- Increasing bag size (Owen 1990)
- Relaxing shooting bans in refuges (Owen 1990)
- Ease present restrictions on the sale of dead geese, while avoiding over exploitation (SOAEFD 1996)
- Co-operate with Iceland and Greenland to produce an action plan to reduce breeding success by destroying eggs / goslings, or reducing control of the Arctic fox, a natural predator of geese (SOAEFD 1996)
- Chemical control (Owen 1990).

Reduction of the numbers of geese may not be the solution to the goose-agriculture conflict as it is the spatio-temporal distribution, rather that the population size, which causes conflict (Moser & Kalden 1992). In addition all of the above suggestions would be difficult to implement due to international agreements, public outcry and disagreement by wildfowlers and conservationists (Owen 1990).

1.7 SUMMARY

Pink-footed and Greylag geese wintering in Britain feed in farmland surrounding roost sites. Food availability and causes of disturbance affect the locations of feeding flocks. It has been shown that grazing geese can cause damage to crops and therefore economic loss to farmers. At present there are no schemes to manage Pink-footed geese or Greylag geese in Scotland to reduce conflict with farmers. The most feasible solutions to the conflict between grey geese and agriculture appear to be the creation of Alternative Feeding Areas (AFA's) or the establishment of a scheme to compensate farmer for losses suffered due to goose grazing. An understanding of where geese are likely to feed would be helpful in targeting management plans such as these (Patterson & Fuchs 1992).

CHAPTER 2 – THE STUDY AREA: STRATHEARN AND STRATHALLAN

2.1 INTRODUCTION

The study area was situated in east central Scotland along the River Earn and Allan Water (Figure 2.1) covering an area of 420km^2 with altitude's ranging from 0 to 500 masl. The area is bounded to the north by the Turret Hills and to the south by the Ochil Hills. Of the two main rivers flowing through the study area the River Earn is the largest, ranging in width between *c.*30 and 45m while the Allan Water is *c.*15 – 20m wide. Smaller rivers and burns in the study area such as the Pow Water, Machany Water, Turret Burn and the Ruthven Water did not reach more than 10m in width.

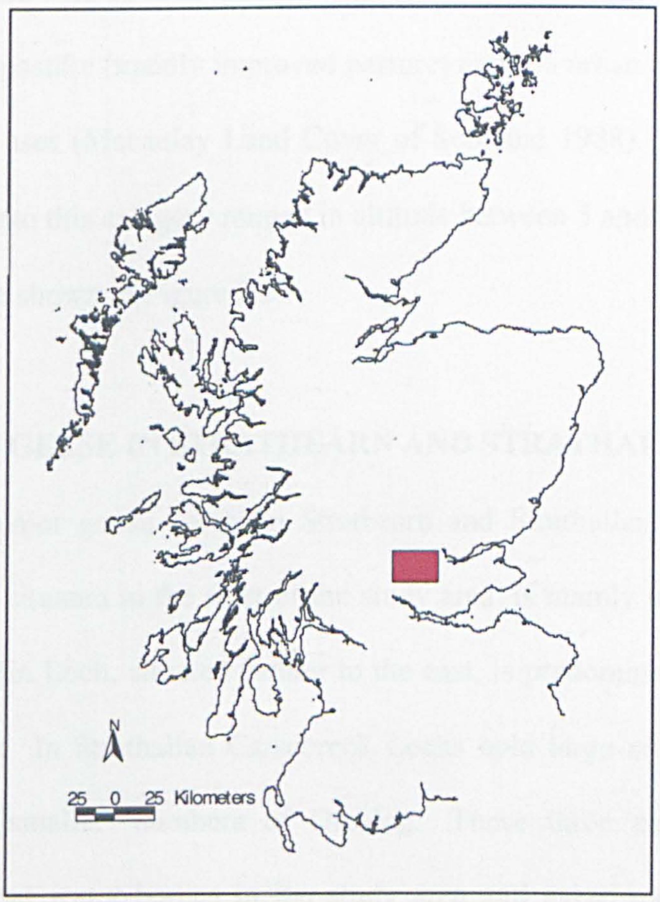

Figure 2.1 The location of the study area within Scotland

The landcover of the study area was 55% arable land, 13% wooded, 12% unimproved grassland, 9% improved grassland, 7% heather moorland, and 4% urban areas, roads, and other minor land uses (Macaulay Land Cover of Scotland 1988).

Within the study area, analysis and prediction of goose use was restricted to land in the 'rural' category of the Land-Line digitized data (Ordnance Survey, Southampton, United Kingdom, scale 1:12500), which corresponded to the limits of the 'agricultural' land class in the Land Cover of Scotland (LCS88) (1988, The Macaulay Institute, Craigiebuckler, Aberdeen, Scotland, scale 1:25000). The area within the 'rural' category of the OS Land-Line data is typical of agricultural areas of lowland Scotland with 73% of the area classified as arable land, 11% as wooded, 9% as permanent pasture (mainly improved pasture) and 7% urban areas, roads, and other minor land uses (Macaulay Land Cover of Scotland 1988). The 3607 study fields which fell into this category ranged in altitude between 5 and 267 masl (mean = 92 masl) and are shown in Figure 2.2.

2.2 STATUS OF GEESE IN STRATHEARN AND STRATHALLAN

There are three major goose roosts in Strathearn and Strathallan. In Strathearn Drummond Pond, situated to the west of the study area, is mainly used by Greylag geese while Dupplin Loch, situated further to the east, is predominantly a roost for Pink-footed geese. In Strathallan Carsebreck Lochs hold large numbers of Pink-footed geese and smaller numbers of Greylag. These three major roosts are the largest lowland water bodies in the study area and geese roosting here are subject to little or no shooting (Bell *et al* 1997). The following account of the

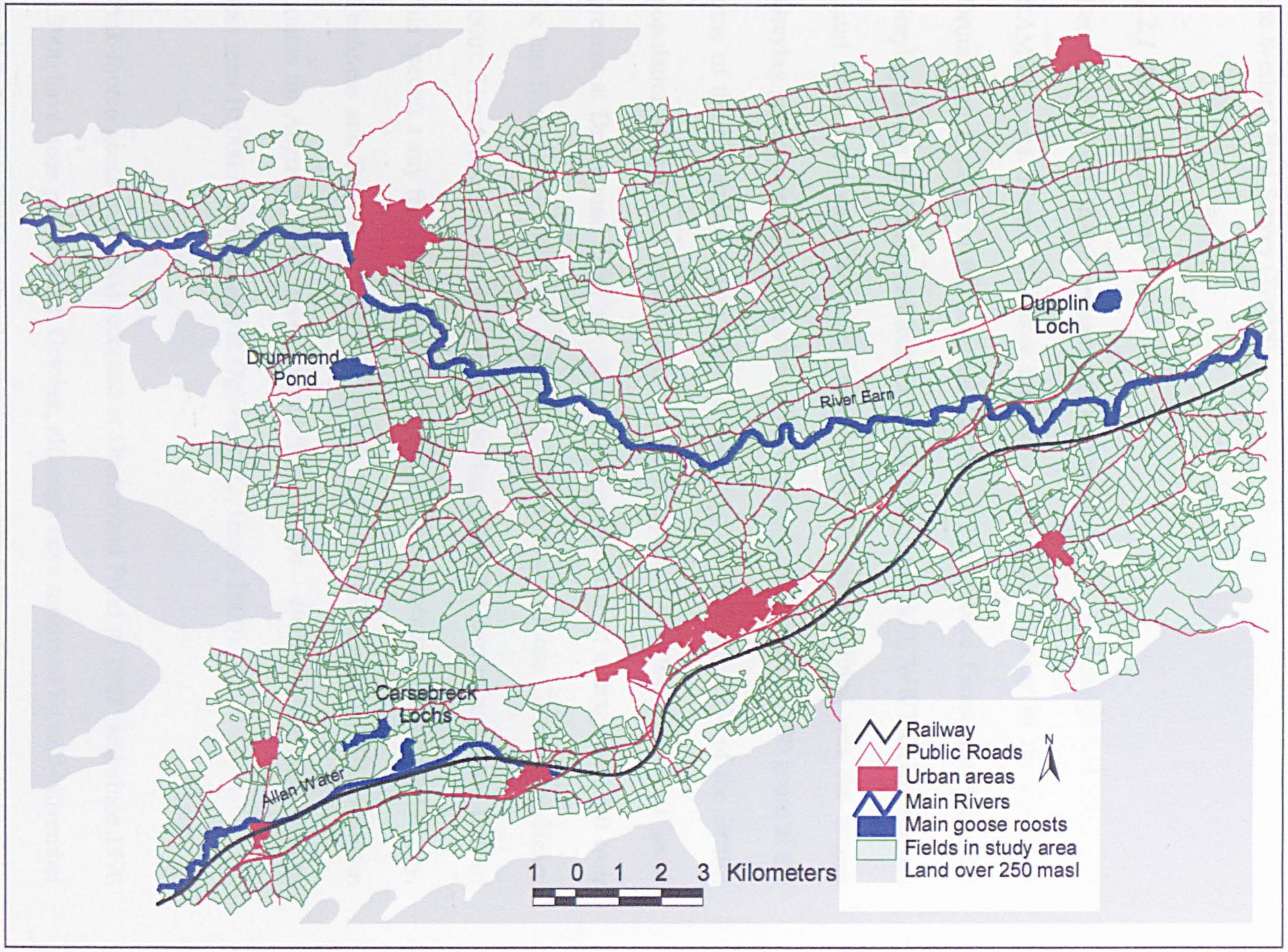

Figure 2.2 The study area in Strathearn and Strathallan, showing individual fields.

numbers and trends of geese using these roosts is based on data the National Census of Pink-footed Geese and Icelandic Greylag Geese in Britain, supplied by the Wetland Bird Survey (WeBS).

2.2.1 Drummond Pond

Drummond Pond, in the grounds of Drummond Castle, is a designated SSSI and RAMSAR site. Figure 2.3 show the five-year moving average of the counts at Drummond Pond from the National Census of Pink-footed Geese and Icelandic Greylag Geese in Britain and Ireland (Boyd & Ogilvie 1972, WWT Goose Census data) carried out each November since 1960. Drummond Pond was the largest Greylag goose roost in Britain in the 1960s holding on average *c.*7900 geese at the time of the November census between 1965 and 1970, nearly 14% of the British population (Boyd & Ogilvie 1972). Since the early 1980s the number of geese present at Drummond Pond has dropped considerably to an average of 1590 over the last five years, 2.0% of the British population (WWT Goose Census data, Hearn 2000). The decline in the numbers of Greylag geese is a part of a general shift of this species away from their previous stronghold in east central Scotland to Orkney, Caithness and Ross & Cromarty (Boyd & Ogilvie 1972, Hearn 2000). Autumn counts for Angus & Perth have dropped from 30,000 – 40,000 in the late 1960s to less than 10,000 in 1999 (Boyd & Ogilvie 1972, Hearn 2000).

Pink-footed geese were first recorded at Drummond Pond in 1988, and since 1990 *c.*3000 have been present each October, although none remained by mid-November (Bell & Newton 1995). By clearing local stubble fields of spilt grain before the

Greylag geese arrived the Pink-footed geese might have contributed to the drop in numbers of Greylag geese in recent years (Bell & Newton 1995).

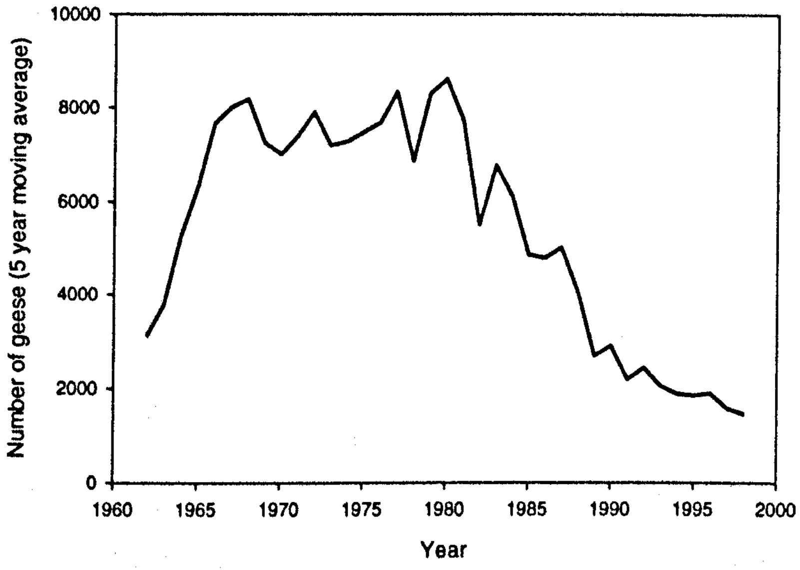

Figure 2.3 Five year moving average of the November counts for Greylag geese at Drummond Pond. Data from the WWT National Census of Pink-footed geese and Greylag geese in Britain and Ireland.

In addition to Drummond Pond, Greylag geese in Strathearn were recorded to use a further nine roosts by Bell *et al* (1997) with only 54% of recorded flocks of Greylag observed between the winters of 1987/88 and 1993/94 roosting at Drummond Pond. Counts of all Greylag goose roosts in Strathearn throughout the winters of 1988/89 to 1993/94 show that the area held relatively constant numbers of Greylag throughout the winter. Most geese roost at Drummond Pond when they first arrive in autumn, but disperse to the smaller roosts as the winter progresses (Bell & Newton 1995).

2.2.2 Dupplin Loch

Dupplin Loch is the main Pink-footed goose roost in Strathearn. Dupplin Loch appears to be unattractive to roosting geese as it is relatively small (*c.*30ha) and is surrounded by mature woodland. However, the loch is undisturbed such that at times it has held more Pink-footed geese than any other site in Britain (Newton *et al* 1973, Bell & Newton 1995). The number of Pink-footed geese using the roost has remained relatively constant since the 1960s, when accurate goose counts began (Figure 2.4). Seasonal trends in the numbers of Pink-footed geese shows a very clear peak in numbers using the roost in early autumn (Figure 2.5). In November 1973 Dupplin Loch held 27,500 Pink-footed geese, at the time representing 33% of the British population. More recently numbers have regularly peaked at over 30,000 and in September 1991 57,500 geese were roosting at the loch, 25% of the British population (Bell & Newton 1995). These large numbers of geese cannot be sustained, and by mid November much of the spilt grain in the area is depleted. At this time the numbers of Pink-footed geese fall to *c.* 6000 (*c.* 3% of the British population) and remain at around this level for the rest of the winter (Bell & Newton 1995). Pink-footed geese in Strathearn have been recorded to use floodwaters as alternative roost sites on occasion (Bell & Newton 1995, Bell *et al* 1997) but the vast majority of flocks observed roosted at Dupplin Loch (93% Bell *et al* 1997).

Large numbers of Greylag geese roosted at Dupplin Loch in the past, with numbers averaging *c.* 2000 in the 1970s but in recent years a maximum of a few hundred Greylag geese roost at Dupplin and often fewer (WWT Goose Census data). As discussed previously this decline is part of a wider shift of Greylag geese away from traditional roosts in east central Scotland.

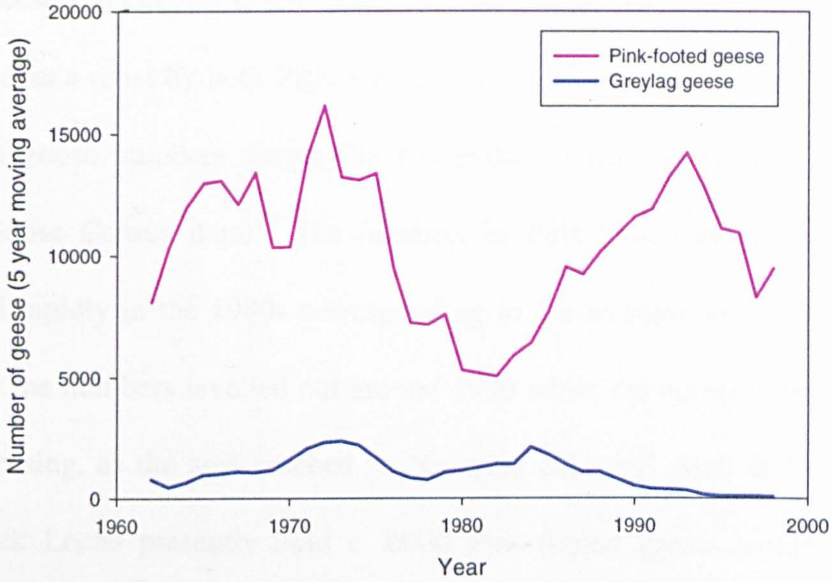

Figure 2.4 Five year moving average of the autumn counts for Pink-footed and Greylag geese at Dupplin Loch. Data from the WWT National Census of Pink-footed geese and Greylag geese in Britain and Ireland.

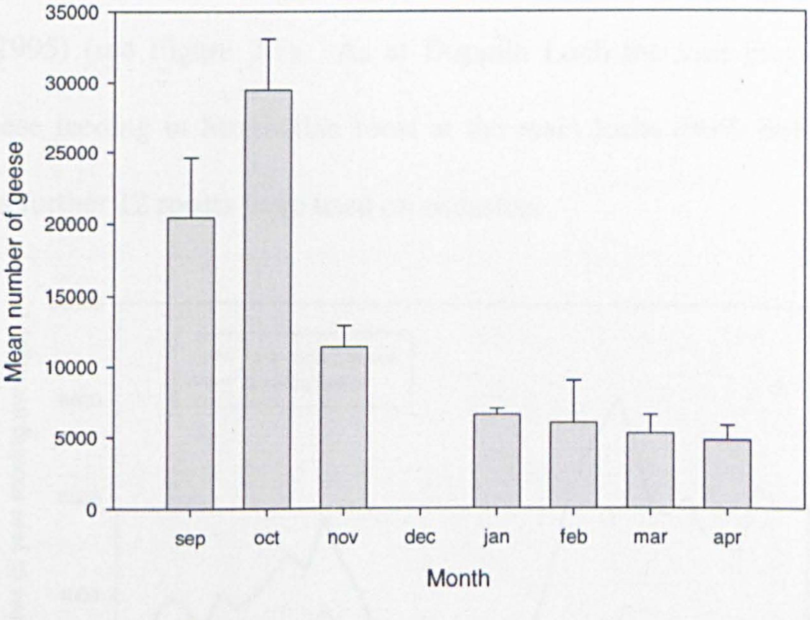

Figure 2.5 Seasonal trends in the mean number of Pink-footed geese using Dupplin Loch from 1987 to 1998. Data from the WWT. Error bars = standard error of mean.

2.2.3 *Carsebreck Lochs*

Carsebreck Lochs are a complex of three lochs, Carsebreck Loch, Upper Rhynd and Lower Rhynd, situated close to the Allan Water. Since the National Census of Pink-footed Geese and Greylag Geese in Britain and Ireland began in 1960 the lochs have been used as a roost by both Pink-footed and Greylag geese. Figure 2.6 shows the trends in goose numbers during the November census' (Boyd & Ogilvie 1969, WWT Goose Census data). The numbers of Pink-footed geese using the roost increased rapidly in the 1980s corresponding to the increase in the national trend. However the numbers levelled out around 1990 while the numbers nationally were still increasing, as the area reached its 'carrying capacity' (Bell & Newton 1995). Carsebreck Lochs presently hold *c.* 6000 Pink-footed geese, around 3% of the British population, at the time of the November census. While the pattern of goose use of the lochs throughout the season is not as marked as at Dupplin Loch, there is a clear passage of Pink-footed geese in both the early autumn and the spring (Bell & Newton 1995) (see Figure 2.7). As at Dupplin Loch the vast majority of Pink-footed geese feeding in Strathallan roost at the main lochs (90% Bell *et al* 1997), although a further 12 roosts were used on occasion.

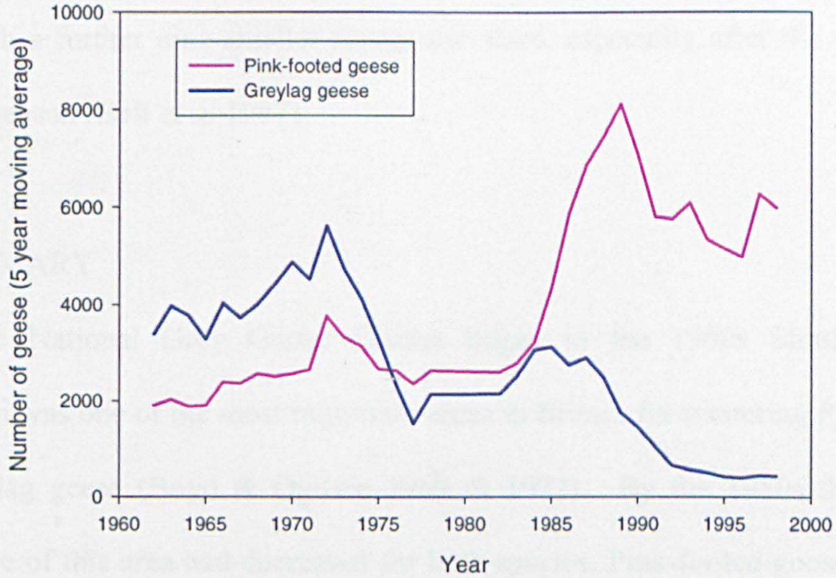

Figure 2.6 Five year moving average of the autumn counts for Pink-footed and Greylag geese at Carsebreck Lochs. Data from the WWT National Census of Pink-footed geese and Greylag geese in Britain and Ireland.

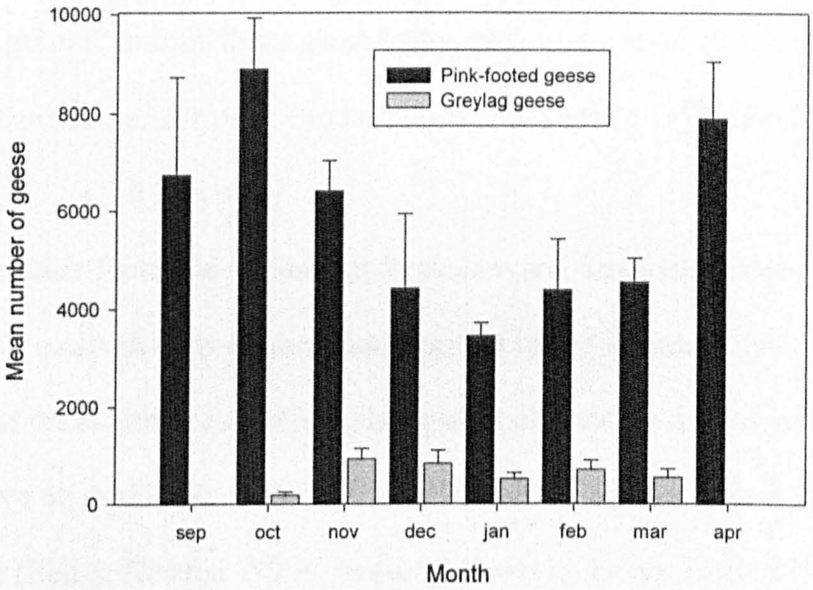

Figure 2.7 Seasonal trends in the mean number of Pink-footed and Greylag geese using Carsebreck Lochs from 1987 to 1998. Data from the WWT. Error bars = standard error of mean.

In the 1960s Carsebreck held relatively large numbers of Greylag geese, *c.* 4000 which at the time was nearly 6% of the British population. As in Strathearn, since that time the numbers have crashed to fewer than 500 geese in recent years (WWT Goose Census data). Only 30% of Greylag flocks observed roosted at Carsebreck lochs, with a further nine smaller roosts also used, especially after the end of the shooting season (Bell *et al* 1997).

2.3 SUMMARY

When the National Grey Goose Census began in the 1960s Strathearn and Strathallan was one of the most important areas in Britain for wintering Pink-footed and Greylag geese (Boyd & Ogilvie 1969 & 1972). By the 1980s the relative importance of this area had decreased for both species, Pink-footed goose numbers did not increase in line with the national trend while Greylag goose numbers at all three main roosts have declined considerably despite an increase in the British population (Bell & Newton 1995). The decline in numbers of Greylag geese is a part of a general shift of these geese away from east central Scotland to roosts in Orkney, Caithness and Ross & Cromarty (Boyd & Ogilvie 1972, Hearn 2000).

Passage of Pink-footed geese through Strathearn and Strathallan causes an influx of geese at all roosts in early autumn, and again in spring in Strathallan. The size and duration of the autumn peak reflects the amount of grain shed at harvest, suggesting geese move on as there is inadequate food resources to sustain them for the rest of the winter (Bell & Newton 1995). Seasonal trends in the numbers of Greylag geese using the roosts are much less apparent as the area is close to the southern limit for this species, and therefore there is a smaller passage (Bell & Newton 1995). In addition, as Greylag geese roost in smaller numbers (WWT Goose Census data) depletion of food close to the roosts is likely to be less severe in this species and therefore food resources are likely to last longer.

CHAPTER 3 – PREDICTING GOOSE DISTRIBUTION FROM LANDSCAPE CHARACTERISTICS

3.1 INTRODUCTION

3.1.1 A review of methods for predicting the distribution of animals

Knowledge of the distribution of animals is often a basic requirement of conservation management. In certain circumstances survey work can provide the required information, if for example knowledge of distribution is only required for a specific area or if it is possible to co-ordinate volunteers to cover large areas (e.g. Sharrock 1976). Census work may hold logistic problems, however, such as cost and access to remote areas (Osborne & Tigar 1992, Tucker *et al* 1997). In such circumstances prediction of the distribution of animals from data of a smaller sample area will often prove more cost-effective. There are a range of techniques available that can be employed to predict distribution of a species from sample data.

INTERPOLATION

Interpolation mapping is a family of methods where the value of a variable at a specific point on a map is estimated by local interpolation (Legendre & Legendre 1998). Interpolation methods used in ecological situations range from simple linear interpolation (Farina 1997) to kriging (Robertson 1987, Palma *et al* 1999). Although interpolation techniques take account of the spatial patterns in species distribution (Legendre 1993) they do not take account of the effect of habitat quality when predicting where animals will occur (Augustin *et al* 1996).

WILDLIFE-HABITAT MODELS

Species distribution is often related to landscape characteristics, with species being present only if suitable habitat is available. Landscape characteristics can either be measures of the real requirements of a species (e.g. food availability) or proxy measures (i.e. houses as a measure of human disturbance). If the relationships between landscape characteristics and species distribution are known then the species distribution can be predicted from information on the landscape characteristics. An added advantage of using predictive models based on the availability of suitable habitat is their ability to predict the effect of future change in land-use on the species (Saarenmaa *et al* 1988, Austin *et al* 1996, Cowley *et al* 2000). Such analysis requires data on landscape characteristics for both the sample area and the area where prediction of species distribution is required. In the past field surveys and maps have had to be used to provide landscape data (e.g. Osborne & Tigar 1992, Fielding & Haworth 1996, Collingham *et al* 2000, Cowley *et al* 2000). In recent years the advent of Geographical Information Systems (GIS) has enabled the storage, manipulation and display of spatial data, a tool which is being increasingly used in the creation of predictive models (e.g. Pereira & Itami 1991, Buckland & Elston 1993, Augustin *et al* 1996, Austin *et al* 1996, Tucker *et al* 1997). A wealth of landscape data is now available in digitised form (e.g. Ordnance Survey Landline data). Remote sensing, the use of aerial photography and satellite imagery, has also been used in recent years to identify landscape characteristics on the ground (Austin *et al* 1996, Tucker *et al* 1997, Osborne *et al* 2001) and species distributions (Crist & Wiens 1996). GIS and remote sensing have therefore greatly increased both the quality and quantity of information that can be incorporated into predictive models (Austin *et al* 1996, Cowley *et al* 2000, Corsi *et al* 2000).

MULTIPLE REGRESSION

A range of statistical techniques are available for analysing the effect of landscape characteristics on species distributions. Multiple regression can be used to model the effect of a suite of landscape characteristics on species abundance (e.g. Morrison *et al* 1987). This technique, however, is inappropriate for data where the species is absent from a large proportion of sample points, as is often the case with species distribution. In such cases analysis of the presence or absence of a species is often a more appropriate approach.

TECHNIQUES FOR MODELLING PRESENCE / ABSENCE DATA

Logistic regression and discriminate function analysis are two techniques for predicting the species distribution by relating landscape characteristics to the presence or absence of a species and have been frequently used to model species distribution (Pereira & Itami 1991, Osborne & Tigar 1992, Buckland & Elston 1993, Austin *et al* 1996, Fielding & Haworth 1996, Manel *et al* 1999, Collingham *et al* 2000, Cowley *et al* 2000, Osborne *et al* 2001). Both techniques yield very similar results (Fielding & Haworth 1995, Manel *et al* 1999) but are limited in assuming a linear response to environmental predictors (Manel *et al* 1999). More recently artificial neural networks (ANN) (e.g. Spitz & Lek 1999) and tree regression analysis (e.g. Rejwan *et al* 1999) have been used to predict species distribution. These techniques do not require the dependent variable to be linearly related to the predictor variables and make no assumptions about the distributions of the predictor variables (Manel *et al* 1999, Rejwan *et al* 1999). Although such techniques are advantageous if relationships between landscape characteristics and species distribution cannot be made linear (Rejwan *et al* 1999), if the assumptions of more traditional modelling techniques are met, ANN's will not outperform them (Manel *et al* 1999). In addition the output is difficult to interpret (P.E. Osborne pers. comm.).

SPATIAL AUTOCORRELATION

None of the above techniques takes account of the spatial arrangement of dependent variables, predictor variables or residuals, and they assume that all points are spatially independent. Ecological variables, however, are often spatially autocorrelated, that is to say that random points are likely to be more correlated the closer they are to each other (Legendre 1993). All the wildlife-habitat models outlined above assume that data points are spatially independent and therefore spatial autocorrelation will result in an overestimation of the degrees of freedom and therefore the possibility of false significance in statistical tests (Legendre 1993, Augustin *et al* 1996, Fielding & Bell 1997). Correctly predicted species presence or absence will also be a conservative measure of model performance as no account is taken of the spatial element (i.e. the distance of false positives from real positives) (Austin *et al* 1996, Fielding & Bell 1997). Spatial autocorrelation in residuals of a wildlife-habitat model, the result of unexplained covariates or animal behaviour, is often ignored (Augustin *et al* 1996), although Fielding and Haworth (1996) found only weak spatial dependence of logistic regression model residuals in their study. Augustin *et al* (1996) have developed an approach, called autologistic regression, that incorporates both the effect of spatial autocorrelation and landscape characteristics by including an additional covariate into a logistic regression model which takes account of species abundance in neighbouring cells.

ASSESSING MODEL PERFORMANCE

Once a model has been built it is important that its power to predict species distributions is assessed. The number of correctly classified cases may not be the most appropriate measure of model fit (Fielding & Bell 1997, Manel *et al* 1999). Fielding and Bell (1997) discuss a range of statistics which describe various aspects of the results of presence / absence models, including the use of receiver operator characteristic (ROC) plots which assess the accuracy of models through the whole range of threshold values (e.g. Fielding & Haworth 1996).

Assessing model accuracy from the correct classification of sample points used to create the model can be optimistically biased and therefore model accuracy should be assessed on independent data (Verbyla & Litvaitis 1989). The most rigorous test of a statistical model is to apply it to an independent data set (e.g. Austin *et al* 1996), but resampling methods can be used to obtain more realistic measures of classification accuracy with the available data (Verbyla & Litvaitis 1989). A range of resampling techniques exist which involve creating a model with a portion of the data and testing the model accuracy with the rest. Cross validation, splitting the data in two and using one sub-sample to develop the model and the second to assess model accuracy, results in a loss of data on which the model is built (Verbyla & Litvaitis 1989). A preferable method of resampling, in which no such loss of data occurs, is jack-knifing. With jack-knifing each sample point is excluded in turn from the analysis so that the prediction of species present at the excluded sample point is independent. This technique is frequently used to assess model accuracy (e.g. Osborne & Tigar 1992, Manel *et al* 1999, Cowley *et al* 2000). Bootstrapping is another re-sampling technique. This involves taking a random sample of data that is the same size as the original data set, but with replacement, and predicts the presence of the species for the remaining data. The process is repeated many times, then the mean predicted value for each data point is calculated and used to assess model fit. Although bootstrapping is the best assessment of model fit it requires the most computer power (Verbyla & Litvaitis 1989).

SOME PROBLEMS OF WILDLIFE HABITAT MODELS

Predictive models based on associations between habitat types and species distribution may not be accurate, even if all the assumption above are addressed. Factors affecting species use of a habitat have been shown to vary between regions, possibly due to regional differences in habitat composition and animal behaviour (Fielding & Haworth 1996, Manel *et al* 1999). Species may not occur in all suitable habitat and may be present in unsuitable habitat due to factors such as delayed reaction of a species to changes in habitat (e.g. succession) (Fielding & Haworth 1996), undersaturation (Fielding & Bell 1997), individual variation (e.g. as a result of social status) (Fielding & Bell 1997). Scale is an important factor and should be considered. Wiens *et al* (1987) found that habitat characteristics affecting the distribution of bird species were dependent on the spatial scale at which species distribution was assessed. These factors suggest that caution should be exercised when extrapolating models to other areas, at different scales or when making predictions in the effect changes in land-use (Fielding & Haworth 1996). Beutel *et al* (1999) commented that as conservation strategies aim to optimise habitat quality and because species presence may not necessarily indicate high quality habitat, alternatives to studying species distribution such as survivorship, reproductive success or physiological condition may be more appropriate for highlighting areas of conservation interest (e.g. Paradis *et al* 2000).

3.1.2 Predicting the feeding distribution of geese

In this chapter the probability of geese using individual fields will be predicted from the field's landscape characteristics. Information on goose distribution was obtained from the surveying of sample fields, and in the majority of these fields no geese were observed. Pink-footed and Greylag geese have a tendency to feed in fields which they had used on previous days and are also likely to select fields where other geese are present. Consequently, the observation of a large flock of geese in a field, or observations of geese repeatedly using the same field, was not considered to be a much more accurate measure of field suitability than the observed presence / absence of geese. Therefore analysis of the effect of landscape characteristics on the presence / absence of geese, as opposed to their density, was considered appropriate.

As analysis was of presence / absence data multiple regression was considered inappropriate. The relationships between habitat variables and goose use appeared linear when simple transformations were applied so there was no need for techniques such as ANN and tree regression analysis. Therefore, logistic regression and discriminate function analysis were the two most appropriate statistical techniques for predicting the distribution of geese, and of these logistic regression was selected for this analysis.

Table 3.1. Factors potentially affecting feeding distribution of Pink-footed (PF) and Greylag (GL) geese.

Field characteristic	**Possible effect**	**Possible explanation**	**Effect shown**		**References**
			PF	**GL**	
Distance to roost	Decreased field use further from roost	Increased flight cost	✓	✓	Newton *et al.* 1973 Bell 1988 Keller *et al.* 1995 Giroux & Patterson 1995
Crop type	Increased use in fields with preferred food type	Increased nutrient intake	✓	✓	Newton & Campbell 1973 Forshaw 1983 Madsen 1984 Bell 1988 Patterson *et al.* 1989 Gill 1994 Giroux & Patterson 1995 Hearn & Mitchell 1995 Mitchell *et al.* 1995
Distance to water source	Increased use near water source	Decrease cost of moving when water required for drinking, bathing			
Field area	Increased use of larger fields	Increased probability of use purely due to size Decreased chance of visibility being impaired by field boundary	✓		Newton & Campbell 1973 Madsen 1984 Gill 1994
Proximity to roads	Decreased use of fields near road	Increased human disturbance	✓	✓	Newton & Campbell 1973 Madsen 1984 Keller 1991 Gill 1994
Proximity to buildings	Decreased use of fields near buildings	Increased human disturbance	✗		Gill 1994
Proximity to urban areas	Decreased use of fields near urban areas	Increased human disturbance			
Slope	Decrease use of sloping fields	Decreased ability for geese to detect potential predators			
Proximity to trees, windbreaks	Decreased use of fields near windbreaks	Decreased visibility	✓		Madsen 1984

Previous studies have shown the effect of proximity to human disturbance, food types and travel time from roost on field choice by Pink-footed and Greylag geese (refs. in Table 3.1). However, Pink-footed geese have been shown to concentrate a day's feeding within a mean area of 1.1km^2 (Giroux & Patterson 1995), and therefore the chance of a field being used by geese may not only be affected by the characteristics of the particular field but also by the suitability of neighbouring fields. A radius of 500m would therefore define the area within which geese are most likely to feed during the day, so the suitability or use of neighbouring fields within this radius may affect goose use of the field.

3.1.3 Aims

The objectives of this chapter are:

(i) To quantify the effects of both disturbance-related and non-disturbance related field characteristics on the feeding distribution of Pink-footed and Greylag geese.

(ii) To assess the effect of both the predicted and observed goose presence in neighbouring fields on goose use of a field (autologistic regression).

(iii) To build models that predict the feeding distribution of Pink-footed and Greylag geese from these relationships.

3.2 METHODOLOGY

3.2.1 Goose surveys

Geese are very susceptible to disturbance from traffic (Keller 1991) so surveys were performed only from public roads where geese were habituated to regular traffic. Ten vantage points and two sections of road with good visibility were selected across the study area and from these 755 sample fields, situated throughout the study area, could be viewed. Fields were only included if entirely visible to the observer. Care was taken to ensure that during surveying no geese within any study fields were disturbed enough to leave that field. Sample fields were surveyed 2-3 times a week from the 1st October 1997 to 8th May 1998, a total of 71 surveys overall. The number and species of geese present in the fields were noted. Pink-footed geese were observed in 123 of the sample fields, Greylag geese in 43 of the sample fields.

3.2.2 Deriving field characteristics

ArcInfo GIS ver. 7.2.1 (ESRI, Redlands, California, USA) was used to derive a polygon coverage for all 3,599 fields in the study area from digitised OS LandLine data. Table 3.2 lists the landscape characteristics for each field, which were derived from digitised data using the ArcView GIS version 3.1 (ESRI, Redlands, California, USA). Three sources of published spatial datasets were used, the rural category of Land-Line Data (Ordnance Survey, Southampton, United Kingdom) consists of vector coverage of man-made and natural features at a scale of 1:12500. Land-Form PANORAMA Data (Ordnance Survey, Southampton, United Kingdom) provides contour of land elevation at vertical intervals of 10m at a scale of 1:50000. The Land Cover of Scotland digital data set (LCS88) (1988, The Macaulay Institute, Craigiebuckler, Aberdeen, Scotland) provides rural landcover data, interpreted from aerial photographs, in 126 land classes at a scale of 1:25000. Three measurements of distance were taken: the distance from the farthest point in the field to the feature (maximum distance); the distance from the nearest point in the field to the feature (minimum distance); and the average distance to the feature (mean distance) using ArcView GIS. For variables with relatively large distances the difference between the mean and maximum or minimum value were considered insignificant, and therefore only the mean distance was used (see Table 3.2).

Appendices 1 and 2 provide descriptive statistics of the distribution of these data and the correlations between the landscape characteristics.

Altitude and slope information was derived from the Land-Form PANORAMA Data. The 3D Analyst extensions of ArcView GIS was used to create TIN features from the contour data, which interpolate altitude and slope between the contour lines. From the TIN features the mean altitude and slope of each field was calculated. For maps of these variables see Appendices 3 and 4.

Table 3.2. Fields characteristics calculated, including source of data and derived results.

Field Characteristic	Description	Units	Source data	Derived results
Area	Area of field	m^2	OS Land-Line data	value
Roost distance	Distance to nearest roost	m	OS Land-Line data	mean
Road distance	Distance to nearest road or track.	m	OS Land-Line data	mean minimum maximum
Building distance	Distance to nearest building	m	OS Land-Line data	mean minimum maximum
Urban area distance	Distance to nearest urban area	m	LCS 88	mean
Woodland distance	Distance to nearest wooded area	m	LCS 88	mean
Water distance	Distance to nearest permanent water, including ponds, drains, rivers etc.	m	OS Land-Line data	mean
Altitude	Average field altitude	masl	OS Panorama contour	mean
Slope	Average slope of field	degrees	OS Panorama contour	mean

Greylag and Pink-footed geese tend to occupy established roosts. However, Greylag geese in particular, will roost at other sites (Newton *et al* 1973; Bell *et al* 1997). In this study Greylag and Pink-footed goose roosts were defined as sites where more than 5% of observations of roosting geese for the river catchment were made (derived from Bell *et al* 1997). This resulted in nine Greylag goose roosts and three Pink-footed goose roosts being used to calculate the distance from the nearest roost.

Crop type was recorded for each sample field monthly. For analysis a broad single crop type category was assigned to each field. Crop categories used were stubble, grass, winter cereal, spring cereal, ploughed, oil seed rape, turnips and other.

3.2.3 Relationships between field characteristics and goose use

Owing to the low frequency of use of the majority of fields by geese, analysis was performed on the presence or absence of geese in the field as opposed to numbers. To display data trends graphically, fields were grouped into ranked sets of 40, according to the characteristic in question. For each group of fields, the mean and standard deviation of the field characteristic and the proportion of fields that were observed to contain geese were calculated. The proportions of fields containing geese were then plotted against the mean field characteristic for that group. Trends were detected using regression analysis. This technique was considered preferable to logistic regression for uni-variate analysis, as with the latter method large amounts of 'absence' data would be discarded, although not appropriate when considering a suite of predictor variables. Note that the R^2 values will tend to be higher for grouped data than for individual fields. Selection of crop type by geese was assessed using a Chi-squared test.

3.2.4 Logistic regression

Analysis was of presence / absence data and the relationships between habitat variables and goose use appeared linear when simple transformations were applied.

Multiple logistic regression was therefore considered an appropriate modelling technique and stepwise logistic regression was used to model the presence or absence of geese in fields against a suite of predictor variables. All fields in which geese were observed were used together with an equal number of fields that did not contain geese selected at random. This resulted in 234 fields being included in the Pink-footed goose analysis and 86 fields in the Greylag goose analysis, with large quantities of 'absence' data being discarded. The variables in Table 3.2 were incorporated in the model, using a forward stepwise procedure with a probability for entry at $p = 0.05$, and a probability for removal at $p = 0.1$. The performance of logistic regression models is best described by Receiver Operator Characteristic (ROC) curves (Fielding & Bell 1997). In ROC curves the accuracy of fit of a presence-absence model is plotted for the whole range of possible cut off values, rather than for an arbitrary dichotomy such as probabilities > 0.5 being regarded as presence and < 0.5 as absence. A useful summary statistic of the fit of the model is the area under the ROC curve (AUC). The AUC can range from 0 to 1, with a model performing no better than chance having an AUC of 0.5. Logistic regression results were expressed as the AUC ± its SE with the significance of departure from a chance model. In addition the percentage of fields classified correctly at a 50% cut off level is given for simplicity, although the limitations in this approach must be appreciated. These models will be referred to as the ordinary logistic regression models.

3.2.5 Autologistic model

The effect of neighbouring fields was investigated using a simplified form of autologistic regression modelling (Augustin *et al* 1996). ArcView GIS was used to identify the neighbours of each field, defined as fields with centres within 500m of each other. The addition of goose use in the neighbouring area to the existing model was investigated by forcing the proportion of neighbouring fields containing geese as an additional variable in the ordinary logistic regression model. Similarly, the effect of surrounding habitat suitability was investigated by including the mean and maximum predicted probabilities (from the logistic regression model) as variables in a subsequent model.

To assess whether any of the autologistic models were significantly better at predicting goose distribution that the ordinary model, the differences in ROC AUC's of the models were tested for significance using the method of Beck & Shultz (1986).

3.2.6 Jack-knifing

Once a parsimonious model had been derived, jack-knifing was used to check the robustness of the model. Each field in turn was removed from the analysis and the remaining fields used to generate a predictive equation. Goose use of the excluded field was calculated from this equation, giving a prediction independent of the observed data. As with the autologistic model, the significance of the difference in the AUC's was used to compare the jack-knifed and ordinary logistic regression models.

3.3 RESULTS

Results from the survey showed that 16.3% of the sample fields were observed to contain Pink-footed geese and 5.7% of the sample fields contained Greylag geese.

3.3.1 Factors affecting goose distribution

Pink-footed geese show a significant (P < 0.01) decrease in field use further from the roost, in smaller fields, in fields closer to roads and buildings, and in fields with a greater slope (Table 3.3 and Figure 3.1). Greylag geese exhibited weaker relationships between field use and field characteristics. Significant relationships (P < 0.05) were shown with distance from roost and distance to buildings for this species (Table 3.3 and Figure 3.1). The lack of highly significant relationships detected for Greylag geese may be due to the small number of fields used by this species.

Table 3.3. R values and significance of the regression analysis showing the relationships between field characteristics and proportion of fields in each group with geese observed. Both linear and logarithmic curve estimations are shown.

Field characteristic	**Pink-footed geese** N (groups) = 18, d.f. = 16				**Greylag geese** N (groups) = 11, d.f. = 9			
	Linear		Logarithmic		Linear		Logarithmic	
	R	Sig.	R	Sig.	R	Sig.	R	Sig.
Distance to nearest PF roost	-0.571	0.011	-0.499	0.030	-	-	-	-
Distance to nearest GL roost	-	-	-	-	-0.363	0.273	-0.615	0.044
Field Area	0.841	< 0.001	0.862	< 0.001	0.406	0.215	0.490	0.126
Mean distance to road	0.593	0.007	0.748	< 0.001	0.055	0.866	0.152	0.655
Mean distance to building	0.930	< 0.001	0.872	< 0.001	0.635	0.036	0.713	0.014
Distance to urban areas	-0.045	0.870	0.000	0.948	0.197	0.562	0.348	0.295
Distance to woodland	0.261	0.294	0.421	0.243	-0.110	0.750	-0.055	0.884
Distance to water	0.362	0.128	0.376	0.113	-0.379	0.250	-0.268	0.426
Altitude	-0.249	0.305	-0.263	0.276	-0.348	0.295	-0.332	0.320
Slope	-0.759	< 0.001	-0.718	< 0.001	-0.084	0.811	-0.298	0.373
Min. distance to road	0.319	0.197	-	-	0.000	0.962	-	-
Max. distance to road	0.667	0.003	0.766	< 0.001	0.522	0.099	0.512	0.107
Min. distance to building	0.463	0.004	-	-	0.358	0.279	-	-
Max. distance to building	0.841	< 0.001	0.806	< 0.001	0.447	0.168	0.443	0.172

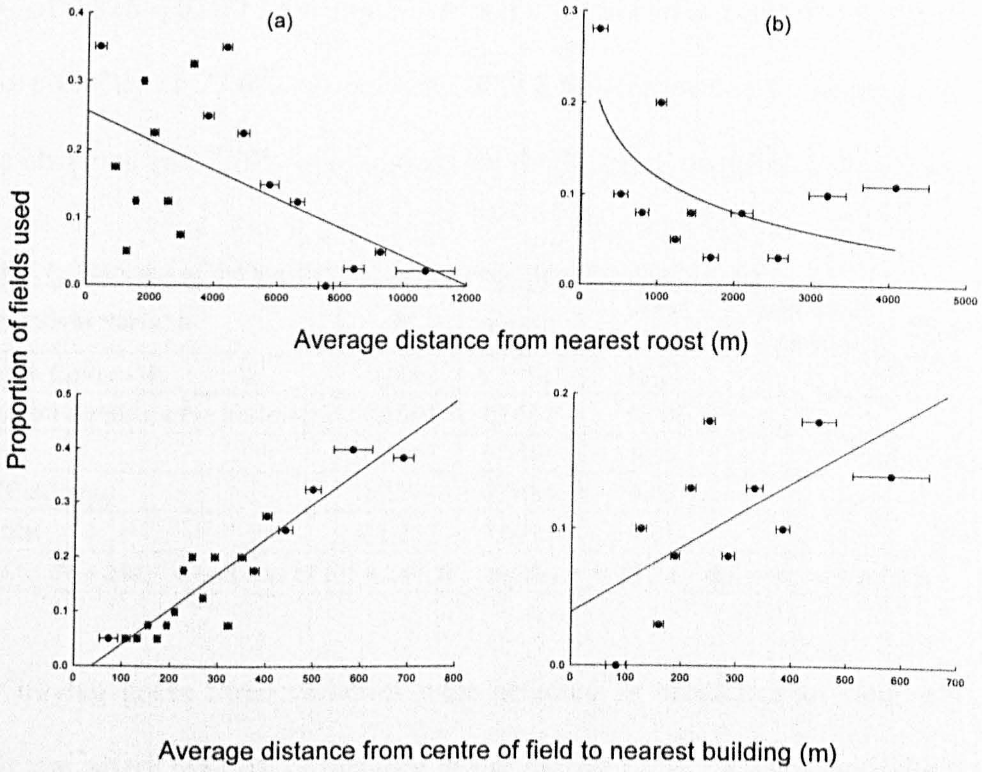

Figure 3.1 The relationship between the proportion of fields used by Pink-footed (a) and Greylag (b) geese and distance to the nearest roost and building. Error bars = St. dev.

For Pink-footed geese Chi-squared tests showed a significant difference between observed field choice and expected use if crops were used in proportion to their availability ($\chi^2 = 18.9$, d.f. = 7, P = 0.008). Greylag goose use of different crop types showed no significant difference from the expected ($\chi^2 = 8.6$, d.f. = 7, P = 0.282), although they showed the same trend as Pink-footed geese in their preference for stubble fields.

3.3.2 Logistic regression

For Pink-footed geese, stepwise logistic regression resulted in four variables being included as predictors of field use. Predictors were distance of the field from the nearest roost, distance from the furthest point in the field to the nearest building, the slope of the field and the log (10) of the field area (Table 3.4). This model had an

AUC of 0.826 ± 0.027 ($P < 0.001$). At a 0.5 cut off level classified the presence of geese correctly on 77.0% of occasions, 80.0% of occasions in for fields where geese were observed and 73.9% of occasions for fields where no geese were observed.

Table 3.4. Statistics of the logistic regression model for Pink-footed geese

Independent variable	B	s.e (B)	Wald statistic	Degrees of freedom	Significance
Distance from roost	-0.0002	$6.1*10^{-5}$	15.25	1	0.0001
Maximum distance from building	0.0044	0.0012	12.26	1	0.0005
Slope	-0.3341	0.1104	9.15	1	0.0025
Log (field area)	2.2374	0.7488	8.93	1	0.0028
Constant	-11.337	3.6573	9.61	1	0.0019
N = 234, Goodness of Fit = 267.26, model χ^2 = 79.34, d.f. = 4, p < 0.0001					

For Greylag geese three variables were selected as predictors of field use. The predictors where log (10) of distance to the nearest roost, distance from the furthest point in the field to the nearest building and altitude (Table 3.5). The model had in AUC of 0.823 ± 0.046 ($P < 0.001$). At a 0.5 cut off level classified the presence of geese correctly on 78.3% of occasions, 75.6% f occasions for fields where geese were observed and 81.0% of occasions for fields where geese were not observed.

Table 3.5. Statistics of the logistic regression model for Greylag geese

Independent variable	B	s.e (B)	Wald statistic	Degrees of freedom	Significance
Log (Distance from roost)	-2.5700	0.8068	10.15	1	0.0014
Maximum distance from building	0.0065	0.0021	9.96	1	0.0016
Altitude	-0.0161	0.0064	6.36	1	0.0117
Constant	6.5616	2.6100	6.3203	1	0.0119
N = 87, Goodness of Fit = 82.37, model χ^2 = 30.15, d.f. = 3, p < 0.0001					

3.3.3 Autologistic regression

For Pink footed geese the inclusion of proportion of neighbouring fields occupied by geese and the highest predicted value for a neighbouring field both just significantly improved the ordinary logistic regression model (significance in difference of AUC's, $P = 0.050$ and $P = 0.044$ respectively) (Table 3.6).

Table 3.6. Results of the addition of autologistic terms to the ordinary logistic regression model.

Goose species	**Autologistic term**	**Area under ROC curve**			**Difference from ordinary model**		
		Value	SE	P	z-value	n	P
Pink-footed goose	Proportion of neighbouring field with Pink-footed geese	0.855	0.025	< 0.001	1.955	234	0.050
	Average predicted probability of neighbours	0.837	0.027	< 0.001	0.799	234	0.424
	Max. predicted probability of neighbours	0.856	0.025	< 0.001	2.023	234	0.044
Greylag goose	Proportion of neighbouring field with Greylag geese	0.862	0.039	< 0.001	1.365	86	0.171
	Average predicted probability of neighbours	0.823	0.046	< 0.001	0.128	86	0.987
	Max. predicted probability of neighbours	0.836	0.046	< 0.001	0.426	86	0.667

However, these improvements were only marginal and, given the extra computation involved, the more parsimonious ordinary logistic regression model was considered preferable. For Greylag geese none of the autologistic terms significantly improved the fit of the model(Table 3.4).

3.3.4 Jack-knifing

For Pink-footed geese the jack-knifed results had an AUC of 0.808 ±0.029 ($P < 0.001$) and at a 0.5 cut off level classified the presence of geese correctly on 73.7% of occasions. Comparing the AUC's of the ordinary and jack-knifed model showed no significant difference between the fit of the models (z-value = 1.380, n = 234, P = 0.168). For Greylag geese the jackknifed results had an AUC of 0.803 ± 0.048 ($P < 0.001$) and at a 0.5 cut off level classified the presence of geese correctly on 76.7% of fields. Again comparing the AUC's of the two models shows there is no significant difference in fit between the two (z-value = 1.262, n = 86, P = 0.208). These results suggest that for both species the ordinary logistic model is robust and capable of predicting goose distribution for fields not included in the regression

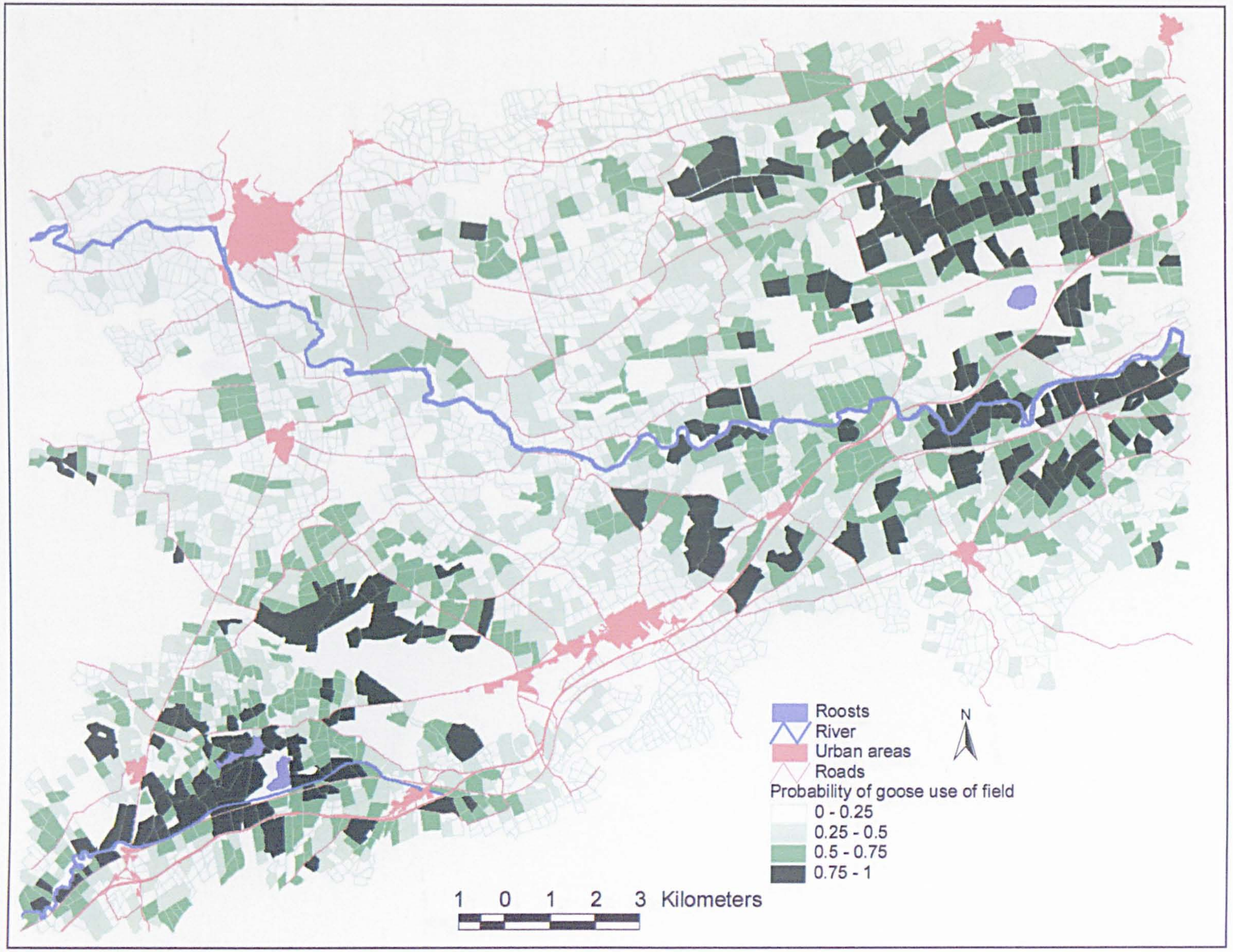

Figure 3.2 The predicted probability of field use by Pink-footed geese.

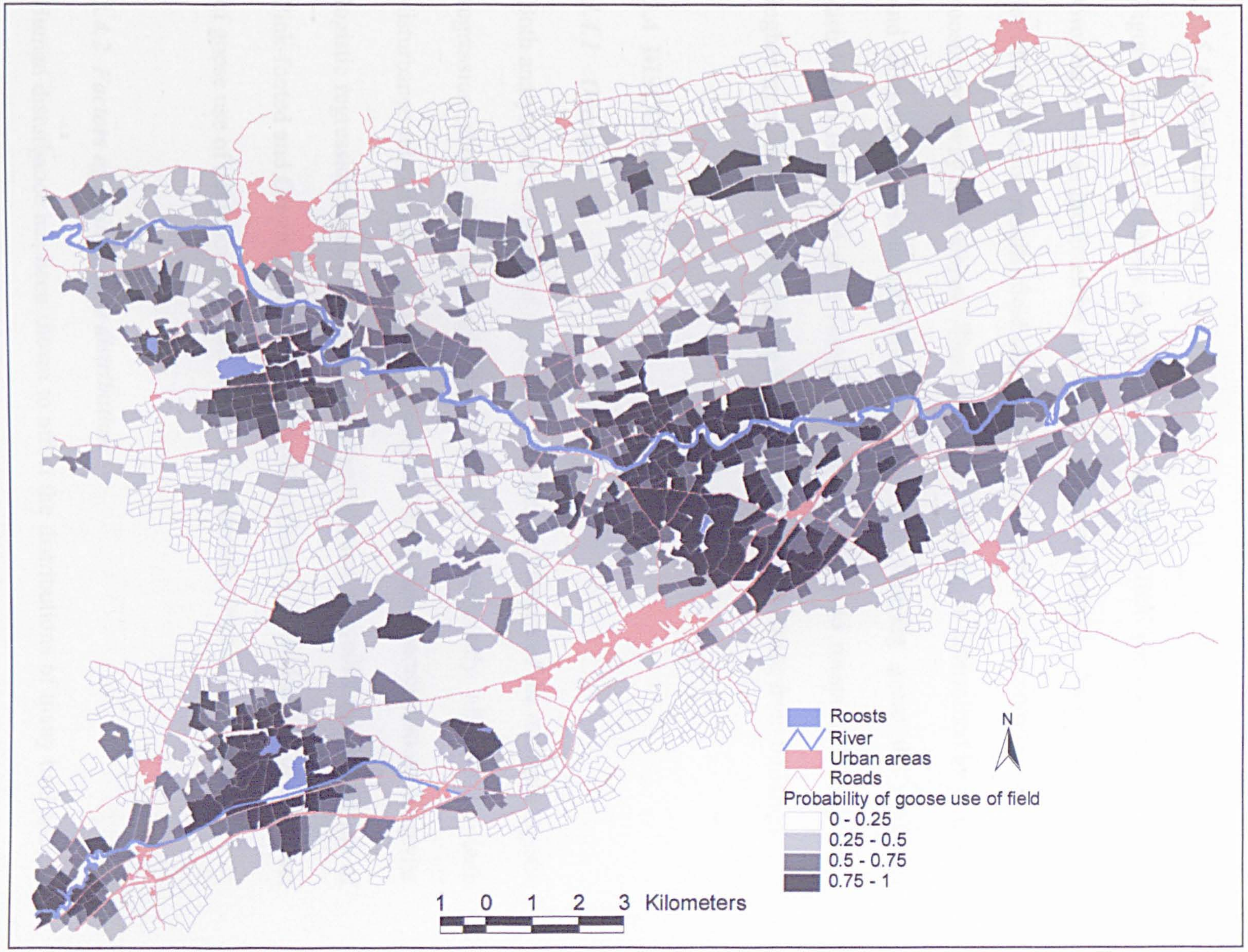

Figure 3.3 The predicted probability of fields use by Greylag geese.

model. It was therefore considered appropriate to extrapolate predicted field use over the whole study area using the ordinary logistic regression model.

3.3.5 Extrapolation

Figures 3.2 and 3.3 shows the probability surface of field use by Pink-footed and Greylag geese as predicted by the logistic regression model. As evident from the logistic regression results, field use by Pink-footed geese is concentrated around the roosts and away from slopes. The finer scale patterning is determined by field size and disturbance associated with buildings. For Greylag geese the predicted distribution is defined on a course scale by proximity to roosts and away from higher areas, finer scale patterning being determined by distance from buildings.

3.4 DISCUSSION

3.4.1 Overview

Both analysis of the effect of individual variables and results of the multiple logistic regression show that field use by geese was significantly affected by both disturbance-related and non disturbance-related landscape characteristics. Stepwise logistic regression successfully used these associations to predict the probability of Pink-footed and Greylag geese using individual fields. Consideration of the effect of goose use of neighbouring fields did not considerably improve predictions.

3.4.2 Factors affecting goose distribution

Human disturbance has been shown to affect the distributions of many bird species (see Hockin *et al.* 1992). The presence of roads has a negative impact on breeding woodland birds, lapwings, godwits and great bustards (Reijnen *et al.* 1995; van der

Zande *et al.* 1980; Osborne *et al* 2001). A number of studies have shown that fields close to roads have suppressed use by Pink-footed geese (Newton & Campbell 1974; Madsen 1984; Keller 1991) and reduced food depletion rates (Gill 1996). This study supported the hypotheses that Pink-footed geese avoided fields closer to roads, although Greylag geese showed less clear relationships. The effect of disturbance associated with buildings on bird distribution has rarely been studied, but the presence of buildings has a highly significant effect on the distribution of great bustards in Spain (Osborne *et al* 2001). The only study exploring the effect of distance to nearest building on goose distribution found no effect on field choice (Gill 1996). However, this study showed distance of field from the nearest building explained more of the variance in the Pink-footed and Greylag goose distributions than distance from the nearest road. In addition, when distance to buildings was included in the logistic regression model for Pink-footed geese the relationship between goose use and distance to the road was not significant. This is a consequence of the positive association between distance to road and distance to nearest building (Pearson correlation = 0.451, $P < 0.001$) and suggests that any effect of roads in this study area was over-ridden by the effect of disturbance associated with buildings. This finding suggests that human presence around buildings causes greater disturbance to Pink-footed and Greylag geese than vehicles, and that more attention should be paid to the effects of buildings when studying bird distributions, especially geese. It has been noted that Greylag geese appear to be more tolerant of human disturbance than Pink-footed geese (Newton *et al.* 1973). This is supported by both field observations and an apparent elevation of the regression line of field use by Greylag geese against distance to the nearest building compared with that for Pink-footed geese (see Figure 3.1).

Field use by Pink-footed and Greylag geese declined as the distance from the roost increased, as previously observed by Bell (1988), Giroux & Patterson (1995) and Keller *et al.* (1995). Although the relationships for Pink-footed and Greylag geese appear to differ with respect to distance from the roost (Figure 3.1), comparison between the two species is made difficult due to the scatter surrounding the fitted lines and the different number of roosts used to calculate distance values for the two species.

Larger fields were used significantly more than smaller fields by Pink-footed geese, but this might be expected as large fields have a greater chance of being used at random. When field size was controlled for statistically, no significant relationship was observed between field size and its use by Pink-footed geese (R^2=0.00, P=0.98) suggesting the relationship between goose use and field area could be a result of increased use due to chance. Depression of Pink-footed goose use, over that expected by chance, has been observed for fields smaller that 6 ha (Newton & Campbell 1974; Gill 1996) possibly due to decreased visibility in smaller fields caused by the field boundaries. In this study only 14% of survey fields were below this size, and therefore suppression of goose use within these fields would be hard to detect.

Many studies have shown seasonal trends by Pink-footed geese in their preference for certain crops (Newton & Campbell 1974; Forshaw 1983; Madsen 1984; Bell

1988; Patterson *et al.* 1989; Gill 1994; Giroux & Patterson 1995; Hearn & Mitchell 1995; Mitchell *et al.* 1995). These seasonal trends were observed in the data for both species (C.D. Urquhart, unpublished data) but when field use over the whole winter was considered the effect of crop type was less noticeable. Pink-footed geese used stubble fields more than expected by chance and pasture and winter cereal less, and Greylag geese showed the same trends (although they were not significant). Unfortunately it was not possible to assess the true quality and quantity of food available in fields using rough crop categories. The effect of crops which covered only a small proportion of the study area such as potatoes, the quality of grass and the amount of spilt grain in stubble fields are likely to affect goose use of a field but were harder to quantify.

3.4.3 Logistic regression model

Logistic regression has often been used to model and predict species distributions (Pereira & Itami 1991; Osborne & Tigar 1992; Buckland & Elston 1993; Manel *et al.* 1999, Cowley *et al* 2000). The predictive models produced for both Pink-footed and Greylag geese highlighted distance from the roost and disturbance from buildings as the two main factors affecting goose feeding distribution, and proved relatively accurate at predicting feeding distribution of Pink-footed and Greylag geese within the study area. There are, however, some limitations to this modelling technique. Knowledge of goose roosts is required, and although data are available for larger roosts, the extent of use of smaller roosts may not be well documented in some areas. This is of particular concern when considering Greylag geese that tend to use smaller roost sites. In addition the model does not take account of the effect of differing numbers of geese at different roosts, again an issue more likely to affect the Greylag goose model due to the larger number of roosts.

Note that crop type is not included in either the Pink-footed or Greylag goose models even though feeding distribution of geese will be influenced by the availability of food. These models therefore indicate the *potential* distribution of geese constrained by the effects of disturbance, flight costs and topography, and highlights were crop damage could occur. Inclusion of the effects of crop type would be possible by combining a probability surface related solely to crop type with the above models using Bayesian statistics (see Pereira & Itami 1991). Such a model is likely to give a more accurate representation of the exact fields used by geese at one particular time, but is unlikely to influence the larger scale pattern. Furthermore, for goose management strategies that involve the creation of alternative feeding areas, knowledge of the potential distribution is more important than the precise field use in any one season.

3.5 SUMMARY

The presence of Pink-footed and Greylag geese in fields was successfully predicted in Strathearn and Strathallan using field characteristics. The main factors affecting distribution of both species were distance from the roost (a cost reduction mechanism) and distance from the nearest building (a disturbance reduction mechanism). Inclusion of autologistic terms did not improve the models notably. The data required for predicting the probability of goose presence within fields may be derived relatively simply from available digitised maps, with no need for survey work, and is therefore relatively easily applied to other areas.

CHAPTER 4 – DAILY MOVEMENTS OF GREYLAG GEESE

4.1 INTRODUCTION

4.1.1 Background

Information on the daily movements of Pink-footed geese has been used to assess how geese use their feeding grounds, and therefore how alternative feeding areas (AFA's) should be arranged (Giroux & Patterson 1995). There is no such information published for Greylag geese and it is often assumed that they have similar requirements to Pink-footed geese (e.g. Vickery & Gill 1999), however this may not be the case. This chapter compares the daily movements of Greylag geese with published data on Pink-footed geese (Giroux & Patterson 1995) to highlight differences between the two species, as any differences will have implications for potential management plans for Greylag geese.

A relatively large number of studies have looked at habitat use by feeding Pink-footed geese from survey work (Newton & Campbell 1973, Newton *et al* 1973, Forshaw 1983, Bell 1988, Gill 1994, Giroux & Patterson 1995, Hearn & Mitchell 1995, Keller *et al* 1997, Mitchell *et al* 1995). Field attributes such as crop type (Newton & Campbell 1973, Forshaw 1983, Madsen 1984, Bell 1988, Patterson *et al* 1989, Gill 1994, Giroux & Patterson 1995, Hearn & Mitchell 1995, Mitchell *et al* 1995) and disturbance (Newton & Campbell 1973, Newton *et al* 1973, Keller 1991, Gill 1994, Giroux & Patterson 1995, Madsen 1995) have been shown to affect field use by Pink-footed geese (see Chapter 2). In addition, radio-tracking of Pink-footed geese has provided information on the pattern of field use of individual geese (Keller *et al* 1997), length of stay in the feeding area (Giroux & Patterson 1995), roost fidelity (Giroux 1991) and the size and frequency of movements made (Giroux & Patterson 1995, Keller *et al* 1997).

In contrast relatively little attention has been focused on the feeding behaviour of Icelandic Greylag geese. Several studies have looked at the feeding distribution of Greylag geese in Scotland (Newton & Campbell 1973, Newton *et al* 1973, Bell 1988, Patterson *et al* 1989). These studies showed that Greylag geese differed slightly from Pink-footed geese in their preferred use of crops (Newton & Campbell 1983, Patterson *et al* 1989). They are also less affected by disturbance, being less demanding regarding field size (Newton *et al* 1973, Madsen 1985a) and less affected by disturbance from roads (Newton & Campbell 1973). Icelandic Greylag geese have never been radio-tracked and therefore the only information on their movements is from sightings of collared individuals, on which no research has yet been published.

In this study Greylag geese were radio-tracked primarily to investigate how landscape characteristics affect goose movements so that realistic rules could be incorporated into a simulation model (see Chapter 5). The aim of this chapter is to compare the daily movements of wintering Greylag geese and Pink-footed geese. There are no published recommendations for implementing management plans specifically for Greylag geese, such as AFA's, therefore any differences between the two species will have implications for Greylag goose management. The radio-tracking data from Greylag geese was used to calculate statistics of goose movement for comparison with published data on the movements of Pink-footed geese. Giroux and Patterson (1995) published a comprehensive study of daily movements and habitat use of radio-tracked Pink-footed geese in northeast Scotland, which has been used as the main source of data for comparison with the results in this chapter. The study area used by Giroux and Patterson (1995) was around Newburgh, Grampian, and covered 340km^2, slightly less than the 420km^2 area used in this study, and held an average overwintering population of 6,000 – 8,000 Pink-footed geese.

4.2.1 Aims

The aims of this chapter are

(i) To obtain data on Greylag goose movements from radio-tracked geese that is representative of the whole population.

(ii) To quantify the daily movements of Greylag geese in a range of summary statistics.

(iii) To assess the similarities and differences between the daily movements of Pink-footed and Greylag geese by comparing results to published data on Pink-footed geese.

4.3 METHODS

4.2.1 Radio-transmitter attachment

Twenty-three Greylag geese were fitted with radio transmitters during four catches during the winters of 1997/98, 1998/99 and 1999/2000. Catches were spread through the winter, with two catches in November and February, at two locations in the study area. Geese were caught using cannon netting and fitted with BTO metal rings and Darvic neck collars to enable the field identification of individual geese.

The radio-transmitters (TW-3 twin cell tags, BIOTRACK Ltd.) had a mean weight of 46.5g, approximately 1.25% of the body weight of the tagged birds at the time of catching, and had batteries that lasted approximately two and a half years. Transmitters were attached to the backs of the geese using an elastic harness that fitted behind the wings and in front of the legs, with the transmitter temporarily secured onto the down and feathers using superglue. This method of transmitter attachment has proved successful on Greenland White-fronted geese (*A. albifrons flavirostris*) (Glahder *et al* 1996, Glahder *et al* 1997). Alternative methods of transmitter attachment were not considered appropriate. Gluing radio-transmitters onto the backs of Pink-footed geese proved only partially successful with transmitters becoming detached after a mean period of 23 days (Hearn & Mitchell 1995). While the attachment of radio-transmitters onto the tail feathers of Pink-footed geese proved successful (Giroux *et al* 1990) this was considered inappropriate for Greylag geese as their strong beak could remove the tail feathers onto which the transmitter was attached.

Greylag geese feed in family groups consisting of a pair of adult birds and their young from the previous summer. If two members of the same family group were tagged then similar, if not identical, movement data would be obtained from each bird. To prevent this pseudo-replication, only adult male geese had radio-transmitters fitted. This ensured that only one goose from each family unit could be radio-tracked.

4.2.2 Radio-tracking methodology

Radio-tagged geese were given a period of 5-7 days to become accustomed to the radio-transmitters before data collection commenced. During the winters of 1997-98 and 1998-99, individual tagged geese were tracked continuously for half-day periods, either from dawn to mid-day, or mid-day to dusk, using a Telonics TR-4 receiver and three element flexible yagi antenna. The location of the goose was recorded with the flock size, crop type, duration of stay in the field and reason for leaving (i.e. cause of disturbance if scared). Greylag geese in the study area were often observed to return to the same fields in subsequent days. Therefore to reduce the repetition and dependence between recorded goose movements for individual geese, radio-tracking periods were spaced as far apart as possible, separated by at least three days.

Giroux and Patterson (1995) radio-tracked Pink-footed geese for whole days. However the strategy of radio-tracking Greylag geese for half day periods was considered more appropriate for the requirements of this study as it enabled more frequent radio-tracking of each individual goose, and consequently the collection of more independent data. Extrapolation of the number of movements made, or the distance flown in one day, from data obtained for a half day period was considered to be entirely appropriate. If the daily movements of geese do not follow a set pattern, as suggested by the data, then the number of movements / distance flown in a given time will be proportional to the amount time period. Even differences in movements of geese between the morning and afternoon will not affect the results, as individual geese were radio-tracked for mornings and afternoons alternatively, therefore calculations are based on observations from throughout the day. As discussed later, calculation of the amount of time geese spend in fields will be underestimated if observation periods are less that a full day. Consequently, analysis of the length of time geese spent in each field was not performed.

During the winter of 1999-2000 the methodology was altered to maximise the number of goose movements recorded. All radio-tagged geese were located at the roosts and then at approximately 2-3 hour periods throughout the day. As Greylag geese make few movements between fields during the day, it was considered appropriate to assume that the goose had flown directly between fields if the goose had moved. As a result no data were collected on the time geese spent in the fields or on the cause of leaving in this season. The data from this season was excluded from some analysis, as detailed in the methodology. For all years, radio-tracking continued until the goose left the study area. As in previous winters, subsequent days of radio tracking of an individual goose were separated by at least three days.

4.2.3 Analysis of goose movements

If there is correlation between sequential locations or variation in the behaviour of individuals, the use of radio-locations as opposed to individual animals as sample units in analyses of radio-tracking data, will result in non independence and inflation of the number of degrees of freedom (Aebischer *et al* 1993). In this chapter measures of the daily movements of Greylag geese have been calculated for comparison with published literature, and therefore the radio-locations or movements of geese have been used as sample points. As discussed in Chapter 5 the dangers of taking this approach may not be as significant for the radio-tracking data of Greylag geese as with some other radio-tracking data. In addition

ANOVA's were performed on some statistics to assess whether there was variation between individuals.

The distance flown by an individual was calculated as the straight-line distance between the point of take-off and the point of landing. The total distance travelled by the individual during this period was calculated by summing the distance of all movements made by an individual during one observation period. However, for comparison with data obtained for Pink-footed geese (Giroux & Patterson 1995) the total distance travelled per day was required. As geese were not tracked for whole days it was necessary to estimate the total distance travelled per day and the distance travelled on the feeding area per day. The distance travelled on the feeding area by each goose for each day observed was calculated using the following equation:

$$\text{Dist. travel (feeding area)} = \Sigma(\text{Dist. non roost moves}) * \text{N (hours)} / \text{No (hours obs.)}$$

Where N (hours) is the number of hours of feeding time in the day and N (hours obs.) is the number of hours the individual was tracked. As the amount of feeding time varies through the season, the amount of feeding time was calculated from the 15th October to the 1st April. Radio-tracking data was used to calculate the mean time the geese left the roost from sunrise, and the mean time from sunset they returned. The amount of feeding time per day was calculated by adding or subtracting these means from sunrise and sunset times and from this the number of hours of feeding time for each day were calculated. A polynomial line was fitted to the data on the number of hours of feeding time through the season (see Figure 4.1).

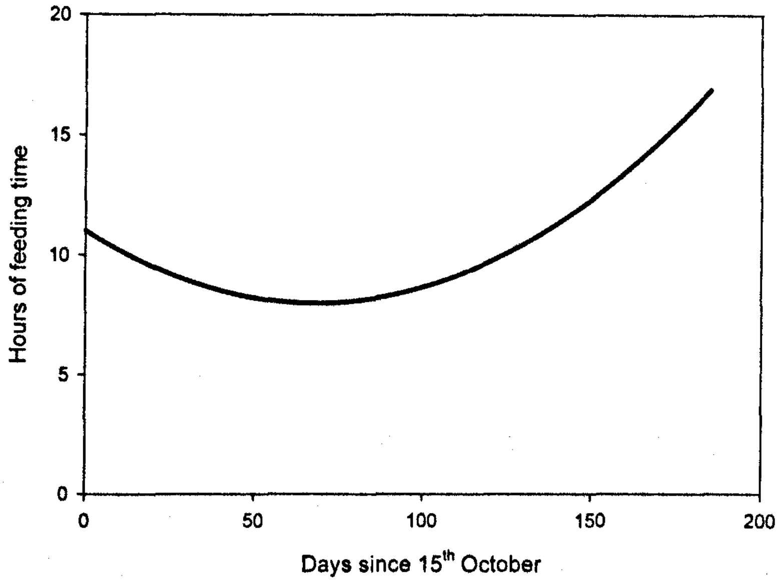

Figure 4.1 The variation in the number of hours of feeding time for geese throughout the winter.

This equation was used to calculate N (hours) for each day radio-tracking data were collected. The distance travelled on the feeding ground was only calculated for days when geese were tracked continuously (i.e. during the winters of 1997/8 and 1998/9) as movements may have been missed during the final season (1999/2000) when geese locations were recorded only every two to three hours. The total distance travelled by each goose for each day observed was calculated using the following equation:

$$\text{Total Dist.} = (\text{roost move} * 2) + (\Sigma(\text{non roost moves}) * N\ (\text{hours}) / No\ (\text{hours obs.}))$$

The total distance travelled could only be calculated for days where goose movements either to or from the roost were recorded and was only calculated for days when geese were tracked continuously (i.e. during the winters of 1997/8 and 1998/9).

The maximum distance that radio-tracked geese fed from their roost site was calculated for the observation period only as it was not possible to estimate the maximum distance from the roost reached over the whole day from the data available. The maximum distance at which the goose was observed from the roost could be less than the maximum distance reached over the whole day resulting in an underestimation in the mean result, an important consideration when comparing the results with those of Pink-footed geese.

The number of non-roost moves per day was estimated for each day that a goose was radio-tracked using the following equation. Again only days where geese were continually radio-tracked were included in the analysis as movements could have been missed during the final field season.

Number moves per day = N (moves obs.) * N (hours in day) / N (hours obs.)

Where N (moves obs.) is the number of moves observed during the observation period, N (hours in day) is the number of hours of feeding time in the day and N (hours obs.) is the number of hours that the goose was observed. In addition, the number of take-offs per hour of radio-tracking and the average distance per move were calculated.

The mean and median size of the flocks with which radio-tracked geese fed were calculated. The effect of crop type on the size of goose flocks and the density of geese was assessed by testing the difference in flock size between the four main crop types used (autumn sown cereal, grass, potatoes and cereal stubbles) using the Kruskal-Wallis one-way ANOVA.

The frequency of goose movements resulting from disturbance and the causes of disturbance were noted. The effect of the cause of movement (i.e. caused by disturbance or not) on the length of the subsequent move was tested with a Mann-Whitney U test.

The mean and median distance at which geese fed from their roosting site the previous night was calculated from all goose locations recorded where the roost used was known. In addition the mean and median distance of feeding geese from the nearest roost was calculated. The use of roosts in the study area was investigated, although it was not possible to assess the roost fidelity of Greylag geese in this area as roosting locations were not recorded frequently enough.

Although carried out by Giroux and Patterson (1995) no analysis was performed on goose use of crops in proportion to their availability as data on the crops over the whole study area was not available. Defining an area considered available for the geese could prove problematic and could affect the calculated proportion of each crop available as crops are not randomly distributed. A potentially better technique for assessing the preference of geese for certain crops is to compare the crop type of fields flown over and not landed in with those where geese choose to land. This was the technique used in Chapter 5 for assessing the effect of other landscape variables on the chance of a goose landing. It was not possible to perform analyses on the duration of stay of geese in fields. As geese were not tracked for whole day periods, shorter stay lengths were more likely to be recorded than longer stay lengths, therefore resulting in an underestimate of the length of time geese feed in a field. An alternative approach was used in Chapter 5, which investigated the probability of geese leaving in each half-hour after landing, a result not comparable with any published Pink-footed goose data.

4.4 RESULTS

4.3.1 Results of radio-tracking

Over the three year period, 23 Greylag geese had transmitters fitted and 20 of these were successfully radio-tracked before leaving the study area. The three other geese left the study area during the settling in period after capture before radio-tracking began. During first two seasons 12 individual Greylag geese were radio-tracked for a total of 57 half-days (241 hours) while they remained in the study area. During the final season eight geese were tracked for 70 half-days, a total of 386.3 hours. During this time 244 locations and 227 goose movements were recorded. Figure 4.2 shows the roosts and fields used and movements recorded from the radio-tracked Greylag geese. For comparison Giroux & Patterson (1995) radio-tracked 10 Pink-footed geese for a total of 47 continuous days, giving 498 hours plus an additional 275 hours of observations.

Individual geese remained in the study area between 0 and 123 days after being caught, with a mean stay length of 29.2 days (± 6.7). Although the range is similar to that found with Pink-footed geese in north-east Scotland, the mean length of stay of Greylag geese in this study is 45% less than the 53 days (± 13) found for Pink-footed geese in northeast Scotland (Giroux & Patterson 1995).

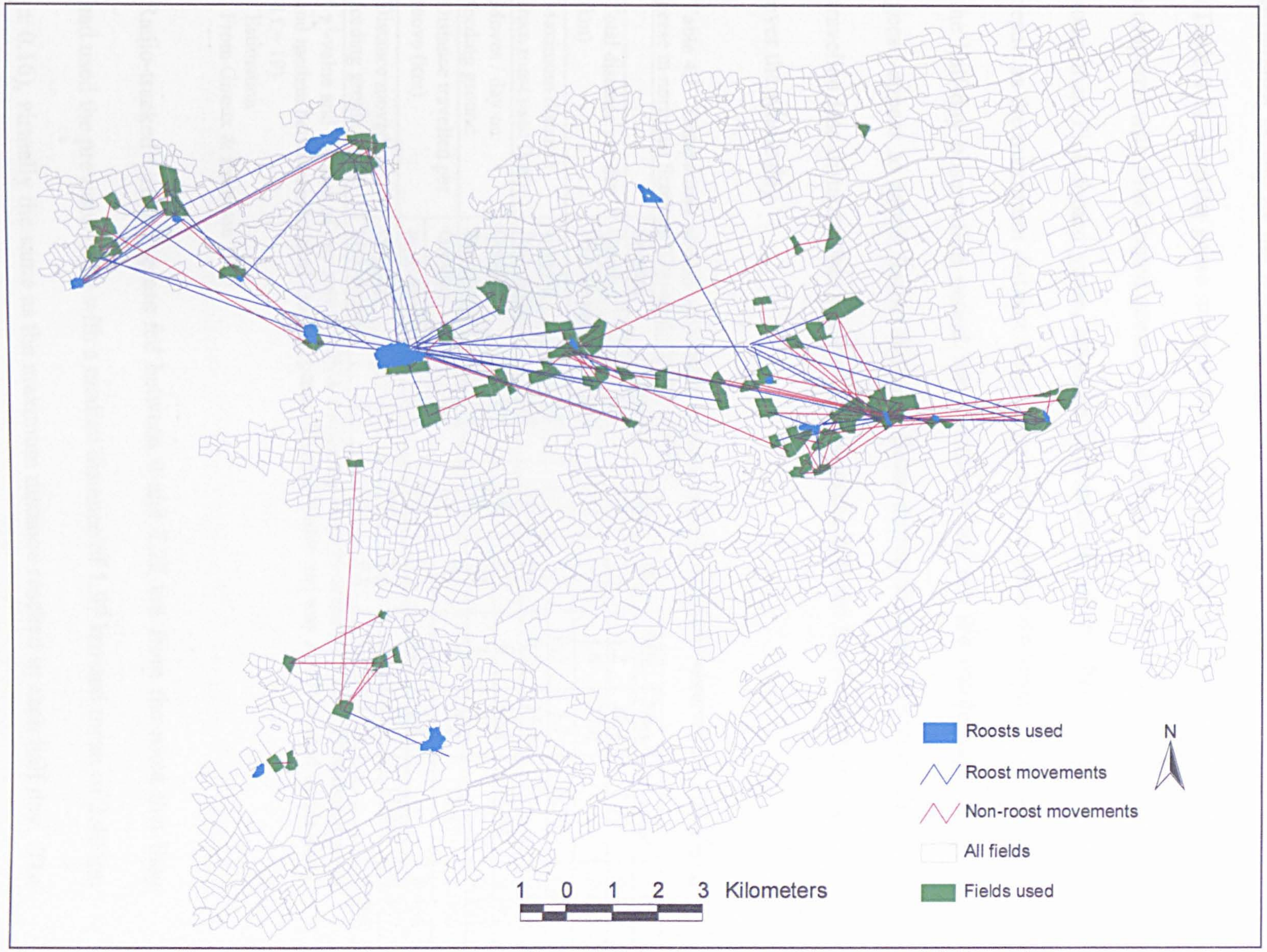

Figure 4.2 A map showing the observed movements of radio-tracked Greylag geese, and the roosts and fields used.

4.3.2 Daily movements

A Kruskal-Wallis one way ANOVA showed that there was no significant difference in any of the measures of daily movements between individual geese (Table 4.1). Greylag geese made around half the number of moves during the day compared with Pink-footed geese. Greylag geese also fed around 50% closer to the roost than Pink-footed geese, although care must be taken when interpreting this result as the maximum distance Greylag geese were observed from the roost during the half-day observation period was calculated and not the whole day. Greylag geese appear to move further between fields during the day, however, they still travelled less distance than the Pink-footed geese both on the feeding grounds and over the whole day.

Table 4.1. Comparison of daily movements of Greylag geese with those observed for Pink-footed geese in northeast Scotland (Giroux & Patterson 1995).

	Species	Median	Mean	SE	Min	Max	χ^2-value	P[1]
Total distance per day (km)	Greylag [2]	8.3	8.3	1.0	1.2	23.4	7.90	0.543
	Pink-footed [3]	10.6	11.7	0.9	1.6	27.0	-	0.053
Maximum distance from roost used (km)	Greylag	2.0	2.5	0.3	0.3	5.7	8.50	0.291
	Pink-footed [3]	4.8	4.8	0.4	0.5	11.4	-	0.004
Moves / day on feeding ground	Greylag [2]	2.9	3.6	0.5	0	13.4	12.69	0.392
	Pink-footed [3]	7.0	7.3	0.5	1	17	-	0.362
Distance travelled per move (km)	Greylag	0.7	1.3	0.1	0	7.2	18.47	0.066
	Pink-footed [3]	0.8	0.8	0.1	0.2	3.1	-	0.466
Distance moved on feeding ground (km)	Greylag [2]	2.4	4.4	0.7	0	16.3	11.86	0.457
	Pink-footed [3]	5.3	5.6	0.5	0.7	17.3	-	0.068

[1] χ^2-value and P-value of one way AVOVA comparing mean between individual Pink-footed geese and median between individual Greylag geese (Kruskal-Wallis one way ANOVA used in this study, d.f.= 19)

[2] Estimation

[3] From Giroux & Patterson 1995

Radio-tracked Greylag geese fed between 0 and 7.22 km from the roost that they had used the previous night with a median distance of 1.97 km and mean of 2.40 km (± 0.16), virtually the same as the maximum distance reached in each half day. The median distance of flights to and from the roosts was 1.62 km with values ranging from 0 to 7.11 km, a mean of 2.37 km (± 0.18). As they often fed close to roosts that they had not used the previous night, however (see Figure 4.1), feeding Greylag geese never fed more than 3.32 km from the nearest roost used by any radio-tracked goose, with a median distance of 0.57 km and a mean of 0.72 km (± 0.04). The number of movements per hour for Greylag geese during the winters of 1997/8 and 1998/9 when geese were continually radio-tracked was 0.373 compared with 0.750 movements per hour observed for Pink-footed geese (Giroux & Patterson 1995).

4.3.3 Flock size

The size of flocks with which radio-tracked Greylag geese fed ranged from 5 to 2,140 with a mean of 468 (± 35) and a median of 290. Radio-tracked Pink-footed geese in northeast Scotland fed in much larger flocks with a mean size of 2,026 geese (Giroux & Patterson). Both species feed in significantly different sized flocks on different crops (see Table 4.2). In both species radio-tracked geese fed in larger flocks in stubble and potato fields than on grasslands. For Greylag geese, however, there was no significant difference in flock size between flocks feeding on stubble, potatoes and winter cereal (Kruskal-Wallis one-way ANOVA χ^2-value = 0.357, d.f. = 2, $p = 0.837$) while Pink-footed geese fed in significantly smaller flocks in cereal fields than in grassland, potato and stubble fields (Giroux & Patterson 1995). Moreover when the density of Greylag geese (flock size / area of field) was considered there was no significant difference in density of geese between different crop types. This suggests that the difference in flock size observed for Greylag geese is largely due to the relationship between field size and crop type (Kruskal-Wallis one-way ANOVA χ^2-value = 41.13, d.f. = 3, $p < 0.001$).

Table 4.2. The mean flock size ± SE (mean) for Pink-footed and Greylag geese in different crop types.

Species	**Grassland**	**Stubble**	**Potatoes**	**Cereals**
Greylag geese [1]	297 ± 32	671 ± 97	586 ± 81	528 ± 71
Pink-footed geese [2]	3322 ± 244	4363 ± 254		2031 ± 20

[1] Significant difference between crop types (Kruskal-Wallis one-way ANOVA χ^2-value =17.61, d.f =3, p = 0.001)

[2] Giroux & Patterson (1995) data for period 21 Dec – 29 Feb. Significant difference between crops (Student-Newman-Keuls test $p < 0.05$)

4.3.4 Causes of disturbance

For 106 take-offs during the winters of 1997/98 and 1998/99 it was possible to assess whether geese moved field as a result of disturbance. Forty-eight percent of these movements were caused by disturbance, although the cause of the disturbance was only ascertained in 26 (51%) of these cases. This is not significantly different from the 52% (n=335) of movements caused by disturbance for Pink-footed geese derived from Giroux and Patterson (1995) (χ^2-value = 0.472, d.f = 1, p = 0.492). Table 4.3 shows the causes of disturbance observed for both Greylag geese and Pink-footed geese (from Giroux & Patterson 1995). Excluding disturbance caused by the observer there is no significant difference in the causes of disturbance for the two species, with motorised vehicles and farming activity causing most disturbance to both species of goose (χ^2-value = 1.91, d.f = 4, p = 0.753). The effect of observer (field worker) on the geese could not be compared between species, as the number of disturbances caused by the observer will be dependent on the behaviour of the observer, which could have differed between studies.

Table 4.3. Sources of disturbance to Greylag geese and Pink-footed geese. * From Giroux & Patterson (1995). Chi-squared test of difference in causes of disturbance between two species (excluding unidentified disturbance and disturbance due to observer) χ^2-value = 1.91, d.f. = 4, p = 0.753.

Cause of Scaring	Number of times observed	
	Greylag geese	**Pink-footed geese***
Observer	0	10
Unidentified	25	34
Motorised vehicles and farming activity	10	25
Air traffic (airplanes and helicopters)	6	7
Human activity (horse-riding, bird watching, pheasant shooting, dog walking)	4	9
Deliberate scaring by farmers	4	12
Others (sheep, other birds)	2	3

Greylag geese showed no significant difference in the proportion of moves resulting from disturbance for different crop types (χ^2-value = 0.782, d.f. = 3, p = 0.676). Although Pink-footed geese in stubble and potato fields made significantly more take-offs due to disturbance than geese in other fields, significantly fewer of these take-offs resulted in movement between fields. Consequently the Greylag goose results cannot be directly compared with the results for Pink-footed geese as the overall effect of crop type on the number of movements caused by disturbance is not apparent from the published data (Giroux & Patterson 1995).

4.3.5 Use of roost sites

Radio-tracked Greylag geese were located at their roost site on 104 occasions. On 31 occasions (29.8% of records) the geese were roosting at the main roost in the study area, Drummond Pond. Radio-tracked geese used 15 other roost sites on between one and nine occasions. Five of these sites were temporary floodwaters along the River Earn, while the other 10 sites were permanent water bodies. There were 22 bodies of water over $4000m^2$ in the study area. Radio-tracked Greylag geese used eight of these. Much smaller water bodies, however, were also used as roost sites and sites as small as $700m^2$ and $1300m^2$ were used on eight and nine occasions respectively. These small roosting sites were often shooting ponds where potatoes or grain were put out to encourage wildfowl.

Radio-tracked Greylag geese were recorded using a mean of 2.9 (± 0.6) different roosts while in the study area. As geese were only located at roosts *c.*19% of the time (mean = 5.5 (± 1.2) roost locations recorded per goose) this result is likely to be a gross underestimation of the number of roosts used by individual geese while in the study area. The roost locations recorded for each goose were separated by a minimum of three days and therefore it was not possible to estimate the time an individual remained at one roost before moving. Giroux (1991), from 500 recorded roost locations, found Pink-footed geese changed roost approximately every 10 days and used a mean of 3.4 roost sites while remaining in the study area. Although the Greylag goose results suffer from limited data they suggest that even though Greylag geese spent on average 45% less time in the study area than Pink-footed geese, they use a larger number of roosts.

4.5 DISCUSSION

4.4.1 Overview

Radio-tracking of Greylag geese proved successful, data being collected from 20 individuals. The results show that Greylag geese differed from Pink-footed geese in the way they use the feeding grounds. Comparison with Pink-footed geese showed that Greylag geese used a larger number of roost sites and appeared to move roost more frequently. Greylag geese, however, fed much closer to the roost and moved much less frequently during the course of the day than Pink-footed geese. These findings have implications for Greylag goose management.

4.4.2 Success of radio-tracking

Using radio-tagged birds to sample movements of the population assumes that radio-transmitter attachment does not affect animals or that negative effects are not important (Murray & Fuller 2000). Assessment of the effect of using a harness to attach transmitters on geese has suggested that productivity, survival (Ward & Flint 1995) and flight performance (Obrecht *et al* 1988) may be affected, although any effect will be dependent on the technique of harness fitting used. The method of harness attachment used in this study proved successful for Greenland White-fronted geese (*A. albifrons flavirostris*), and no effect of the transmitter on behaviour was apparent during studies on their wintering grounds (Glahder *et al* 1996). The attachment of radio-transmitters appeared successful in this study. Although not formally assessed, radio-tagged geese fed in flocks with other geese and appeared to behave normally while in the study area. Sightings of the majority of radio-tagged geese, both in the winter they were caught and in subsequent winters, at other feeding sites showed that the geese were able to move around the country and survive to the next year. No transmitters detached while the geese remained in the study area. In addition one individual caught in the winter of 1998-99 returned to the study area for several days the following winter, with its radio-transmitter still transmitting, having presumably spent the breeding season in Iceland.

4.4.2 Comparison of daily movements of Greylag and Pink-footed geese

Results of daily movements of radio-tracked Pink-footed geese in northeast Scotland by Giroux and Patterson (1995) provides data that is comparable with data collected from Greylag geese in this study. There were some differences between the data for the two species. In this study it was necessary to estimate distance moved by geese per day and number of moves made per day from the results of half days of radio-tracking. In addition the Greylag goose data was based on a larger sample size of geese but with fewer data from each individual. Comparison is further complicated as the two data sets were collected in different years and in different places. Overall, however, similar data collection techniques, sample sizes and size of study areas made the comparison of movements of the two species possible. Analysing data using data points or daily summaries as opposed to individual animals as data points allowed comparison with published data and although not ideal (see Chapter 5), is unlikely to affect the results significantly. There was no significant difference in the various measures of goose movements between individuals. In addition there is likely to be little correlation between measures of goose movements for an individual in subsequent radio-tracking periods as days of radio-tracking were separated by at least 3 days. As a result the analysis is likely to be a good assessment of the differences in movement between the two species of geese.

Pink-footed geese roost in large numbers at relatively few roost sites (Hearn 2000), and smaller roost sites within their feeding ranges are only used occasionally (Bell *et al* 1997). Pink-footed geese in northeast Scotland have been shown to feed a median distance of 4.0 – 4.3km from the nearest roost (Bell 1988, Keller *et al*

1997). These figures fit well with the median maximum distance of 4.8km from the roost recorded from radio-tracked Pink-footed geese (Giroux & Patterson 1995). Pink-footed geese feed in distinct core feeding areas that are consistent between years (Keller *et al* 1997). Radio-tracking data has shown that while individual geese are not confined to particular feeding areas, within the course of one day goose use is restricted to a few fields close together, with geese rarely moving between core feeding areas (Giroux & Patterson 1995, Keller *et al* 1997).

Greylag geese were recorded at 20% more roost sites than Pink-footed geese throughout Britain in the 1999 National grey goose counts (82 compared with 65 for Pink-footed geese) even though the total wintering population of Pink-footed geese is almost three times that of Greylag geese (Hearn 2000). These figures underestimate the extent of the difference between the two species in their use of roosts. Greylag geese are more likely to be concentrated at major roosts in the autumn, when counts are made, than later in the winter (Bell *et al* 1997) and smaller roost sites are less likely to be counted. Bell *et al* (1997) found that while 90-93% of Pink-footed geese in Strathearn and Strathallan roosted at the major roosts through the winter only 30-54% of Greylag geese did so. Data from radio-tracked Greylag geese agreed with these findings with only 31% of radio-tracked geese using the major roost sites, with an additional 14 sites being used. Greylag geese therefore use a greater number of roost sites than Pink-footed geese and as a consequence there will tend to be smaller numbers of geese using individual roosts. Radio-tracked Greylag geese fed approximately 2km from the roost site compared with *c.*5km for Pink-footed geese (Giroux & Patterson 1995).

Greylag geese are less affected by disturbance and are less likely to avoid smaller fields than Pink-footed geese (Pink-footed geese avoid smaller fields as their visibility is restricted) (Newton *et al* 1973, Madsen 1985a) and less affected by disturbance from roads than Pink-footed geese (Newton & Campbell 1973). Levels of disturbance also have a significant effect on the choice of roost sites for geese (Newton *et al* 1973). If Pink-footed geese were more susceptible to disturbance than Greylag geese at the roost as well as while feeding in the field, this is likely to be the cause of Greylag geese using a wider range of roost sites.

The observed difference in the distance at which the two species fed from the roost is likely to be influenced by differences in the response of the two species to disturbance. The larger numbers of Pink-footed geese using each roost site, compared to Greylag geese, will result in faster depletion of food resources in suitable fields close to the roost and therefore the need for geese to fly further to obtain enough food. This is supported by Gill's findings (1994) that the order of use of fields by Pink-footed geese was significantly related to the distance from the roost. If Pink-footed geese were more conservative in their selection of fields than Greylag geese, as a result of disturbance, then there would be less fields suitable for them to feed in. With fewer suitable fields available, Pink-footed geese would deplete resources in suitable fields close to the roost more quickly, further accentuating the difference between the two species.

On the feeding grounds Greylag geese, like Pink-footed geese, often make short moves between fields during the day with median move lengths of 0.7 and 0.8km respectively. They therefore feed in a relatively restricted area over the period of a day. Pink-footed geese fed *c.*4km from the nearest roost site (Bell 1988, Keller *et al* 1997) similar to the distance flown by the geese (Giroux & Patterson 1995). In contrast Greylag geese fed a median distance of just 0.6km from the nearest roost, although *c.*2km from the roost they had used. Feeding areas for Greylag geese are therefore situated very close to roost sites, but geese do not necessarily feed in the closest feeding area, possibly due to local disturbance or depletion of food. The frequency of movements within and between feeding areas was not calculated for Greylag geese, as distinct feeding areas were not defined. Figure 4.1, however, shows large numbers of movements between the feeding areas during the day as well as when geese are flying from the roost. It is possible that the slightly greater mean distance moved by Greylag geese (1.3km compared with the 0.8km found by Giroux and Patterson (1995) and 1.1km found by Keller *et al* (1997) for Pink-footed geese) is a result of Greylag geese making more movements between feeding areas during the day compared with Pink-footed geese. As movement between feeding areas for Greylag geese is likely to result in geese feeding close to roosts that they had not used the previous night, regular changes in roost site would be expected and were observed. It is unclear whether the feeding areas used by Greylag geese in Strathearn and Strathallan were selected by geese because they were close to roosts or whether the roost sites were selected because they were close to good feeding areas. Keller *et al* (1997) noted that Pink-footed geese were very mobile, with large seasonal ranges and a high turnover of geese. Greylag geese do not travel as far as Pink-footed geese during the course of an average day, make fewer moves during the day and feed closer to the roost. On a larger scale, however, Greylag geese appear to be more mobile than Pink-footed geese, both changing roosts within the study area and moving out of the study area more frequently than Pink-footed geese.

In conclusion Greylag geese differ from Pink-footed geese in their use of the feeding grounds. Pink-footed geese roost at major roosts in very large numbers. This is likely to result in depletion of food resources in fields close to the roost so geese have to fly further to obtain enough food. In contrast Greylag geese were found to use a greater number of roost sites. Smaller numbers of geese are unlikely to deplete food resources as quickly and therefore feeding areas were generally situated very close to the roosts. Greylag geese are very mobile and move readily between roosts and feeding patches, possibly in response to local depletion or disturbance. This strategy results in Greylag geese flying shorter distances during the day than Pink-footed geese, but possibly at the expense of increasing predation risk (i.e. shooting) or decreasing energy intake.

As a results of their work on Pink-footed geese, Giroux and Patterson (1995) recommended that creating a number of small areas managed for geese (*c.*1 km^2), scattered through the feeding range, was likely to be a better approach to reducing goose damage than the establishment of a single large reserve. There is no evidence to suggest that the size of management units for Greylag geese should differ from those recommended for Pink-footed geese. Both species made daytime movements of about the same distance, and Pink-footed geese made considerably more movements during the course of a day than Greylag geese, therefore Greylag geese are unlikely to use a larger area during the course of one day than Pink-footed geese. However the results of this chapter do suggest that for Greylag geese AFA's should be situated very close to goose roosts, as opposed to being scattered throughout the feeding area. As Greylag geese use a large number of minor roosts, the knowledge of where these are located is necessary for AFA's to be positioned correctly.

4.5 SUMMARY

Radio-transmitters were attached to 23 Greylag geese, 20 of which were radio-tracked successfully. Data from these geese suggested that Greylag geese differ from Pink-footed geese as they use a larger number of roost sites, and possibly change roost site more frequently. In addition they feed much closer to roost sites, although not necessarily the roost site which they used, and make fewer movements during the day. These results have implications for potential management schemes aimed at reducing damage caused to crops by geese.

CHAPTER 5 – PREDICTING GREYLAG GOOSE DISTRIBUTION BY MODELLING GOOSE MOVEMENT

5.1 INTRODUCTION

5.1.1 Why model movement?

Wildlife-habitat models are often used to predict distributions of animals by defining suitable habitat from landscape characteristics (e.g. Pereira & Itami 1991, Osborne & Tigar 1992, Buckland & Elston 1993, Manel *et al* 1999, Cowley *et al* 2000). While such models can predict the suitability of the habitat for an animal, difficulties may occur when predicting the distribution of animals dispersing from a fixed point. This is because areas close to the point of dispersal will be encountered more often and are therefore more likely to be occupied. Simple distance measurements (e.g. distance from the point of dispersal) can be incorporated into regression models as a proxy for encounter rate (e.g. Chapter 3). The movement paths of individual animals are important in determining the animal's ability to utilise resources (Smith 1974, Jones 1977). Therefore if an animal's path is influenced by spatial heterogeneity, the availability and, consequently the use, of resources will be affected (Johnson *et al* 1992). In situations where time for dispersal is limited and animal movement is affected by a heterogeneous landscape (and therefore encounter rate of patches is not necessarily proportional to the distance from the initial location) movement models may prove a more realistic method of predicting distribution. The modelling of movements in ecology has received increasing attention in the last 50 years; a summary of some techniques for the modelling of animal movement are given below.

5.1.1 A review of methods for modelling animal movement

EMPIRICAL MODELS

Empirical models simply describe the relationship between organism density and distance from point of release by fitting equations to observed trends (e.g. Freeman 1977). These were some of the first quantitative tools used to describe dispersal and although they could be incorporated into regression models, they do not solve the problem of the effect of spatial heterogeneity (Turchin 1998).

DIFFUSION EQUATIONS

Skellam (1951) was the first ecologist to apply the expressions for molecular diffusion to ecological problems (Okubo 1980, Turchin 1998). By assuming that individuals move in a random direction the density of organisms at a point can be approximated by diffusion equations. The diffusion models assume that movements of an organism are random, not affected by spatial heterogeneity, drift or previous direction of travel, and therefore although giving an insight into population dynamics, are an over-simplification of the movements of real organisms (Turchin 1998). Simple diffusion models can be developed to incorporate a number of biological phenomena, producing a whole family of generalised diffusion models. Patlak (1953) derived a generalised diffusion model that included the correlation of successive moves of an individual, spatial heterogeneity and directional bias (Okubo 1980, Turchin 1998). The direction an organism moves is often correlated with the direction of its previous move, producing paths with more persistence in direction than if subsequent moves were independent (Levin *et al* 1970, Smith 1974, Karieva & Shigesdad 1983, Bovet &

Benhamou 1988, McCulloch & Cain 1989). In Patlak's model successive movements of an individual were correlated by constraining the angle of turn between subsequent movements so individuals are more likely to continue in the direction of their previous movement; this is called a correlated random walk. Spatial heterogeneity was incorporated by altering the angle of turn, speed and move duration, dependent on habitat quality. Patlak's model also allowed external forces to influence the direction of movement resulting in a bias for organisms moving in a specific direction. Comparison of Patlak's model to other diffusion models found that most were special cases of the Patlak model (Turchin 1998). Reaction-diffusion models extend simple diffusion models by the addition of birth and death terms, as well as movement terms (Tilman *et al* 1997, Turchin 1998) a simple example being inclusion of an exponential growth factor by Skellam (1951).

Although diffusion equations can be applied to real life situations (e.g. the advection-diffusion-reaction model for skipjack tuna (Sibert *et al.* 1999)) formulating viable schemes for establishing connections with data is conceptually more difficult as models become more complex (Turchin 1998). Where parameters are hard to derive, modelling dispersal on a computer and choosing the diffusion coefficients that best fit the observed data may be the only solution (as in Dobzhansky *et al.* 1979).

DISCRETE RANDOM WALK MODELS

Diffusion models are continuous models that assume that many moves occur between sample points whereas discrete random walk models employ a smaller number of movements (McCulloch & Cain 1989). Correlated discrete random walk models, where the directions of subsequent movements are correlated (Kareiva & Shigesada 1983, Bovet & Benhamou 1988, Marsh & Jones 1988, McCulloch & Cain 1989) and random walk models with directional bias (Marsh & Jones 1988) have been developed to investigate the patterns of animal movement. Such models enable us to quantify aspects of animal movement, such as sinuosity (a measure of the amount of turning in the path) (Bovet & Benhamou 1988), or net displacement (Kareiva & Shigesada 1983, McCulloch & Cain 1989) enabling comparisons between behaviour in different habitats or between different species and the exploration of the consequences of varying rules of movement.

INDIVIDUAL BASED MOVEMENT MODELS

In individual based movement models (IBMMs) the movements of individuals are constrained by behavioural rules, each with a stochastic element, with the movement of many individuals approximating to the behaviour of the population. The advantage of such models is their ability to simulate the observed animal behaviours and reactions very closely (Marsh & Jones 1988, Turchin 1998). The downfall of IBMMs, however, is that modelling techniques vary widely, dependent on the results required and the organism in question. This means that comparison between different IBMMs is exceptionally difficult (Marsh & Jones 1988, Turchin 1998). Thus while IBMMs may not prove useful in formulating general theoretical hypotheses about animal movements they may prove effective means of predicting the movements for a specific species.

One of the first models based on individual movement behaviour used to predict spatial distribution was by RE Jones (Jones 1977, Jones *et al* 1980). In this simulation model the distribution of eggs of the cabbage white butterfly *Pieris rapae* was predicted. Observations of the movement and oviposition of butterflies in a cabbage patch were used to derive probabilities of a butterfly stopping at a plant and the probability of a butterfly laying eggs when stopped (both were dependent on plant age and species). The flight path of a butterfly was a correlated random walk and in addition each butterfly had a directional bias (Jones 1977). This model was tested by releasing butterflies with dyed eggs and comparing the observed distribution of dyed eggs with that predicted from the model for a larger area and for a longer time period than used in the original model. Predicted patterns of oviposition were similar to those observed and therefore it is possible to gain an insight into the long-distance movements of the cabbage white butterfly from smaller scale observations as behavioural rules were not scale dependent (Jones *et al* 1980).

A whole family of simulation models has been created with rules ranging from simple movements in a homogenous environment (Siniff & Jessen 1969, Kaiser 1976) to movements in heterogeneous environments (Turner *et al* 1993 & 1994, Boone and Hunter 1996, Schippers *et al* 1996) and the inclusion of linear barriers (Boone & Hunter 1996, Schippers *et al* 1996), mortality (Dewdney 1984, Collins & Jefferson 1990, Turner *et al* 1993 & 1994, Schippers *et al* 1996), energetics (Turner *et al* 1993 & 1994), depletion (Turner *et al* 1993 & 1994), individual variation (Saarenmaa *et al*

1988), predator-prey systems (Dewdney 1984) and evolution (Collins & Jefferson 1990).

5.1.3 Modelling goose movements

In Chapter 3 the feeding distribution of Greylag geese was predicted in Strathearn and Strathallan from the landscape characteristics of fields using logistic regression. Landscape characteristics affecting the distribution of Greylag geese were distance from the roost, altitude and distance from buildings. The aim of this chapter is to predict the distribution of the geese by an alternative method, modelling the daily movements of geese. Modelling the movement of individuals in response to the environment may produce a more realistic model of goose feeding distribution than regression techniques. If goose movements are affected by the spatial heterogeneity of the landscape this could affect the distribution of feeding geese in a way not predictable from the logistic regression technique used (see Figure 5.1).

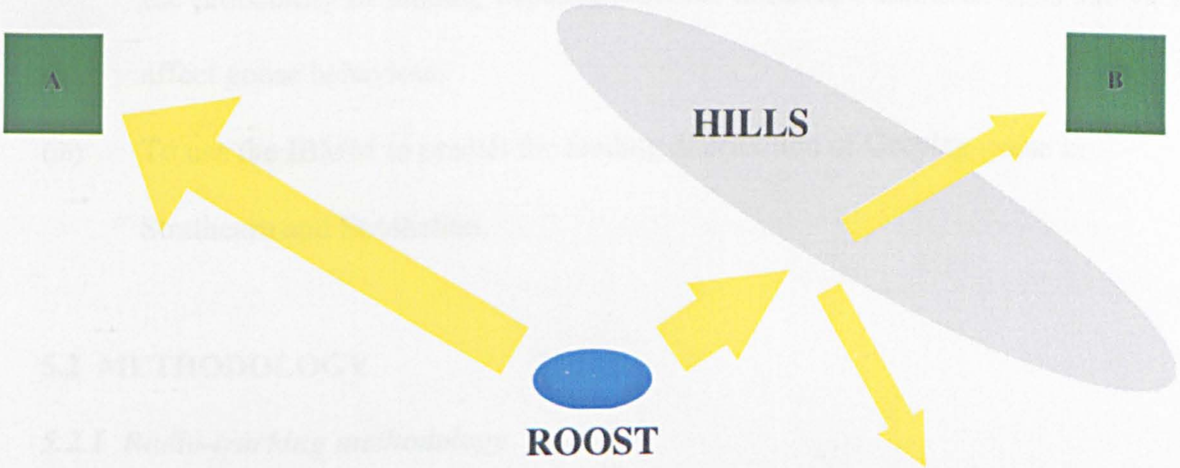

Figure 5.1. A diagram showing the possible effect of a heterogeneous landscape on the flight paths of geese. Fields A and B are the same distance from the roost and have identical landscape characteristics, and therefore if encountered by geese have the same probability of being used. Logistic regression would predict both fields to be used equally. If the hills constrain goose flight, however, fewer geese will encounter field B and therefore field B will be less likely to be used by the geese.

As the aim is to model relatively small scale goose movements in a heterogeneous environment, even complex generalised diffusion models are likely to be much too simplistic to model goose movement realistically on a field based scale. Therefore the distribution of Greylag geese in Strathearn and Strathallan will be predicted using an IBMM, which simulates goose movements, with the goose decision based in data from the study of radio-tracked birds.

5.1.4 Aims

The objectives of this chapter are to:

(i) To use data from radio-tagged Greylag geese to assess the effect of landscape characteristics on the behaviour of geese, namely the direction of flight and the decision to land.

(ii) To build an individual based movement model (IBMM) that simulates goose movements to feeding areas through the day, with rules for flight direction and the probability of landing dependent on the landscape characteristics shown to affect goose behaviour.

(iii) To use the IBMM to predict the feeding distribution of Greylag geese in Strathearn and Strathallan.

5.2 METHODOLOGY

5.2.1 Radio-tracking methodology

Twenty-three Greylag geese were fitted with radio transmitters on four catches during 1997/98, 1998/99 and 1999/2000. For further details see Chapter 4. Radio-tagged geese were given a period of 5-7 days to become accustomed to the radio-transmitters before data collection commenced. During the winters of 1997-98 and 1998-99, individual tagged geese were tracked continuously for half-day periods, either from dawn to mid-day, or mid-day to dusk. The location of the goose was recorded with the flock size, crop type, duration of stay in the field and reason for leaving (i.e. cause of disturbance if scared). Greylag geese in the study area were often observed to return to the same fields on subsequent days. Therefore to reduce the repetition and dependence between recorded goose movements for individual geese, radio-tracking periods were spaced as far apart as possible, separated by at least three days (for further debate on the non-independence of radio-tracking data see the discussion).

During the winter of 1999-2000 the methodology was altered to maximise the number of goose movements recorded. All radio-tagged geese were located at the roosts and then at approximately 2-3 hour periods throughout the day. As Greylag geese make few movements between fields during the day, it was considered appropriate to assume that the goose had flown directly between fields if the goose had moved. As a result no data were collected on the time geese spent in the fields or on the cause of leaving in this season. For all field seasons radio-tracking continued until the goose left the study area. As in previous winters, subsequent days of radio tracking of an individual goose were separated by at least 3 days

5.2.2 Duration of visits

The analysis of the amount of time geese spent in a field was performed using data from the first two field seasons. The time of arrival or departure of geese in a field was not recorded if it fell outside the observation time and therefore analysis of recorded durations only would result in an under representation of longer field stays. To combat this bias, the probability of geese leaving was calculated using the following equation

$$\mathrm{P\ (T) = NO.\ LEFT\ (T)\ /\ NO.\ OBSERVED\ (T)}$$

where:

P (T) is the probability of a goose leaving in the t^{th} half-hour after landing

NO. LEFT (T) is the number of geese that left in the t^{th} half hour after landing

NO. OBSERVED (T) is the number of geese observed for the t^{th} half hour after landing

This gave the probability of geese leaving the field for each half-hour period after landing. A Chi squared test was performed on the numbers of geese that left / did not leave for each half-hour period to see if the chance of geese leaving the field was constant over time.

5.2.3 Deriving landscape characteristics

ArcInfo GIS ver. 7.2.1 (ESRI, Redlands, California, USA) was used to derive a polygon coverage of all 3,700 fields in the study area from digitised OS LandLine data. Landscape characteristics for each field were calculated from OS LandLine, OS Panorama contour and Macaulay Land Cover for Scotland 1988 (LCS 88) data (see Table 5.1) as in Chapter 3.

The study area was converted to a grid of 256 by 203 100m square pixels. For each pixel landscape characteristics were derived in ArcView. In addition field-based characteristics of pixels lying within the boundaries of fields were derived from the field coverage. Table 5.1 describes both the landscape characteristics derived per pixel and the field-based landscape characteristics derived for pixels lying within field boundaries.

Table 5.1. Fields characteristics calculated for pixels and fields, including source of data.

Field Characteristic	Description	Units	Source data	Field based data	Pixel based data
Area	Area of field	m^2	OS Land-Line data	Field value	-
River distance	Dist. to river	m	OS Land-Line data	Field mean	Pixel value
Road distance	Dist. to nearest road or track	m	OS Land-Line data	Field mean, minimum & maximum	Pixel value
Building distance	Dist. to nearest building	m	OS Land-Line data	Field mean, minimum & maximum	Pixel value
Woodland distance	Dist. to nearest wooded area	m	LCS 88	Field mean	Pixel value
Water distance	Dist. to nearest permanent water, including ponds, drains, rivers etc.	m	OS Land-Line data	Field mean	Pixel value
Altitude	Average field altitude	masl	OS Panorama contour	Field mean	Pixel value
Slope	Average slope of field	degrees	OS Panorama contour	Field mean	Pixel value
Landcover	LCS 88 landcover category		LCS 88		Pixel category

5.2.4 Factors affecting where geese flew

The effect of landscape characteristics on the direction geese flew was investigated by comparing the character of land flown over by geese with land that could have been flown over if the goose had flown in a random direction. Goose flight paths were assumed to be a straight line between observed goose take off and landing points, as it was not possible to record the actual flight path of the goose in the field, and pixels lying on this line were identified as pixels flown over by the goose.

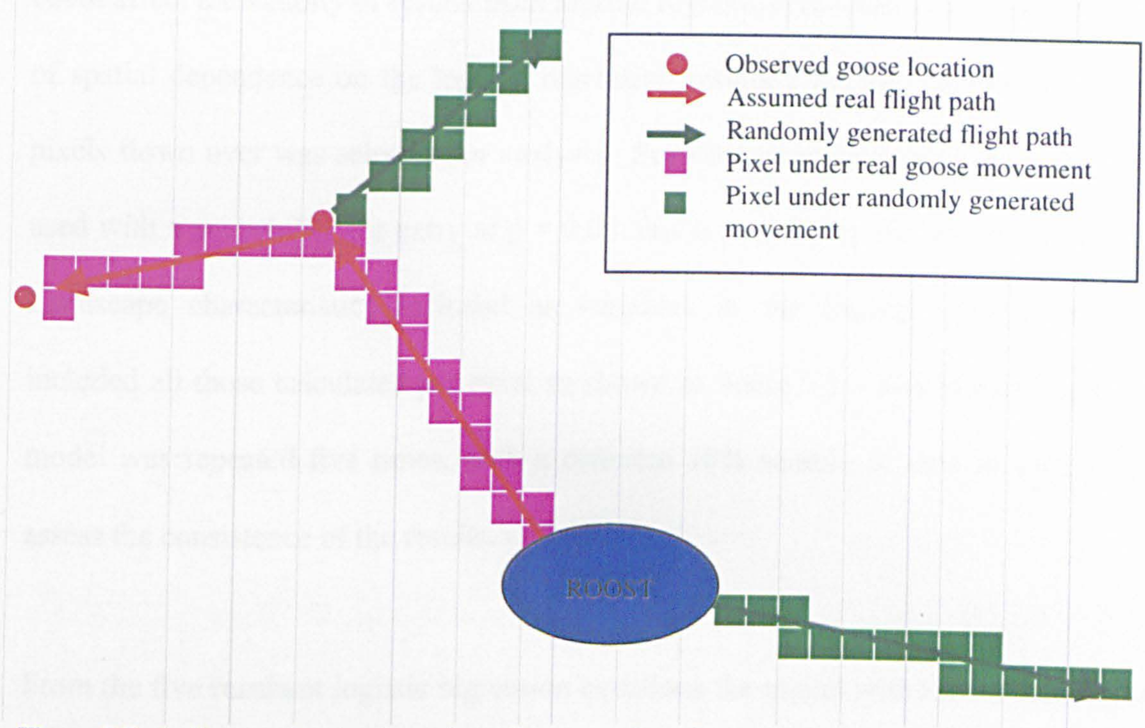

Figure 5.2. A diagram showing how pixels flown over in real goose movements and randomly generated movements were identified for the analysis of goose flight direction, from recorded locations of radio-tracked geese for one roost movement and one non-roost movement. Each grid square represents a 100m x 100m pixel.

For each recorded goose movement a random movement was also generated i.e. a flight path from the same take off point, of the same length as the recorded movement but in a randomly generated direction (Figure 5.2). Goose movements were divided into roost movements (from the roost to a field at the start of the day) and non-roost movements (between fields throughout the day). For both real and randomly generated roost and non-roost movements, the values of all pixels flown over were determined (see Figure 5.2). Logistic regression was used to compare landscape characteristics of pixels which geese chose to fly over (real movements) with what they would have flown over if landscape characteristics had no effect on flight direction (randomly generated movements). Separate models were produced for both roost and non-roost movements. The landscape characteristics of pixels flown over by geese are spatially dependent and could affect the validity of results from logistic regression models. To reduce the effect of spatial dependence on the logistic regression results a random sample of 10% the pixels flown over was selected for analysis. Forward stepwise logistic regression was used with a probability for entry at $p = 0.05$, and a probability for removal at $p = 0.1$. Landscape characteristics included as variables in the logistic regression model included all those calculated per pixel as shown in Table 5.1. The logistic regression model was repeated five times, with a different 10% sample of data in each run, to assess the consistence of the results.

From the five resultant logistic regression equations the model with the median logistic regression coefficient was selected as the most representative. This logistic regression equation was used to derive a chance of geese flying over each pixel in the study area, called the '*probability of flying*' probability surface. Probability surfaces were created in this way for both roost and non-roost movements.

The feeding area of the geese in the study area was based along the valleys of two rivers and so distance from the nearest river was a landscape variable included in this analysis. A model incorporating distance from the river would not be transferable to areas where there was no major rivers, for example, geese roosting on lochs and coastal roost sites. An alternative analysis of factors affecting where geese flew was performed excluding distance from the river as a landscape variable. The logistic regression analysis was performed as above but excluding distance from the river as a possible covariate, and alternative probability surfaces for geese flying over each pixel created, for both roost and non-roost movements. These alternative logistic regression models could be used to predict the probability of geese flying over pixels in goose feeding areas where there are no major rivers and therefore are more widely transferable.

5.2.5 Factors affecting where geese landed

To investigate the landscape characteristics affecting where geese chose to land, the landscape characteristics of pixels that were flown over and not landed in were compared to those where the goose did choose to land. As when investigating factors affecting where geese chose to fly, goose movements were assumed to be a straight line between observed goose take off and landing points. Where geese chose to land was analysed on a field scale with all pixels in one field having the same probability of being landed in (rather than the pixel scale used for analysis of flight direction). This was considered a more realistic approach than a pixel-based probability as geese used fields as units (bounded by fences that require flying over). The landscape characteristics investigated are shown in Table 5.1. As when assessing the effect of landscape characteristics on goose flight paths, separate analyses were performed to investigate roost and non-roost movements.

To assess which factors affected the chance of geese landing in fields, fields were grouped into ranked sets of 20, according to the landscape characteristic in question.

For each group of fields, the mean and standard deviation of the field characteristic and the proportion of pixels where geese chose to land were calculated. The proportions of pixels landed in were then plotted against the mean field characteristic for that group (as in Chapter 3). Both logarithmic and linear trends were detected using regression analysis on the data.

Conventionally such data would be displayed as a bar chart with the proportion of pixels landed in calculated for given ranges of landscape characteristic values. This would result in the accuracy of the probabilities varying with the number of fields in each range. By grouping fields, as described above, the accuracy of predicted probabilities across the range of landscape characteristic values is constant giving data more suitable for regression analysis. Note that the R^2 values will tend to be higher for grouped data than for individual fields.

To assess which variables affected where geese were landing, it was necessary to control for the most significant variable and see if other landscape characteristics also affected goose landing. The predicted probabilities of geese landing in each field were derived from the regression equation of the most influential landscape characteristic and the residuals calculated. The residuals were then plotted against the remaining landscape characteristics using the grouping method as described above, and the significance of any relationships calculated, to assess whether more than one landscape characteristic could be used to predict the chance of geese landing.

This approach was considered more appropriate than standard logistic regression as the highly skewed ratio of '*pixels flown over*' to '*pixels landed in*' would affect the outcome of model performance testing (Fielding & Bell 1997, Manel *et al* 1999), unless the majority of data from pixels that were flown were excluded. In addition, exclusion of some pixels where geese did not land would result in an over-estimation of the probability of landing for all pixels, therefore probabilities would require adjustment.

The regression equations were used to derive a probability surface of geese landing in each field over the entire study area for both roost and non-roost movements, with the probability of geese landing outside fields equal to zero. These were called the '*probability of landing*' probability surfaces.

5.2.6 Simulation model

The feeding distribution of geese was predicted by simulating goose movements through the day using rules derived from radio-tracked geese. The model simulates an individual goose flying from the roost site to a field and then between fields throughout the day. When run repeatedly the model results were used to produce a probability surface showing the predicted extent of use of individual fields by geese.

Simulated goose movements in the model were from pixel to pixel, starting at the roost site. As geese fly in a relatively straight line subsequent movements between pixels were strongly correlated, a constraint often incorporated into movements models

(Patlak 1953, Siniff & Jessen 1969, Jones 1977, Kareiva & Shigesada 1983, Bovet & Benhamou 1988, McCulloch & Cain 1989, Turner *et al* 1994, Boone & Hunter 1996, Schippers *et al* 1996). In this model goose movement was constrained so that geese could only move to the pixel straight ahead or to the pixels at 45 degrees on either side, with a greater chance of continuing straight ahead. Flight direction was also constrained by the '*probability of flying*' probability surface. The process of simulated geese moving between pixels was repeated until the goose landed. The chance of landing in each pixel flown over was taken from the '*probability of landing*' probability surface.

An outline of the model is shown in Figure 5.3 and was programmed in Microsoft Excel 97 with macros written in Microsoft VisualBasic. The starting point for each goose was one of the sixteen roosts used by radio-tracked geese, with the probability of a goose starting at a particular roost corresponding to the proportion of radio-track movements observed from the roost.

MODELLING GOOSE FLIGHT

Goose movements over the surface was constrained by the '*probability of flying*' probability surfaces. The probability surface was simplified into bands of 0.1, 0.2, 0.3 etc. to allow goose flight to be constrained without causing so many changes in direction that the simulated flight path became unrealistic.

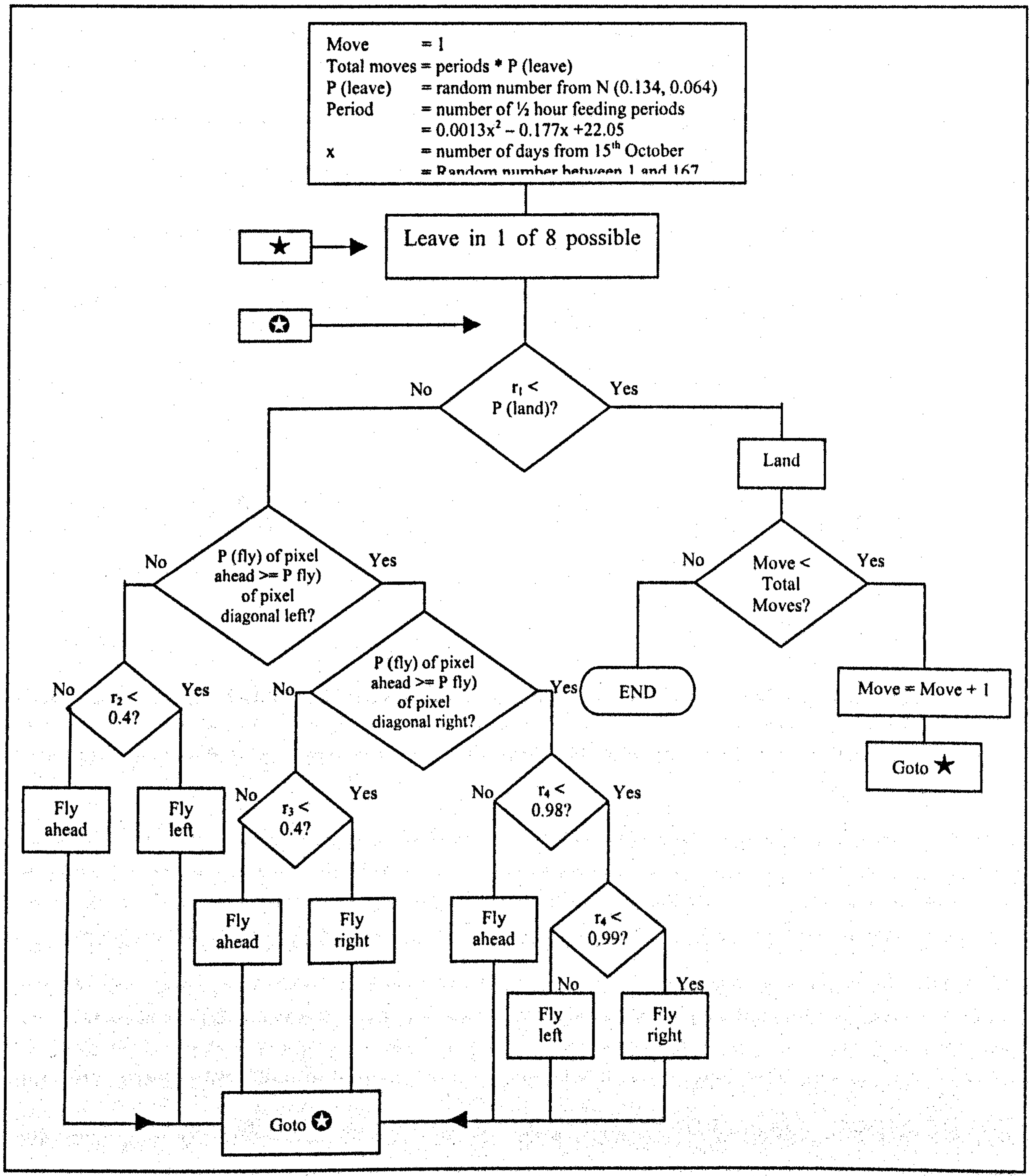

Figure 5.3 Flow chart of simulation model. Note P (land), the probability of landing, and P (fly) the probability of flying, differ in space. If move = 1 then the goose is flying from the roost so P (land) and P (fly) for roost moves are used, if move > 1 then it is a non roost movement and P (land) and P (fly) for non roost movements used. $r_1 - r_4$ are randomly generated numbers between 0 and 1.

If the pixels at 45 degrees to the left or the right had a lesser or equal probability of being flown over there was 98% chance that the goose would continue in a straight line and 1% chance of it turning to the left or the right. The small chance of turning, when flight is not constrained by the probability surface, was selected as it results in realistically direct flight paths while including an element of stochasticity. Many simulated geese leave from the same roost and are constrained by the same probability bands which can result in certain flight paths being repeatedly simulated, an effect reduced by the inclusion of occasional random change of direction.

If the chance of pixels either to the left or right being flown over was greater than the pixel straight ahead then there was a 60% chance of the goose turning in the preferred direction. This probability of turning at the flight constraint boundaries was selected as it gave simulated geese the correct probability of flying in the different probability bands (see later and Figures 5.10a & 5.10b).

MODELLING GOOSE LANDING

The probability of geese landing per pixel was taken directly from the '*probability of landing*' probability surface.

NUMBER OF MOVEMENTS PER DAY

The number of moves a goose makes in a day will be dependent on the frequency of movements and the number of hours spent feeding in a day. The probability of a goose leaving per half-hour was taken at random from a normal distribution with the mean and standard deviation taken from the duration of visit analysis. As the amount of feeding time in the day varies through the season, for each run of the model the amount of feeding time was calculated for a random day between 15th October and 1st April using the polynomial equation derived in Chapter 4. The number of goose movements for the day was calculated as:

2 * NO. HOURS FEEDING TIME * P (LEAVING PER HALF-HOUR PERIOD)

For subsequent goose movements between fields, the model was run as the first goose movement from the roost but using probability surfaces for both flight path and probability of landing derived for non-roost movements.

DERIVING THE PROBABILITY OF GOOSE USE FROM SIMULATED GEESE

The result of this model, when run repeatedly, was a grid with the number of simulated goose landings per pixel. ArcView was used to summarise the results per field, giving the total number of geese landing per field, and the mean number of geese landing per pixel (density) for each field.

To assess the number of simulated goose days required to produce consistent results, the model was run twice for 1000, 5000, 10000, 30000 and 50000 goose days. Regressing the sum and density of geese landing per field for the two runs assessed the degree of consistency between the results of the two runs. When consistent results were obtained from the two runs there was considered to be an adequate number of simulated goose days and this was the number of times the model was run for all subsequent procedures.

To assess whether the simulation model accurately reflected the probability surface for geese flying over the area, the model was modified to give the number of times each pixel was flown over by simulated geese. For an area within 3km of any goose roost, the mean number of times pixels from each probability band were flown over in the simulation model was calculated and compared to what would be expected from the probability surface, for both roost and non-roost movements.

ALTERNATIVE SIMULATION MODEL

The model was then run as above but using the alternative '*probability of flying*' probability surfaces with distance from the river excluded from the flight analysis. As discussed previously this alternative model is transferable to other goose feeding areas where there are no major rivers. The results of this alternative model were compared to those of the ordinary model both by visual comparison of the predicted probability surfaces and by regressing the sum and density of geese landing per field for the two runs, as when comparing the consistency of results from two runs of an identical model previously.

5.2.7 Sensitivity analysis

The data on which this simulation model was based were not extensive. As a result it was necessary to assess the effect of potential error in the relationships used in the model. To assess the effect of error in the '*probability of flying*' probability surface, the upper and lower 95% confidence limits of the coefficient for the logistic regression model were used. The model was run using probability surfaces derived from the lower confidence limits of the coefficient for both roost and non-roost movements and for analyses both including and excluding the distance from river variable. This was repeated to create four probability surfaces using the upper confidence limits of the coefficients. Agreement between the original and modified model results was assessed both by visual comparison of the predicted probability surfaces and by regressing the sum and density of geese landing per field for the two runs, as when comparing the consistency of results from two runs of an identical model previously.

To assess the effect of error in the '*probability of landing*' probability surface it was not considered appropriate to use the confidence intervals for the relationship, as a uniform reduction in the probability of landing would result in geese flying further from the roost, not a realistic measure of any error that could have entered the analysis. Instead it was considered more appropriate to include a random error into the probability of geese landing for each field. For each field the probability of landing was altered by a random error from a uniform distribution between –20% and +20% for both roost and non-roost probability surfaces and the model re-run. This procedure was repeated with the probability surface being altered by a random error of between –50% and +50%. Again agreement between the original and modified model results was assessed both visually and by regressing the sum and densities of geese landing per field for the two runs.

5.3 RESULTS

5.3.1 Radio-tracking geese

During the first two field seasons, 15 geese were caught and 12 were radio-tracked over half day periods for a total of 57 half days during 19th February - 25th March 1998 and 3rd December 1998 - 7th April 1999. During this time 123 goose movements were observed. Three geese left the study area before any data could be collected.

During the final season eight radio-tagged geese were located every 2-3 hours. A total of 104 transitions were observed between 5th November 1999 and 17th January 2000, including two transitions from a goose caught the previous winter. No data of stay duration or scaring were obtained in the winter of 1999-2000. The number of transitions recorded varied greatly between individuals (mean = 10.8, s.d = 10.3), reflecting the variation in the amount of time individuals remained in the study area after capture. Individuals feeding in the same flock were not radio-tracked simultaneously, to reduce dependence in the data.

5.3.2 Duration of visits

Figure 5.4 shows the probability of geese leaving the field in each half-hour period after landing. There is no apparent relationship between the chance of a goose leaving and the amount of time already spent in the field. Chi squared tests on the number of geese leaving or remaining per half hour period showed no significant variation in the proportion of geese leaving over time ($\chi^2 = 3.88$, d.f. = 6, $p > 0.1$). The mean proportion of geese leaving per half-hour period was 0.13 (s.d. = 0.06).

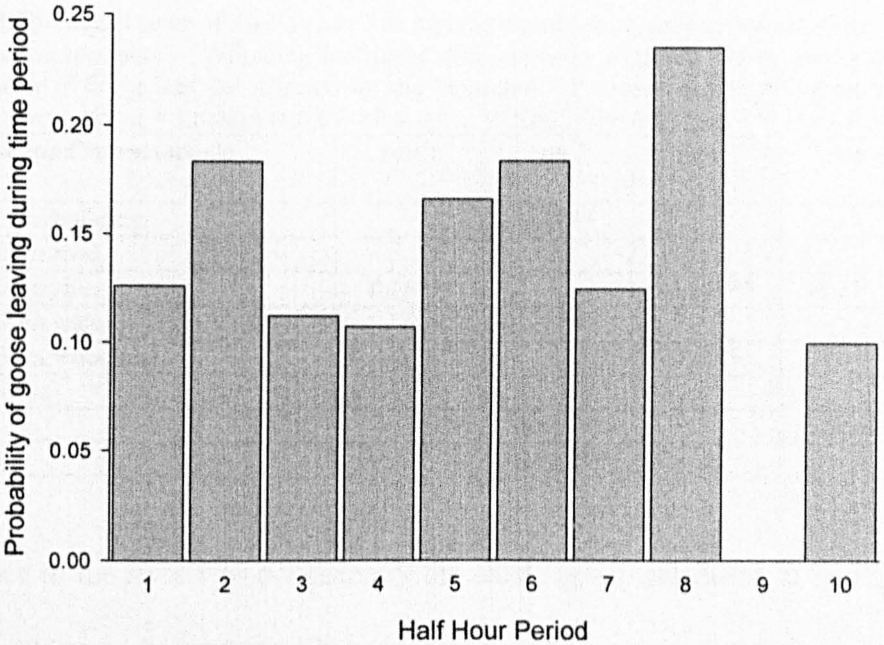

Figure 5.4 The probability of geese leaving during each half-hour period after arrival in the field. Mean = 0.13, sd = 0.06.

5.3.3 Factors affecting where geese flew

The results of the five runs of the logistic regression models comparing the landscape characteristics of pixels flown over and not flown over for both roost and non-roost movements are shown in Tables 5.2a and 5.2b. Further details of the results of the logistic regression models are presented in Appendices 5 and 6.

Table 5.2a Significance of variables in five logistic regression models using a random 10% of pixels for roost movements. Comparing landscape characteristics of pixels flown over and potential pixels flown over if flight was not affected by the landscape. R-values and significance level of variables included in equation. * Equates to 0.05 > P > 0.01, ** 0.01 > P > 0.001 and *** P < 0.001.

Landscape Characteristic	**run 1**	**run 2**	**run 3**	**run 4**	**run 5**
Dist. from building	0.06*				
Dist. from road					
Dist. from river	-0.16***	-0.24***	-0.19***	-0.30***	-0.27***
Dist. from water					
Dist. from woodland					-0.07*
Landcover					
Slope		-0.07*		-0.06*	
Altitude	-0.13***		-0.09**		

Table 5.2b Significance of variables in five logistic regression models using a random 10% of pixels for non-roost movements. Comparing landscape characteristics of pixels flown over and potential pixels flown over if flight was not affected by the landscape. R-values and significance level of variables included in equation. * Equates to 0.05 > P > 0.01, ** 0.01 > P > 0.001and *** P < 0.001.

Landscape Characteristic	**run 1**	**run 2**	**run 3**	**run 4**	**run 5**
Dist. from building		0.11**			
Dist. from road					
Dist. from river	-0.16***		-0.24***	-0.22***	-0.010**
Dist. from water					
Dist. from woodland	-0.7*		-0.09*		
Landcover					
Slope		0.14**		0.09*	
Altitude		-0.25***			

Distance to the river was consistently the most significant factor affecting where geese flew, with geese being more likely to fly over pixels nearer the river, for both roost and non-roost movements. The correlation between distance from the river and altitude ($r = 0.28$, $p < 0.001$) accounts for the result of run 2 from the non-roost movements. With altitude controlled for, the effect of distance from the river is no longer significant. Other variables were included into the logistic regression models, but not consistently and at much lower significance levels than the distance from the river. As such it was considered appropriate to include only the distance from the river in the logistic regression model. The logistic regression models were run again five times for both roost and non-roost movements, with only distance from the river included as a dependent variable. Of the five logistic regression equations generated the equation with the median coefficient value was selected to represent the relationship between the distance from rivers and the chance of a pixel being flown over by geese. The selected logistic regression equations were used to predict probability surfaces of geese flying over each pixel in the study area, for both roost and non-roost movements. For roost movements the probability of flying P (fly) was calculated by the following equation:

$$P\ (\text{FLY}) = 1/\text{EXP}((0.808 * \text{DISTANCE TO RIVER}) + 0.027)$$

For non-roost movements the probability was calculated by the equation:

$$P\ (\text{FLY}) = 1/\text{EXP}((0.420 * \text{DISTANCE TO RIVER}) + 0.509)$$

where distance from the river is measured in kilometers. The probability surface for roost movements is shown in Figure 5.5.

When the distance from the river was excluded from the analysis, altitude was consistently the most significant variable in the model in all five runs for both roost and non-roost movements, with geese more likely to fly over pixels at lower altitudes (see Tables 5.3a & 5.3b). Further details of the results of the logistic regression models are presented in Appendices 7 and 8.

Table 5.3a. Significance of variables in five logistic regression models using a random 10% of pixels, with distance from river excluded, for roost movements. Comparing landscape characteristics of pixels flown over and potential pixels flown over if flight was not affected by the landscape. R-values and significance level of variables included in equation. * Equates to 0.05 > P > 0.01, ** 0.01 > P > 0.001 and *** P < 0.001.

Landscape Characteristic	run 1	run 2	run 3	run 4	run 5
Dist. from building	0.06*	0.11**	0.05*	0.08**	0.10**
Dist. from road					0.07*
Dist. from water					
Dist. from woodland					
Landcover					
Slope					
Altitude	-0.23***	-0.24***	-0.26***	-0.26***	-0.24***

Table 5.3b. Significance of variables in five logistic regression models using a random 10% of pixels, with distance from river excluded, for non-roost movements. R-values and significance level of variables included in equation. * Equates to 0.05 > P > 0.01, ** 0.01 > P > 0.001 and *** P < 0.001.

Landscape Characteristic	run 1	run 2	run 3	run 4	run 5
Dist. from building		0.11**		0.10**	0.06*
Dist. from road					
Dist. from water					
Dist. from woodland	-0.06*		-0.08*		
Landcover					
Slope		0.13**	0.08*	0.13**	
Altitude	-0.14***	-0.24***	-0.17***	-0.17***	-0.11**

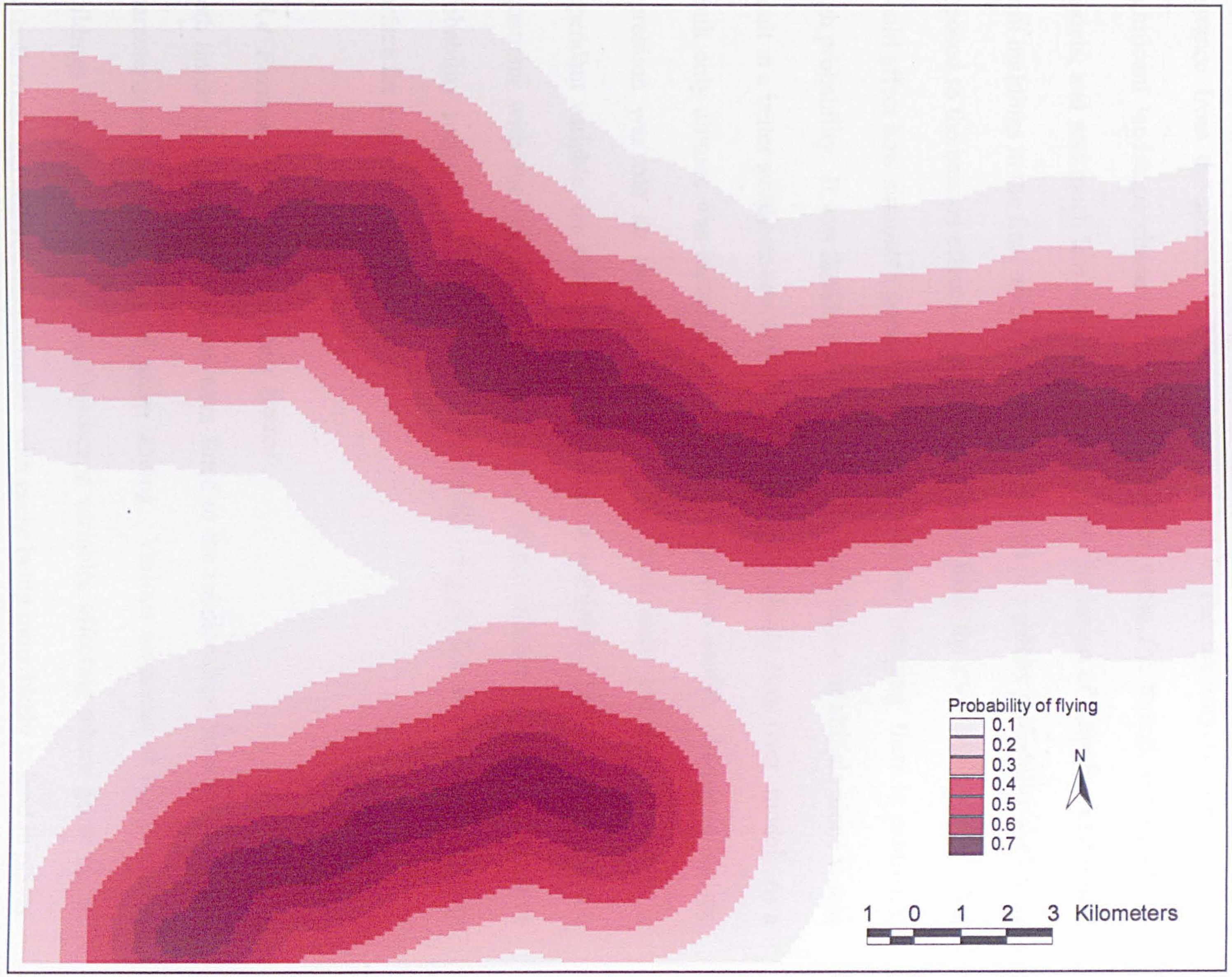

Figure 5.5 The probability of flying bands for goose movements from the roost, based on distance from the river.

As with the analysis including distance from the river, other variables were included in various runs of the model, but not consistently and at lower significance levels. Distance from the nearest building was included in the majority of models as a significant landscape characteristic affecting where geese fly, though not in all the models, and was much less significant than altitude. Inclusion of altitude and distance from buildings in the final model would have resulted in a patchy probability surface as opposed to the banded effect obtained from distance from the river and altitude. This would affect how simulated geese move over the grid by 'trapping' them in patches of high probability. It was therefore considered that the inclusion of altitude alone would result in a better substitute probability surface for the 'distance from river' model. As a result only altitude was included in the logistic regression model. As above logistic regression was run on the five subsets of data with only altitude included as a dependant variable, for both roost and non-roost movements. The logistic regression equations with the median coefficient values were selected to create alternative probability surfaces for the probability of flying. Figure 5.6 shows the probability surface for geese flying from the roost.

5.3.4 Factors affecting where geese landed

Both linear and logarithmic curves were fitted to the relationships between landscape characteristics and the chance of geese landing. Various measures of distance from buildings were the most significant landscape variables affecting where geese landed for both roost and non-roost movements, with geese being more likely to land in pixels

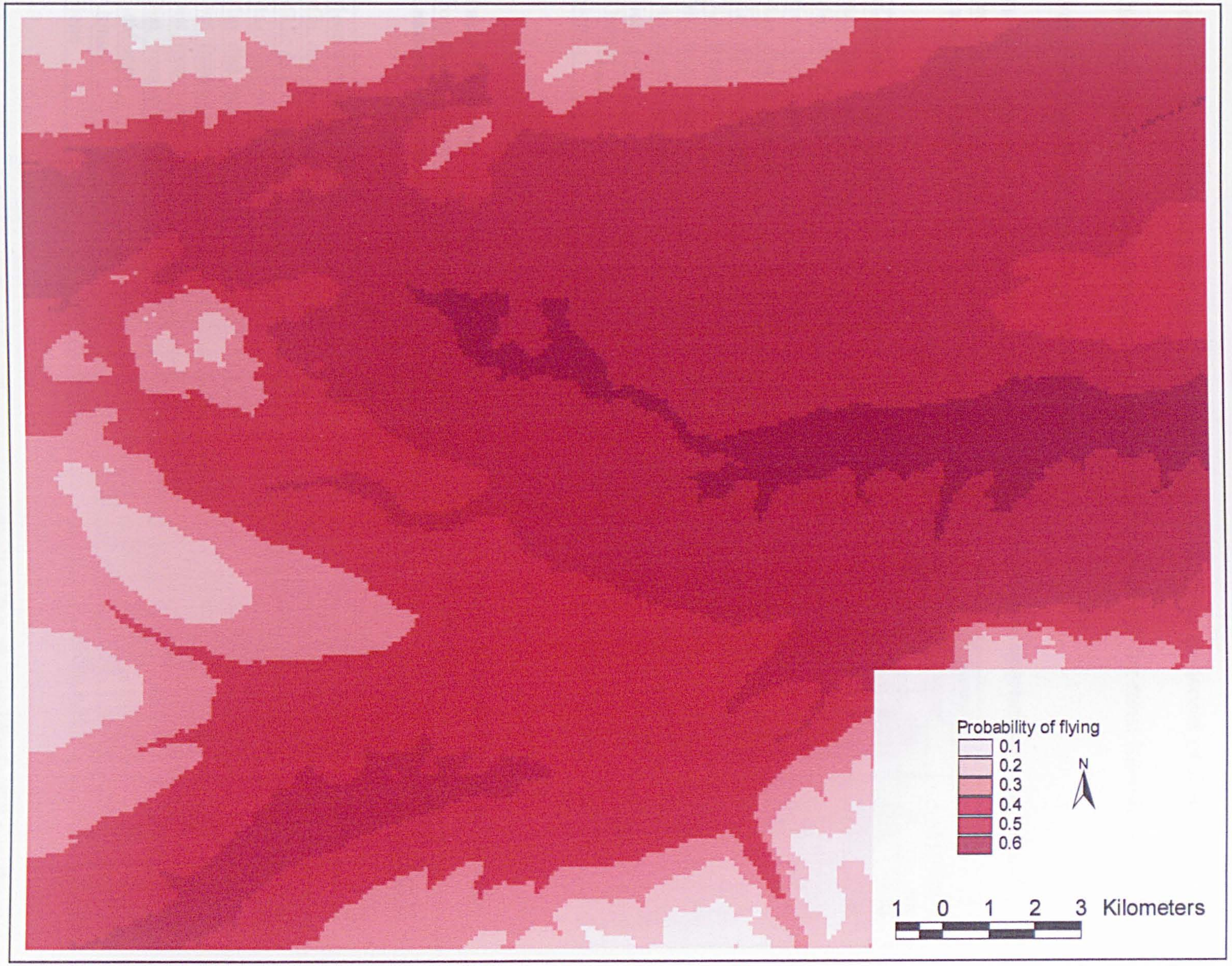

Figure 5.6 The probability bands for goose movements from the roost, based on altitude.

further from the buildings (Table 5.4). The area of the field also showed a relationship with the chance of geese landing, with geese more likely to land in a pixel in a larger field, for both roost and non-roost movements. Of the three measures of distance from the buildings, the maximum distance was the most significant for roost movements, and was also significant for non-roost movements.

Table 5.4 Results of the regression analysis of the effect of landscape characteristics on the chance of geese landing in a pixel.

Landscape Characteristic	**Roost movements (n = 15)**				**Non-roost movements (n = 12)**			
	Linear		**Logarithmic**		**Linear**		**Logarithmic**	
	R	**Sig.**	**R**	**Sig.**	**R**	**Sig.**	**R**	**Sig.**
Mean dist. from building	0.48	0.070	0.53	0.044	0.75	0.005	0.84	0.001
Max. dist. from building	0.73	0.002	0.74	0.001	0.72	0.008	0.78	0.003
Min. dist. from building	0.18	0.526	-	-	0.75	0.005	-	-
Mean dist. from road	0.40	0.138	0.51	0.054	0.31	0.328	0.50	0.101
Max. dist. from road	0.55	0.033	0.57	0.027	0.37	0.243	0.44	0.153
Min. dist. from road	0.20	0.467	-	-	0.06	0.850	-	-
Dist. from river	0.40	0.513	0.00	0.961	0.05	0.857	0.21	0.516
Dist. from water	- 0.05	0.850	0.11	0.704	0.48	0.112	0.45	0.144
Dist. from woodland	ns		ns		0.59	0.042	0.62	0.032
Field area	0.72	0.003	0.67	0.006	0.56	0.059	0.67	0.018
Altitude	- 0.28	0.316	- 0.41	0.125	- 0.19	0.550	- 0.20	0.533
Slope	- 0.44	0.101	-	-	- 0.24	0.451	- 0.16	0.620

Table 5.5 Results of the regression analysis of the effect of landscape characteristics on the residuals from the regression model incorporating the maximum distance from a building.

Landscape Characteristic	**Roost movements (n = 15)**				**Non-roost movements (n =)**			
	Linear		**Logarithmic**		**Linear**		**Logarithmic**	
	R	**Sig.**	**R**	**Sig.**	**R**	**Sig.**	**R**	**Sig.**
Mean dist. from building	0.00	0.989	0.04	0.887	0.29	0.353	0.40	0.193
Min. dist. from building	- 0.32	0.242	-	-	- 0.08	0.798	-	-
Mean dist. from road	0.10	0.726	0.20	0.476	0.08	0.806	0.16	0.623
Max. dist. from road	0.22	0.431	0.23	0.408	0.03	0.941	0.14	0.658
Min. dist. from road	- 0.09	0.738	-	-	0.33	0.302	-	-
Dist. from river	0.14	0.627	0.10	0.729	0.21	0.516	0.33	0.301
Dist. from water	0.10	0.734	0.04	0.892	0.08	0.791	0.03	0.917
Dist. from woodland	0.30	0.275	0.18	0.532	0.51	0.093	0.61	0.035
Field area	0.51	0.052	0.41	0.133	0.24	0.442	0.39	0.215
Altitude	- 0.28	0.296	- 0.40	0.137	- 0.08	0.791	- 0.03	0.917
Slope	- 0.49	0.063	-	-	- 0.35	0.271	- 0.30	0.334

When maximum distance from buildings was controlled for, the residuals did not show significant relationships with any of the other landscape characteristics investigated, including field area (Table 5.5). This is likely to be due to the correlation between area and maximum distance from buildings ($r = 0.441$, $n = 3,599$, $p < 0.001$). These results suggest that how far away a goose can get from buildings in a field is the major factor affecting whether it will land.

The logarithmic regression curve equations fitted to the relationships between maximum distance to buildings and the chance of geese landing per pixel for both roost and non-roost movements were used to calculate the probability of geese landing in any pixel throughout the study area if flown over. The equation for roost movements is:

$$\mathbf{P\ (\text{LAND}) = 0.084 * \text{LN}\ (\text{MAXIMUM DISTANCE FROM THE NEAREST BUILDING}) - 0.445}$$

and the equation for non-roost movements is

$$\mathbf{P\ (\text{LAND}) = 0.104 * \text{LN}\ (\text{MAXIMUM DISTANCE FROM THE NEAREST BUILDING}) - 0.523}$$

where the maximum distance from the nearest building measured in metres.

Figure 5.7 shows the relationship between maximum distance from the buildings and both the proportion of geese observed to land and the logarithmic curves fitted to the data. Although the shapes of the relationships are very similar for roost and non-roost movements, the probability of landing is higher for non–roost movements. This is because geese move shorter distances between fields during the day than when leaving the roost at the start of the day, a difference that is reflected in the probability surfaces.

The logarithmic curves were considered more appropriate models as they were more significant than the linear regression lines in both instances. In addition the effect of disturbance is most likely to be logarithmic with the effect disturbance being greatest when in close proximity to the source and lessening at greater distances. The probability of geese landing in pixels not in fields was fixed as zero.

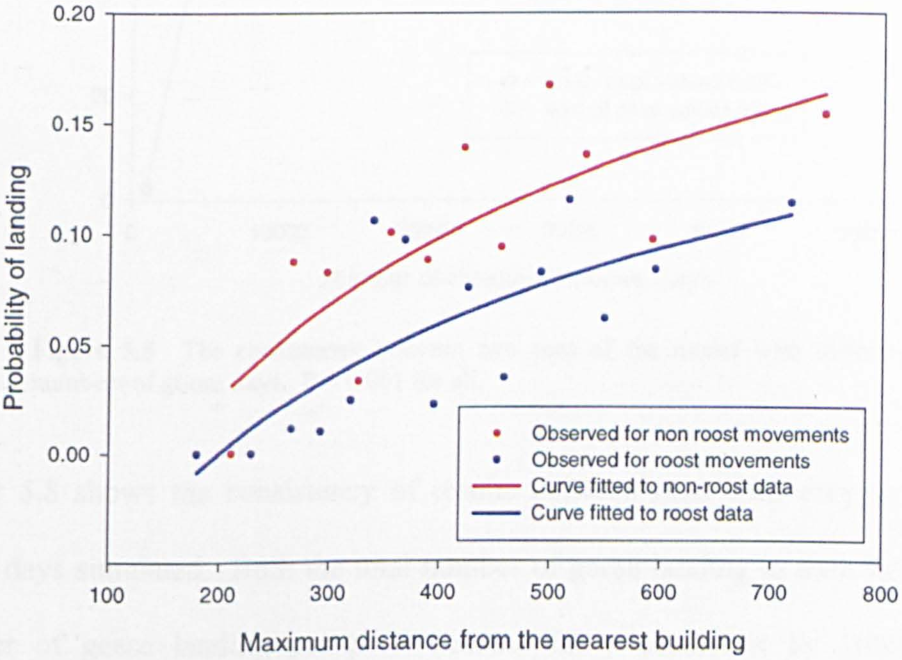

Figure 5.7 The probability of geese landing at varying distances from buildings for both roost and non-roost movements.

5.3.5 Simulation model

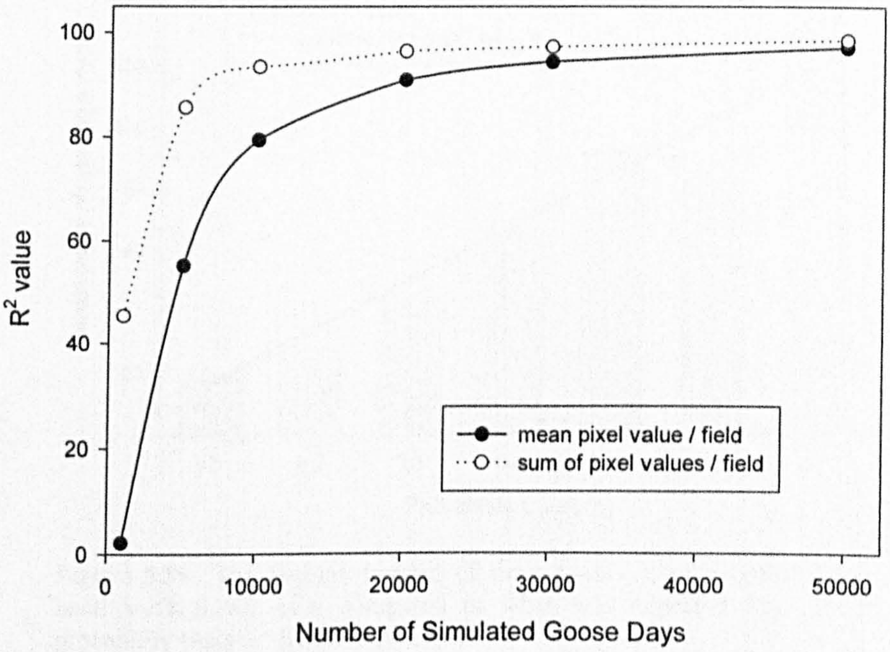

Figure 5.8 The consistency between two runs of the model with differing numbers of goose days. $P < 0.001$ for all.

Figure 5.8 shows the consistency of results between runs with varying numbers of goose days simulated. Both the total number of geese landing in each field and mean number of geese landing per pixel became fairly consistent by 20000 to 30000 simulated goose days. By 50000 simulated goose days the R^2 values of the total number of geese landing in a field and the mean number of geese landing per pixel were 98.6% and 97.2% respectively. It was therefore considered appropriate to use 50000 iterations to produce consistent results and all subsequent models were run for this number of simulated goose days.

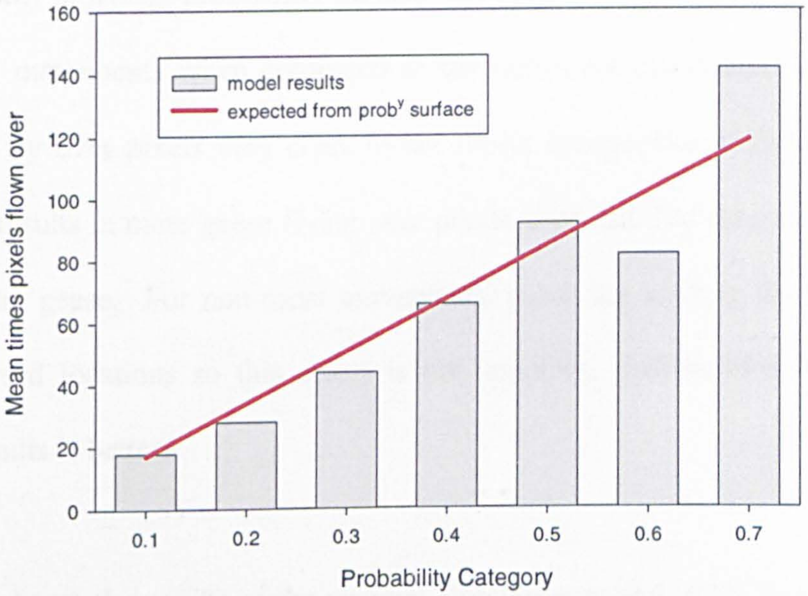

Figure 5.9a The average number of times pixels in each probability band were flown over compared to what was expected from the probability surface. Roost movements.

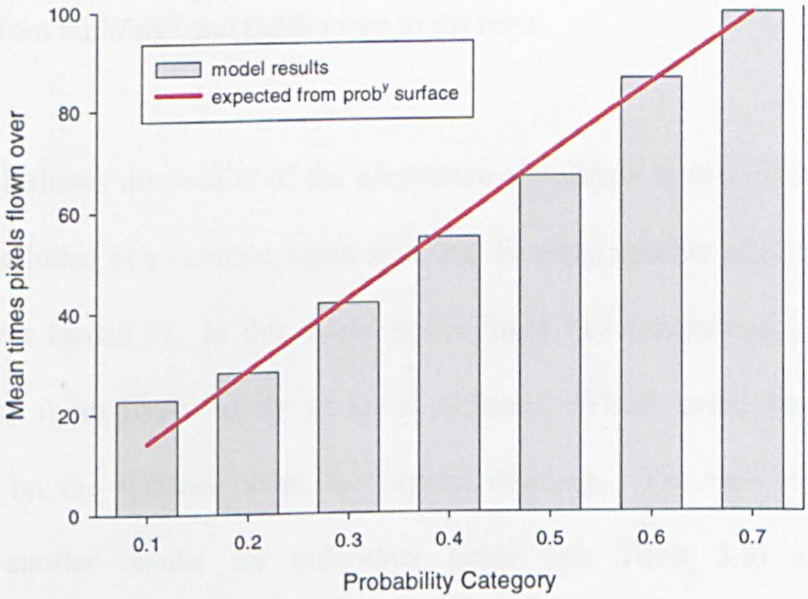

Figure 5.9b The average number of times pixels in each probability band were flown over compared to what was expected from the probability surface.

underlying probability surface on which it is based for both roost and non-roost movements. This suggests that the rules that govern how simulated geese respond to the *'probability of flying'* probability surfaces are realistic. The reduced accuracy of fit of the roost movements when compared to the non-roost movements arises because more geese fly over pixels very close to the roosts irrespective of distance from the river. This results in more geese flying over pixels in probability categories containing more roosting geese. For non-roost movements, geese are starting their flights from more dispersed locations so this effect is not apparent, and therefore the fit to the expected results is better.

Figure 5.10 shows the results of the original simulation model, with the mean number of times each pixel in the field was landed in shown. In this model goose flight was constrained by distance from the river, and geese are predicted to be more numerous in fields far from buildings and fields close to the river.

Figure 5.11 shows the results of the alternative simulation model, with distance from the river excluded as a variable, again showing the mean number of times each pixel in the field was landed in. In this model goose flight was constrained by altitude, with geese being more likely to fly at lower altitudes. Where geese landed was again dependent on the distance from the nearest building. The two models produced relatively similar results for individual fields (see Table 5.6) although visual comparison shows that the altitude based model constrains the direction of goose flight less than the river based model, resulting in a greater spread of fields predicted to be used by geese.

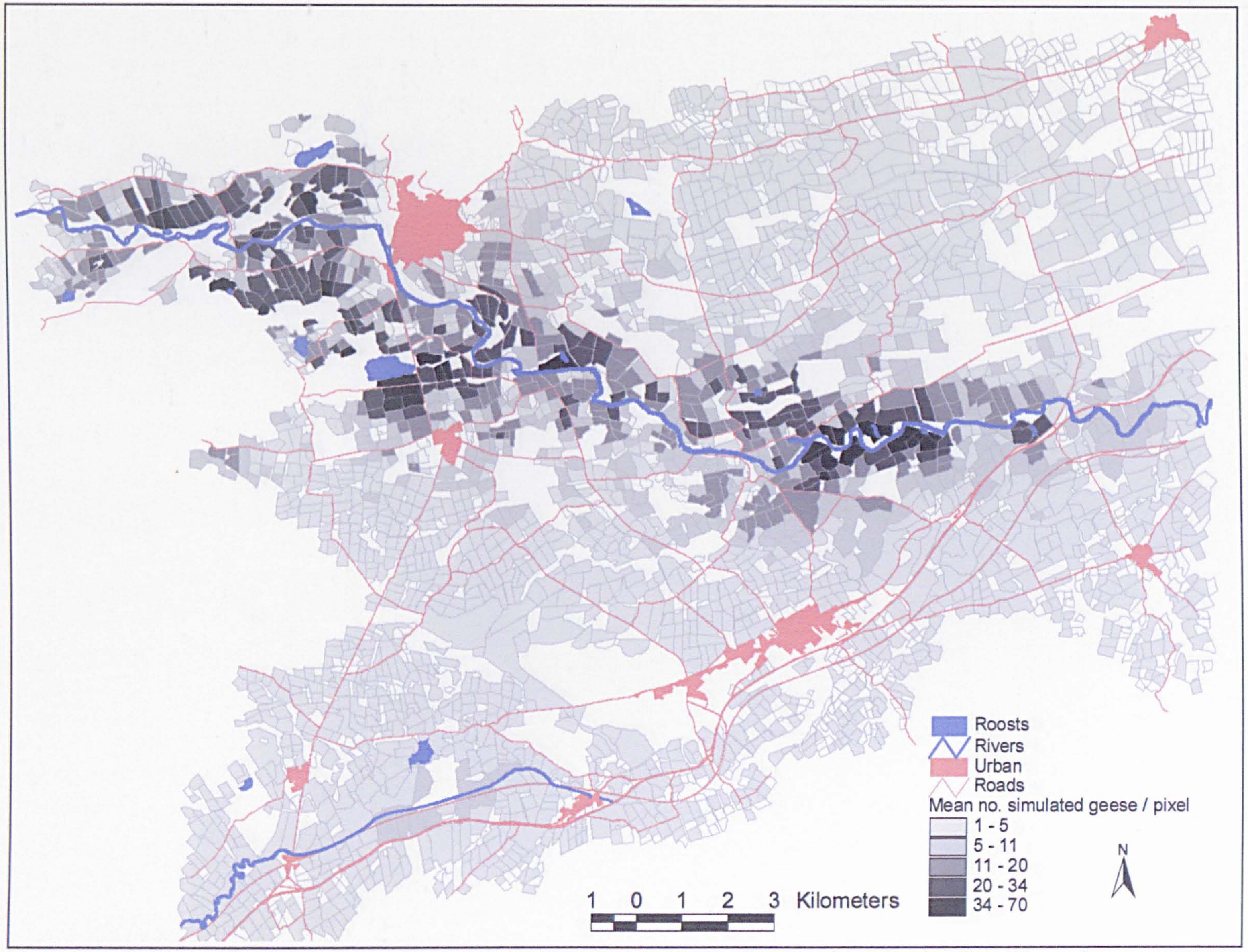

Figure 5.10 Results from the simulation model with flight constrained by distance from the river, showing the mean number geese simulated to land per pixel for each field.

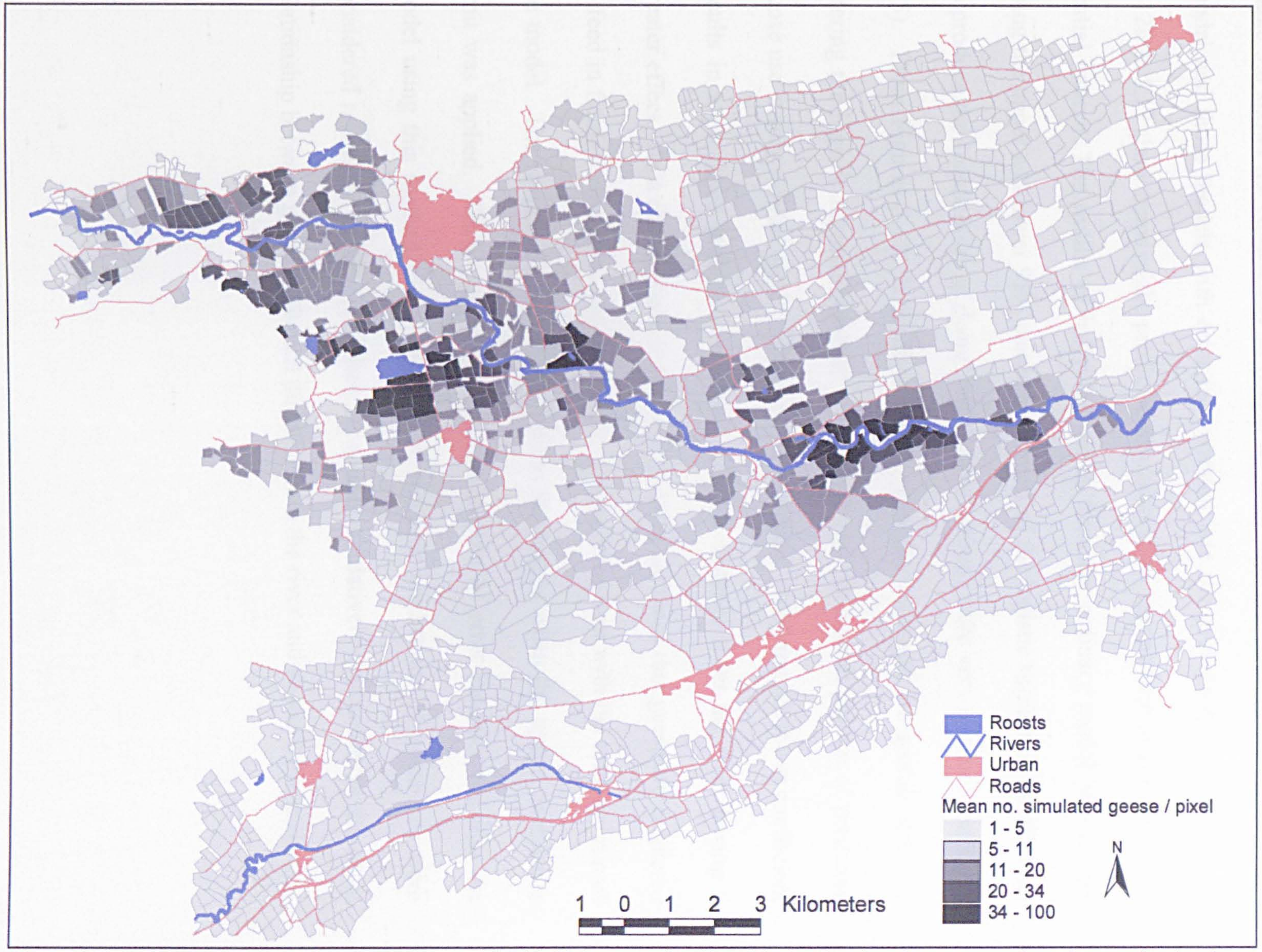

Figure 5.11 Results of the alternative simulation model with flight constrained by altitude, showing the mean number of geese simulated to land per pixel for each field.

5.3.6 Sensitivity analysis

Table 5.6 shows the consistency of results for each field between runs of the ordinary model and those models with error incorporated into the probability, Figures 5.12a, 5.12b & 5.13 show maps of the predicted results to allow comparison of changes in the spatial pattern. The results of individual fields from the ordinary model and models using the upper and lower 95% confidence limits of the logistic regression coefficients to produce the *'probability of flying'* probability surfaces were very similar (See Table 5.5). From Figures 5.12a & 5.12b it can be seen that although the spatial effect of altering the logistic regression model is not great and the overall pattern of predicted goose use is very similar, slight differences can be seen. Applying the lower coefficient results in a predicted probability surface with the distance from the river having a greater effect. As a consequence it can be seen from the maps that geese are predicted to feed in fields further from the river slightly more often than with the ordinary run of the model. The reverse can be observed from the results when the upper confidence limit was applied. Given the relatively large amount of error incorporated into the model using this method, the effects on the resultant predictions of goose use were considered relatively slight. Therefore the model is relatively insensitive to the exact relationship between goose flight and distance from the river and so inaccuracies in the

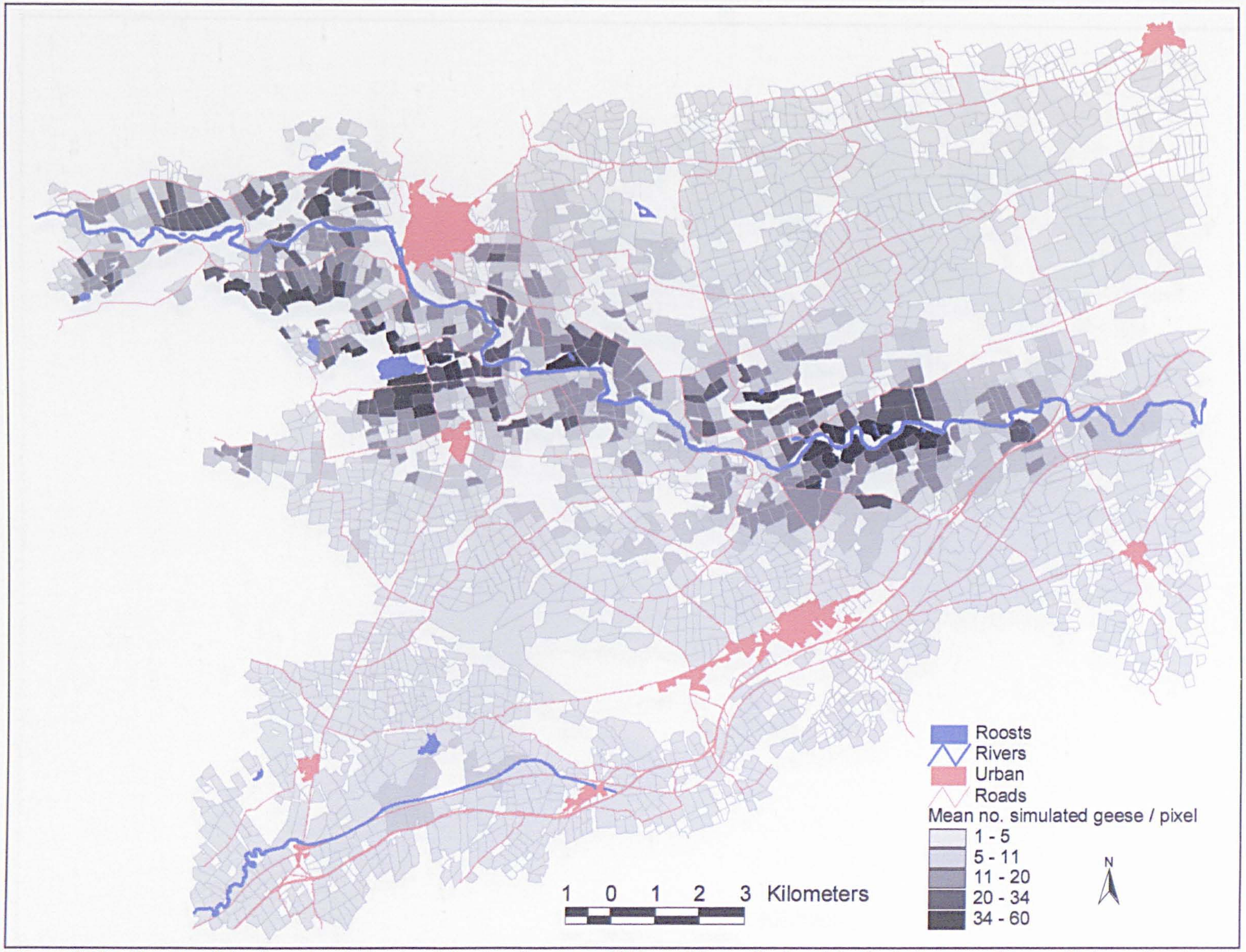

Figure 5.12a Results of the river simulation model using the upper 95% confidence limits of the logistic regression coefficient, showing the mean number of geese simulated to land per pixel for each field.

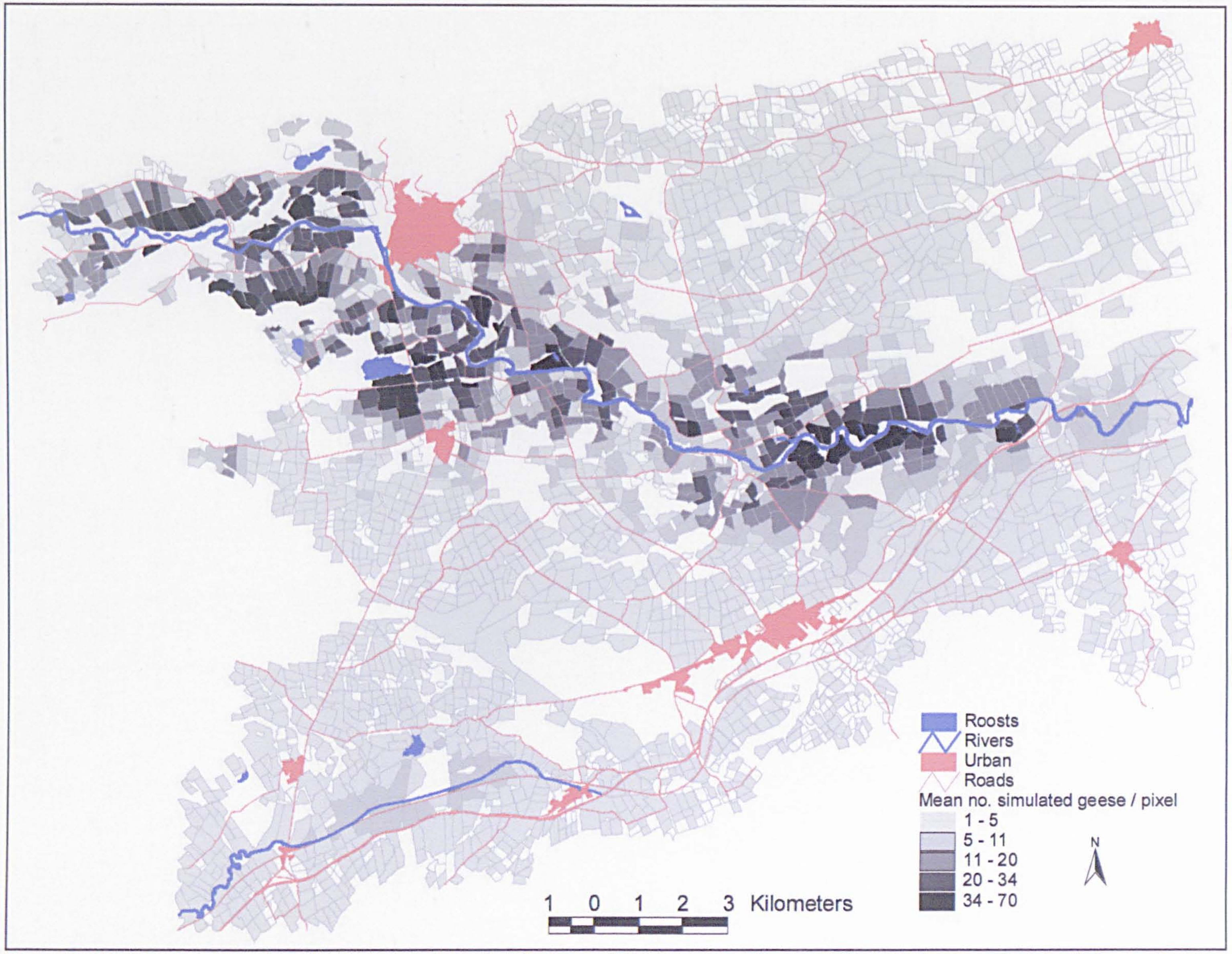

Figure 5.12b Results of the river simulation model using the lower 95% confidence limits of the logistic regression coefficients, showing the mean number of geese simulated to land per pixel for each field.

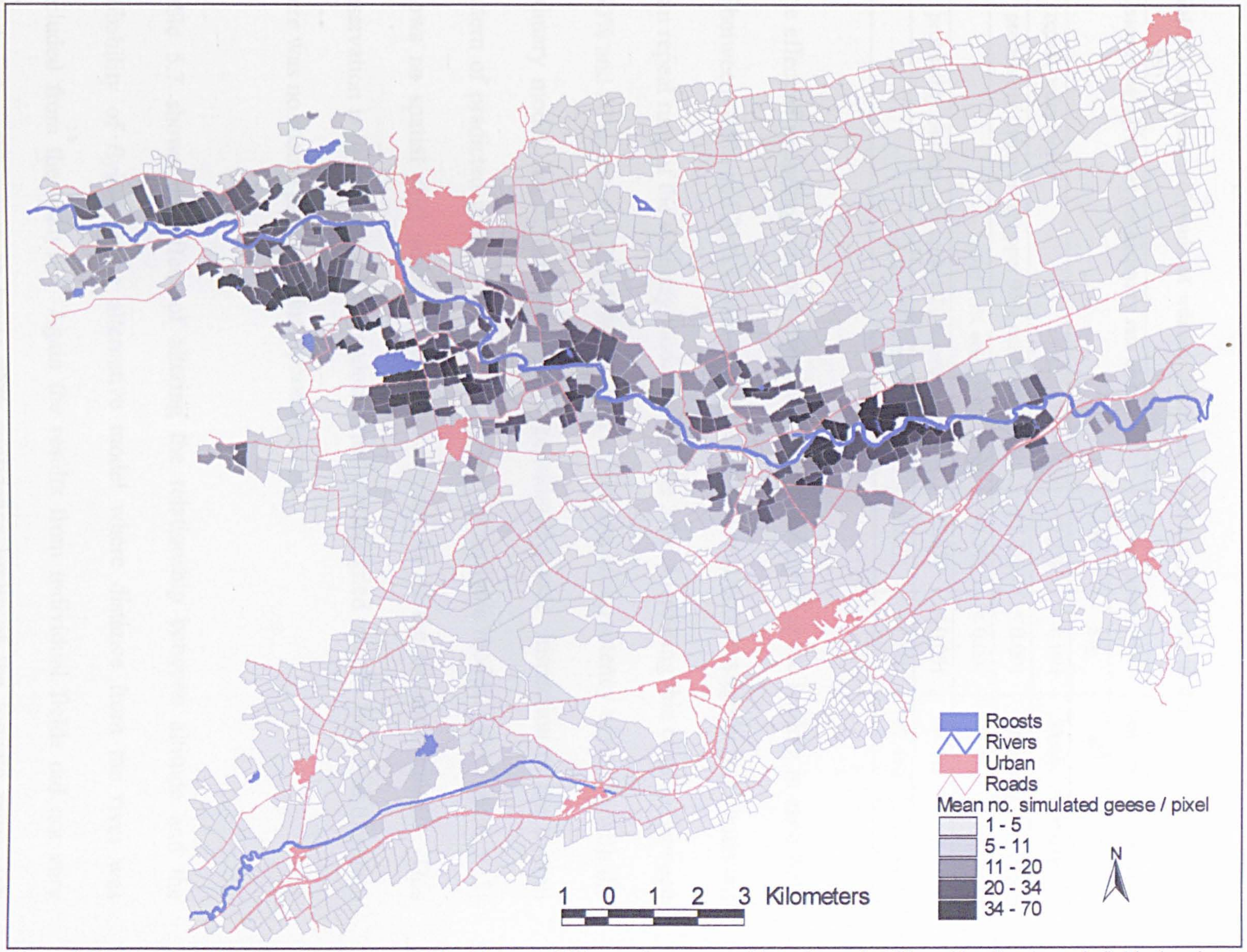

Figure 5.13 Results of the river simulation model with up to 50% error incorporated into the probability of landing in each field, showing the mean number of geese simulated to land per pixel for each field.

equations used in the model to predict the probability of pixels being flown over should not have a great effect on the results.

Table 5.6 Agreement of results of ordinary simulation model and sensitivity models with error included. (n = 3,599)

Comparing agreement of ordinary run and . .	Mean pixel value		Sum of pixel values	
	R^2	Sig.	R^2	Sig.
. . repeat ordinary run	97.2%	< 0.001	98.6%	< 0.001
. . probability flying using upper 95% confidence limit	88.3%	< 0.001	94.1%	< 0.001
lower 95% confidence limit	90.7%	< 0.001	95.5%	< 0.001
. . probability landing with up to ± 20% error	95.8%	< 0.001	97.5%	< 0.001
up to ± 50% error	90.2%	< 0.001	92.4%	< 0.001

The effect of including random error into the probability of geese landing in each field of between –20% and 20% (mean ± 10%) produced results only slightly less consistent than repeat runs of the ordinary model (see Table 5.6). Increasing this error to between –50% and 50% (mean ± 25%) did result in a decrease in consistency of results with the ordinary model, but agreement was still considered good. Inspection of the overall pattern of predicted goose use from the sensitivity analysis models (see Figure 5.13) shows no spatial shift when compared to the results of the ordinary model. This observation is to be expected as random error was assigned to each field and therefore there was no spatial pattern in incorporated error.

Table 5.7 shows the effect of altering the relationship between altitude and the probability of flying in the alternative model where distance from the river was excluded from the analysis. Again the results from individual fields did not vary greatly when the upper or lower 95% confidence limits of the logistic regression coefficients was used to produce the '*probability of flying*' probability surfaces (See

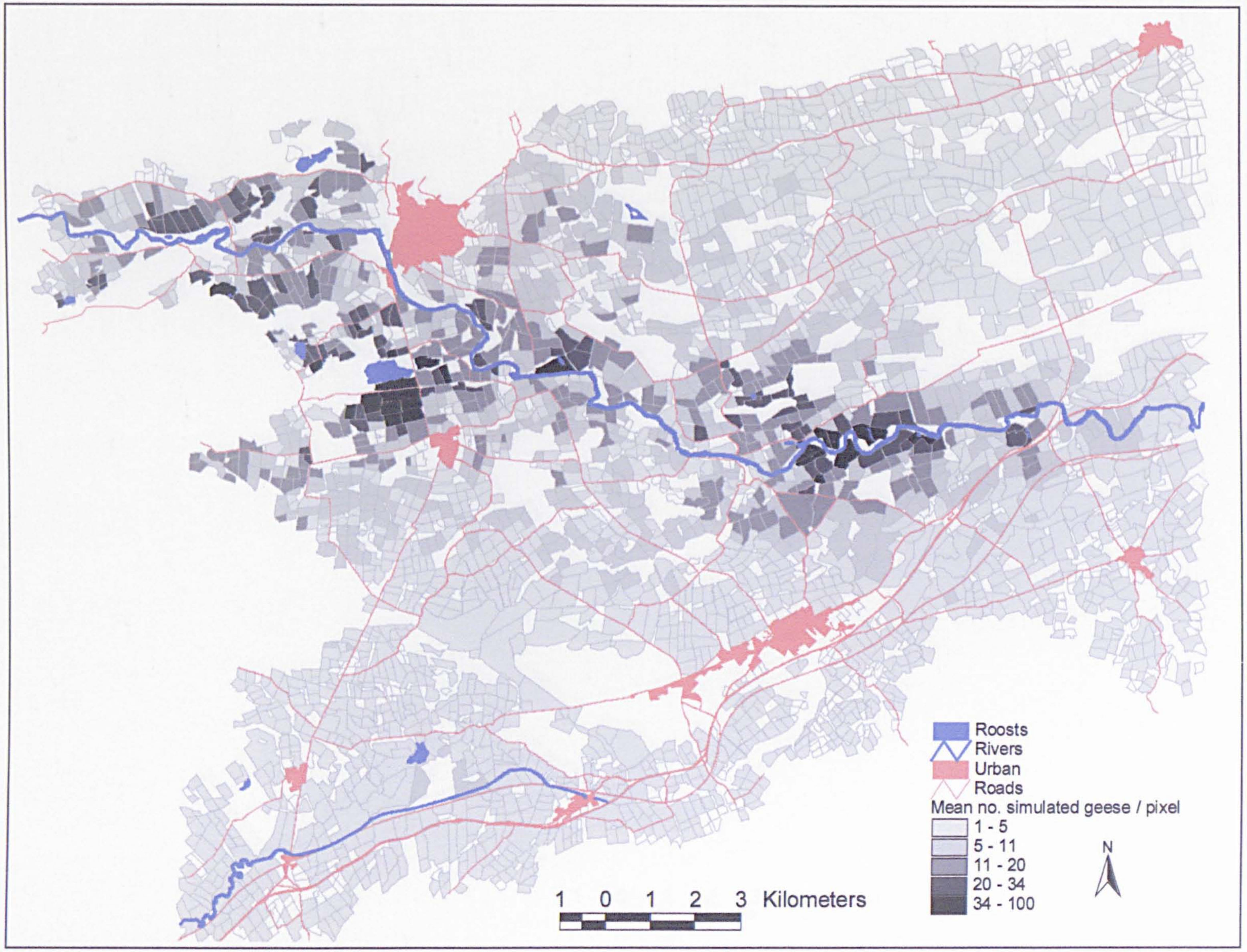

Figure 5.14a Results of the altitude simulation model using the upper 95% confidence limits of the logistic regression coefficients, showing the mean number of geese simulated to land per pixel for each field.

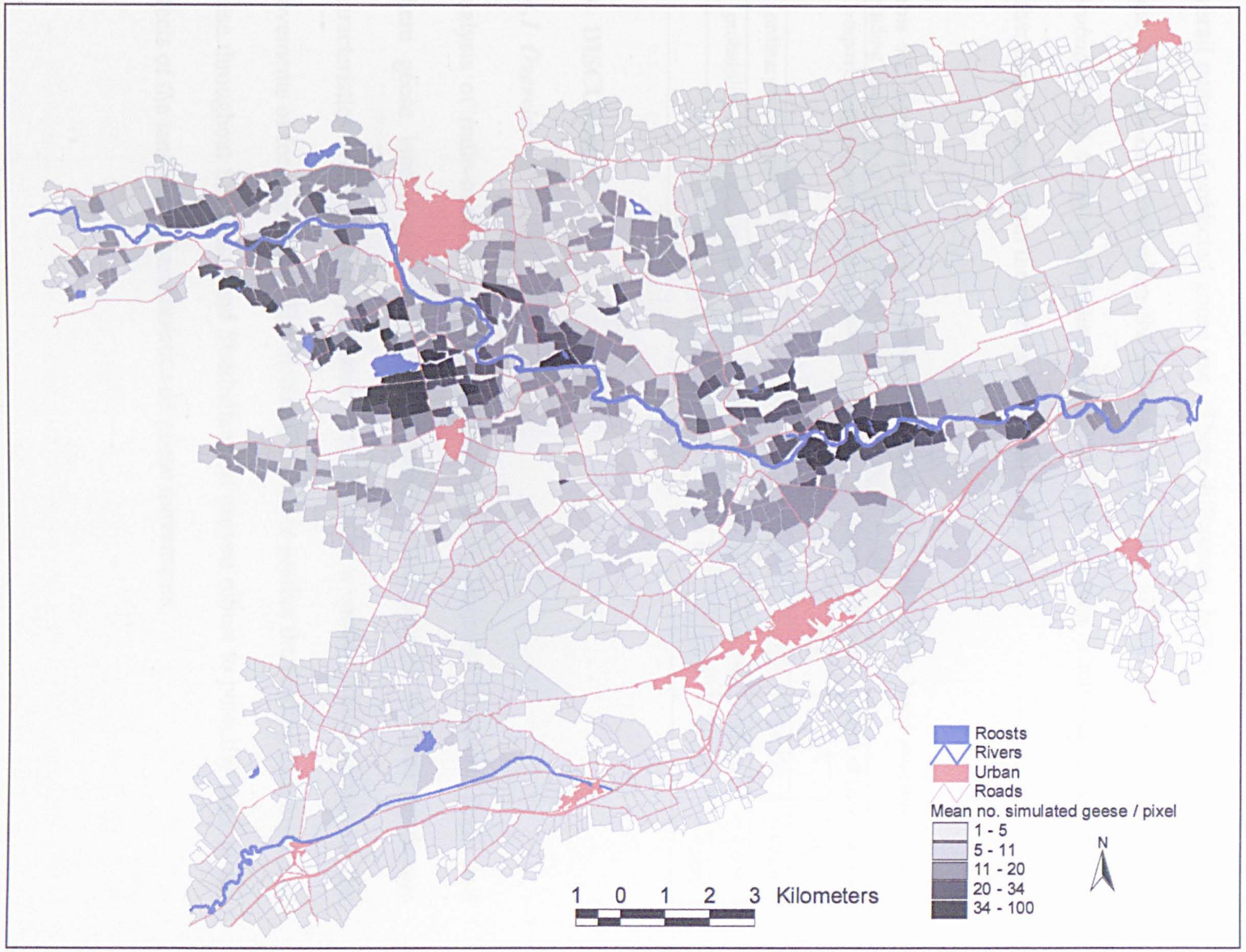

Figure 5.14b Results of the altitude simulation model using the lower 95% confidence limits of the logistic regression coefficients, showing the mean number of geese simulated to land per pixel for each field.

Table 5.7). From Figures 5.14a & 5.14b it can be seen that although the spatial effect of altering the logistic regression model is not great there are slight differences in the overall pattern of predicted goose use. These differences, however, do not follow the clear patterns observed when the ordinary model was altered. This is because the '*probability of flying*' probability surface is more complex when based on altitude, rather than distance from the river (see Figures 5.6 & 5.7).

Table 5.7 Agreement of results of ordinary simulation model and altitude based simulation model, including sensitivity of altitude based probability of flying. (n = 3,599)

Comparing agreement of altitude model run and	**Mean pixel value**		**Sum of pixel values**	
	R^2	**Sig.**	**R^2**	**Sig.**
.. ordinary model run	77.8%	< 0.001	84.3%	< 0.001
.. probability flying using upper 95% confidence limit	88.2%	< 0.001	93.6%	< 0.001
lower 95% confidence limit	89.1%	< 0.001	93.7%	< 0.001

5.4 DISCUSSION

5.4.1 Overview

Analysis of radio-tracking data showed that both the direction of goose flight and where geese landed was related to landscape characteristics. These landscape characteristics were used to constrain movement in a model which simulated the movements of feeding geese. The model was used to predict the feeding distribution of geese throughout Strathearn and Strathallan and proved robust to potential error in the effects of the landscape characteristics on goose movements.

5.4.2 Radio-tracking data

The amount of time that individual geese remained in the study area varied greatly. As a result the amount of radio-tracking data collected also differed greatly among individuals geese. Aebischer *et al* (1993) warn that the use of radio locations as sample units can lead to non-independence and an inflation of the apparent number of degrees of freedom, and suggest the use of animals rather than radio locations as a sample unit. Non-independence can result from:

1) Serial correlation of sequentially collected radio locations

   In this analysis discrete goose movements were analysed. As subsequent movements were punctuated with periods of time that the goose spent feeding, it is unlikely that serial correlation between subsequently collected goose movements would prove a major problem.

2) Individual variation in behaviour between animals

   Radio-tagged geese roosted with large numbers of other geese, flew out to feed in large flocks and moved relatively regularly, therefore utilising different parts of the study area. Furthermore analysis of different measures of goose movements showed that variation between individuals was no greater than that within individuals (Chapter 4). This suggests that the movements of radio-tracked individuals did not vary greatly and was a good representation of typical movements of the whole population of geese in the study area. This was supported by the fact that although only 1.1% of fields in the study area were observed to have been used by radio-tagged geese, of these fields 30% were used by more than one radio-tagged individual at different times.

Analysing the data collected using individuals as sample units would have been too complex and would have required more data. It was considered that although not ideal, analysing goose movements by pooling observations over all individuals was valid.

5.4.3 Effect of topography

Distance from the river appeared to be the main factor affecting where geese flew in the study area, and in the absence of this data, altitude was the next most significant variable. Although flying over flat areas (i.e. along the valley floor) will use less energy that flying up and down hills, the range of altitudes considered in this analysis was small (5 – 268masl, mean = 91, s.d. = 50) and this effect is likely to be slight. Geese are more likely to fly along the valley bottoms because this is where the most fertile soil is, with more stubble fields and better quality grassland. In addition, following a river or valley will lead to more high quality farmland, whereas continued flying uphill would eventually result in encountering less suitable feeding areas such as rough grassland and moorland. Floodwaters along rivers also provide areas for loafing, drinking and bathing which may be an added attraction to the birds.

In reality geese do not make decisions about their direction of flight from consideration of the altitude, or distance from the river, based on the area 100m in front of them alone. Geese are likely to respond to the landscape at a much greater scale, and be affected by other visual cues such as the position of other flocks of feeding geese. It is probable that geese have some prior knowledge of where good feeding areas are situated and fly directly to them. Although the mechanism used to constrain flight in the simulation model may not be that used by the geese, it is likely that the resultant flight paths are realistic as the relationships in the model are based on the results of analysis of goose movements.

5.4.4 Effect of disturbance

The effect of disturbance on bird distributions has been well documented (see Hockin *et al* 1992). Human disturbance of geese has been shown to affect goose feeding distribution, with geese avoiding areas with disturbance from roads (Newton & Campbell 1973; Madsen 1984; Keller 1991), buildings (Chapter 3) and shooting (Newton & Campbell 1973; Gerdes & Reepmeyer 1983; Madsen 1984). Observations of causes of disturbance to radio-tagged geese in this study show that the majority is due to human activity (see Chapter 4). The distance from the nearest building is the variable that best predicted where geese were likely to land. This is due to disturbance caused by the increased human activity around buildings.

5.4.5 Predicting goose distribution

Logistic regression analysis of the presence / absence of Greylag geese has been carried out in the same study area (see Chapter 3). The same landscape characteristics were used as in this study and goose distribution data were collected by surveying sample fields in the winter of 1997-1998. This logistic regression model included distance from roost, maximum distance from buildings and altitude (distance from the river was not included in the model) as field characteristics affecting whether geese used fields. Two of these variables, maximum distance from the nearest building and altitude, were included in the simulation model to constrain goose movements. Distance from the nearest roost was the third variable included in the logistic regression model and roost location is included in the simulation model, as this is where geese start the day. The agreement between the two analyses on the landscape characteristics affecting goose distribution in the study area gives confidence to the findings of the analysis of radio-tracking data. In addition, the sensitivity analysis showed the model to be robust to potential inaccuracies in the form of these relationships. This suggests that the simulation model is likely to be a good representation of goose movements and therefore where geese feed in Strathearn and Strathallan.

The ability to create transferable predictive models is important. For this study area the model including distance from the river as a variable is probably the most accurate. Although transferable to other goose feeding areas along major rivers, this model is not suitable for predicting goose distribution in all situations. Substituting altitude for distance from the river results in a more widely transferable model. As altitude was less significant than distance from the river at predicting where geese were likely to fly, however, the altitude-based model constrained the flight path of geese much less than the original model (see Figs 5 & 6). As a result the altitude-based model is likely to be less accurate at predicting the distribution of geese.

5.4.6 Possible developments

An obvious omission from this model is resource quality or quantity, especially as geese are flying out to fields for the sole purpose of feeding. Owing to the flexibility of

IBMM's it is possible to extent this model to include the effect of resource availability. This would require the creation of a probability surface with a measure of the resource available in each pixel. There are several ways such information could be included in this model:

1. To integrate a probability surface based on resource quality / quantity with the '*probability of landing*' surface using Bayesian integration (see Pereira & Itami 1991). This would result in the probability of a goose landing in a field being dependent on a combination of the extent of disturbance (maximum distance from the nearest building) and resource availability.

2. To include a temporal dimension to the model with the time spent by the goose in the field dependent on resource availability. This would require the model to be extended to register the total time spent by geese in each pixel.

3. To create a depletion model, in which the resources are depleted at each visit by a goose, reducing the amount of resource in the pixel and therefore the probability of subsequent geese landing.

Although such resource modelling is possible, obtaining accurate data on the resources available is problematic. Different crops are used to differing extents, but more importantly the quality and quantity of the resource available cannot be ascertained from knowledge of the crop type alone. For example, the amount of stubble in fields varies greatly (Newton & Campbell 1973) and the quality of grass is likely to affect goose preference as with Barnacle Geese (*Branta leocopsis*) (Patton & Frame 1981, Percival 1993). In addition there are temporal changes in resource availability, for example, grass being depleted by livestock or increasing through growth, stubble being ploughed or depleted by animals and birds other than geese. Even if these data could be obtained and included in the model, it would only be applicable for the place and year in which the data were gathered. It was therefore considered more suitable to build a baseline transferable model that highlights areas which are likely to be used by geese, provided suitable resources are available.

The simulation model is likely to be more transferable to other areas than correlative mapping models in which probability of occurrence at different distances from the roost is fixed. This is because whether a goose flies over a field and has the opportunity of landing in it is dependent on how suitable the landscape was nearer the roost. If there are plenty of suitable feeding areas close to the roost, the goose is less likely to have the need or opportunity to land in fields further away. The whole landscape and not just the characteristics of an individual field therefore influence predicted distribution in the simulation model (see Figure 5.15).

The simulation model also provides the flexibility to vary numbers of geese at each roost, whereas the logistic regression models do not. This is particularly beneficial in this study area where a relatively large number of roosts were used but to very different extents. It is also possible to manipulate the number of geese leaving from each roost to investigate the impact of changes in roost use (e.g. due to development or positive site management) on goose feeding distribution.

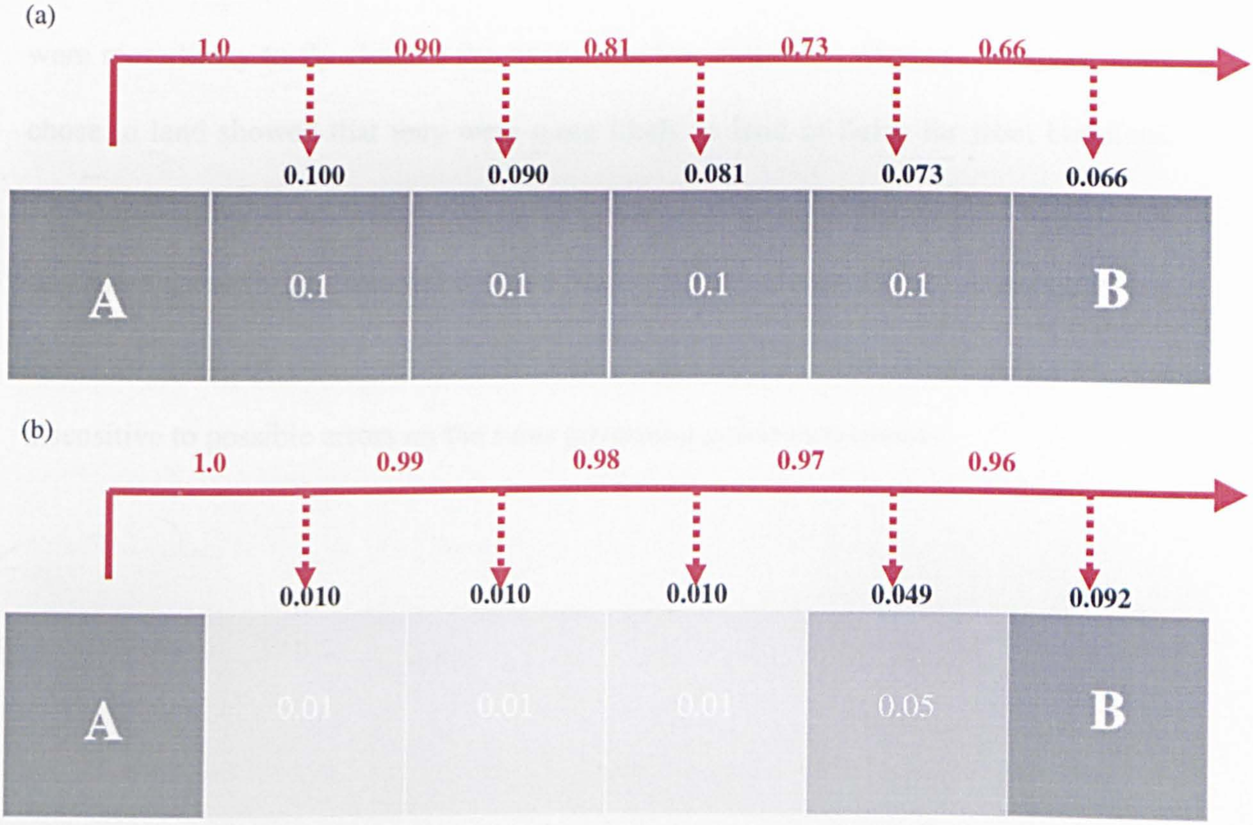

Figure 5.15 Diagram to show the effect of the surrounding landscape on the probability of a simulated goose landing in a particular pixel (pixel B). Grey boxes represent pixels, with the probability of landing shown in white. The red arrow shows the path of a goose flying from A towards B with the probability of a goose reaching each pixel shown in red. The black numbers give the probability of the goose landing in each pixel. It can be seen that the chance of a goose landing in pixel B (which has a probability of landing of 0.1) is dependent on the probability of landing in previous fields in addition to that of the B pixels.

In conclusion IBMM's provide a flexible approach for predicting the distribution of populations, whether modelling the dispersal of individuals to predict meta-population dynamics (e.g. Boone & Hunter 1996) or foraging trips to predict feeding distribution (e.g. Jones 1977). Deriving the decision rules on which these models are based from empirical data obtained from the behaviour of individual animals (e.g. radio-tracking) gives the model realistic parameters and in turn realistic results.

5.5 SUMMARY

Twenty-four Greylag geese were radio-tracked over the course of three winters, and a total of 227 movements recorded. Analysis of goose flight directions showed that they were more likely to fly close to the river, or at low altitudes. Analysis of where geese chose to land showed that they were more likely to land in fields far from buildings. These rules were incorporated into an individual based movement model (IBMM) that simulated geese flying from the roost to feed in fields. Goose feeding distribution was predicted from the results of repeated runs of the model. The model was relatively insensitive to possible errors on the rules governing goose movements.

CHAPTER 6 – COMPARISON BETWEEN THE MODELLING TECHNIQUES WITHIN STRATHEARN AND STRATHALLAN

6.1 INTRODUCTION

6.1.1 Background

Wildlife-habitat models are used relatively frequently to predict animal distribution (see review in Chapter 3) and consequently a number of papers have compared different approaches to this type of modelling (e.g. Manel *et al* 2000). In contrast there are relatively few examples of distribution predictions being made from models of animal movements. No comparison of individual based movement models (IBMM) with more standard approaches (i.e. wildlife-habitat models) could be found in the literature. In this study two modelling techniques have been used to predict the feeding distribution of Greylag geese in Strathearn and Strathallan (see Chapters 3 & 5). The purpose of this chapter is to compare the two approaches and assess whether the IBMM is better at predicting goose feeding distribution than a standard approach, logistic regression.

The first modelling technique, logistic regression, was a deterministic approach derived from goose survey data. This logistic regression model predicted the probability of Greylag geese using a field from the field's landscape characteristics (distance from the nearest Greylag goose roost, distance from the nearest building and the altitude of the field) (see Chapter 3). The second modelling technique, an IBMM, simulated goose movements throughout the day. Simulated goose movements were influenced by the landscape, with the relationships between landscape characteristics and goose movements derived from radio-tracking data. In the model simulated geese fly from the roost with their flight path constrained by altitude or distance from the river. The probability of the goose landing was dependent on how far the field over which they were flying is from the nearest building. After the initial flight from the roost, simulated geese made subsequent movements between fields until the end of the day. These movements were constrained by the same variables as the initial flight from the roost, but with slightly differing rules (see Chapter 5).

The two models take different approaches to predicting the distribution of geese and were based on different types of data, but both models used the same landscape characteristics to predict the feeding distribution of Greylag geese. In addition to comparing the consistency of results obtained from the two modelling techniques, it was therefore possible to compare the relationships between predicted goose use and the landscape characteristics incorporated in the model between modelling techniques.

Two sets of data on the pattern of Greylag goose use in Strathearn and Strathallan were collected: the results of the survey work on which the logistic regression model was based (see Chapter 3); and the radio-tracking data, used in the creation of the IBMM (see Chapter 5). The ability of logistic regression models to predict observed goose use was assessed using standard techniques such as ROC-plots (see Chapter 3). The results of the IBMMs, however, give a measure of the extent of goose use and the shape of the distribution of predicted results cannot be transformed into probabilities. Consequently, standard techniques such as ROC plots cannot be used to assess model fit. In Chapter 5 no measure was given of the ability of the IBMM to predict the observed goose distribution. In this chapter the capability of the two modelling techniques to distinguish between fields where geese were present and fields where they were not is assessed using observations from both the radio-tracking and survey work.

6.1.2 Aims

This chapter aims to:

(i) Assess agreement between the results of the two modelling techniques

(ii) Examine the relationship between landscape variables and the predicted results to enable a comparison of the two modelling techniques

(iii) Compare the results of the two modelling techniques with observed data to assess their accuracy at predicting the distribution of Greylag geese within Strathearn and Strathallan

6.2 METHODOLOGY

6.2.1 Models used in comparison

The raw landscape data required to predict the distribution of Greylag geese, by either modelling technique, are the altitude and the location of buildings, fields and goose roosts. If applying the IBMM with flight constrained by distance from the river then the location of rivers is also required. These data can be extracted from OS Land-Line data with the exception of the location of goose roosts. For the logistic regression model information on the location of Greylag goose roosts was taken from a study on roost use in the area by Bell *et al* (1997). Greylag goose roosts were included in the model if more than 5% of observations for the river catchment were from that roost: a total of nine Greylag goose roosts were selected. Radio-tracking data from this project, however, recorded 16 roost sites being used by radio-tracked geese in the study area (see Chapters 4 & 5) while only four of these sites were included in the original logistic regression analysis. These 16 roost sites used by radio-tracked geese were included in the IBMM with the frequency of use by simulated geese corresponding to that observed. The difference in the roost data used in these two modelling techniques makes the following comparisons between the two techniques problematic:

(i) **Visual comparison** of the predicted goose distributions between models as predicted goose use would not be clustered around the same roost sites.

(ii) **Comparisons of the distance geese are predicted to feed from the roost.** When there are more roost sites geese are likely to feed closer to the nearest roost as there will be an increased chance of geese feeding near a roost where they did not spend the night.

(iii) **Comparisons of the altitude at which geese are predicted to feed.** Landscape variables, in particular altitude, are spatially autocorrelated. Therefore as geese are predicted to feed close to roosts, the altitude of roost sites will affect the altitude at which geese are predicted to feed.

(iv) **Comparison of the fit of models to observed data.** Assessing the fit of the models to the observed data will be dependent on the accuracy of the roost locations incorporated in addition to the modelling technique.

Therefore as well as considering the original logistic regression model and IBMMs (from Chapter 3 & Chapter 5 respectively) the roost sites in both models were adjusted to enable more direct comparisons between modelling techniques. Table 6.1 summarises the different models created. For both modelling techniques new models were created using the alternative source of roost location data. In addition, as the regression model does not account for unequal use of different roost sites, the original IBMMs were run with equal numbers of geese using each roost.

Comparison between models and between predicted and observed results was made at a field scale because fields are the unit in which goose use is predicted by both modelling techniques. In addition this is the scale at which accuracy would be required for goose management plans.

Table 6.1. A description of the source data used in the original and adjusted models. LRM = logistic regression model, IBMM = Individual based movement model.

Model name	**Technique**	**Original model?**	**Roost data source**		**Roosts used equally?**	**Topographic variable**
			Bell *et al* (1997)	Radio-tracking		
OLR	LRM	✓	✓			altitude
LR2	LRM	✖		✓		altitude
OM-R	IBMM	✓		✓	✖	river
OM-A	IBMM	✓		✓	✖	altitude
EQM-R	IBMM	✖		✓	✓	river
EQM-A	IBMM	✖		✓	✓	altitude
M2-R	IBMM	✖	✓		✓	river
M2-A	IBMM	✖	✓		✓	altitude

6.2.2 Comparison of the results of the models

The agreement between the predicted results from the two logistic regression models and six IBMMs (three river model and three altitude models) was assessed by correlating the predicted goose use for each field. For simplicity, in this and all subsequent analyses in this chapter, only the mean number of simulated geese landing per pixel was used as the measure of predicted goose use for the IBMMs. The mean number of geese landing per pixel was considered preferable to the total number of geese landing per field for this comparison because the latter is dependent on both field suitability and field size. Owing to the correlation between area and both maximum distance from the nearest building ($r = 0.44$, $n = 3599$, $p < 0.001$) and altitude ($r = -0.09$, $n = 3599$, $p < 0.001$), comparison of the effects of landscape characteristics between models would be confounded when using the predicted total number of geese per field, but not when using the predicted mean number of geese per pixel (density).

Correlation takes no account of spatial distribution and therefore gives no indication of the differences in the spatial patterns of the two models (i.e. whether one model predicts higher goose use in certain areas / regions). The difference between models was therefore also displayed visually. For each model, fields were ranked by the predicted goose use, with tied ranks being given the mean rank value. The difference between the ranks of the two models was then mapped for each field.

In addition to comparing the agreement between the model predictions, analysis of the relationships between predicted goose use and the individual landscape variables on which the models are based provides an insight into how the models differed. Bar charts were used to show the variation in the predicted extent of goose use at differing distances from the roost, distances from buildings and altitudes for each model (i.e. the significant predictor variables in the models).

6.2.3 Fit to observed data

The data on field use by Greylag geese in Strathearn and Strathallan used to create the logistic regression model was based on surveying 422 fields throughout one winter (see Chapter 3). The IBMMs were based on data from radio-tracked geese. Radio-tracked geese were recorded in 92 fields. For this analysis an additional 92 fields not used by geese were selected by identifying fields that the goose would have landed in had it flown from the same origin for the same distance but in a random direction (see Chapter 5). Greylag geese were observed in 43 fields during the survey work and radio-tracked geese used 25 of the survey fields. A chi-squared test was used to assess the agreement between the two sets of observed data within the survey area.

The ability of the models to distinguish between fields where geese were observed and those that were not used was tested using a Mann-Whitney U test. A non-parametric test was required as the predicted results, particularly the IBMMs, were not normally distributed. The z-score of the Mann-Whitney U test was used as a measure of the ability of the models to predict the presence / absence of geese.

6.3 RESULTS

6.3.1 Comparison on model results

Table 6.2 shows the R-values from the correlations comparing predicted results from different models for each field. All model results were highly significantly correlated ($P < 0.001$) (Table 6.2) although this might be expected with such a large sample size ($n = 3599$). The consistency between the results of the two logistic regression models using different roosts (**LR-O** and **LR-2**) was moderately high (R-value = 0.833, P < 0.001). IBMMs based on the same roost sites also gave consistent results (R-values ranged between 0.891 and 0.925, P < 0.001 for all). The agreements between the IBMMs based on different roost locations, however, were considerably lower (R-values ranged between 0.336 & 0.479, P < 0.001 for all) (see Table 6.2). This suggests that changing the roost locations had a greater effect on the results of the IBMM than the logistic regression model. As expected models using identical roost data (**LR-O** & **M-2** and **LR-2** & **M-EQ**) had more consistent results than models using different roost locations or different frequencies of use. The consistency between modelling techniques using the same roost locations was actually greater that the consistency of the IBMMs using different roosts.

Table 6.2. Comparison of the predicted results of the logistic regression models and IBMMs showing the r-value of the correlations. P <0.001 and n = 3599 for all.

Models	**LR-O**	**LR-2**	**M-OR**	**M-OA**	**M-EQR**	**M-EQA**	**M-2R**	**M-2A**
LR-O		0.833	0.591	0.595	0.634	0.641	0.644	0.658
LR-2			0.637	0.643	0.707	0.722	0.534	0.530
M-OR				0.925	0.894	0.849	0.381	0.339
M-OA						0.891	0.336	0.394
M-EQR						0.912	0.479	0.401
M-EQA							0.420	0.432
M-2R								0.877

The differences in the rank of the predicted results for selected pairs of models are shown in Figures 6.1 to 6.4. The variation between the results of models are not spatially independent and there are relatively large patches where one model out predicts another. These differences can be understood by looking at how predicted goose use varies with changing altitude and distance from the roost, factors that are clearly spatially autocorrelated.

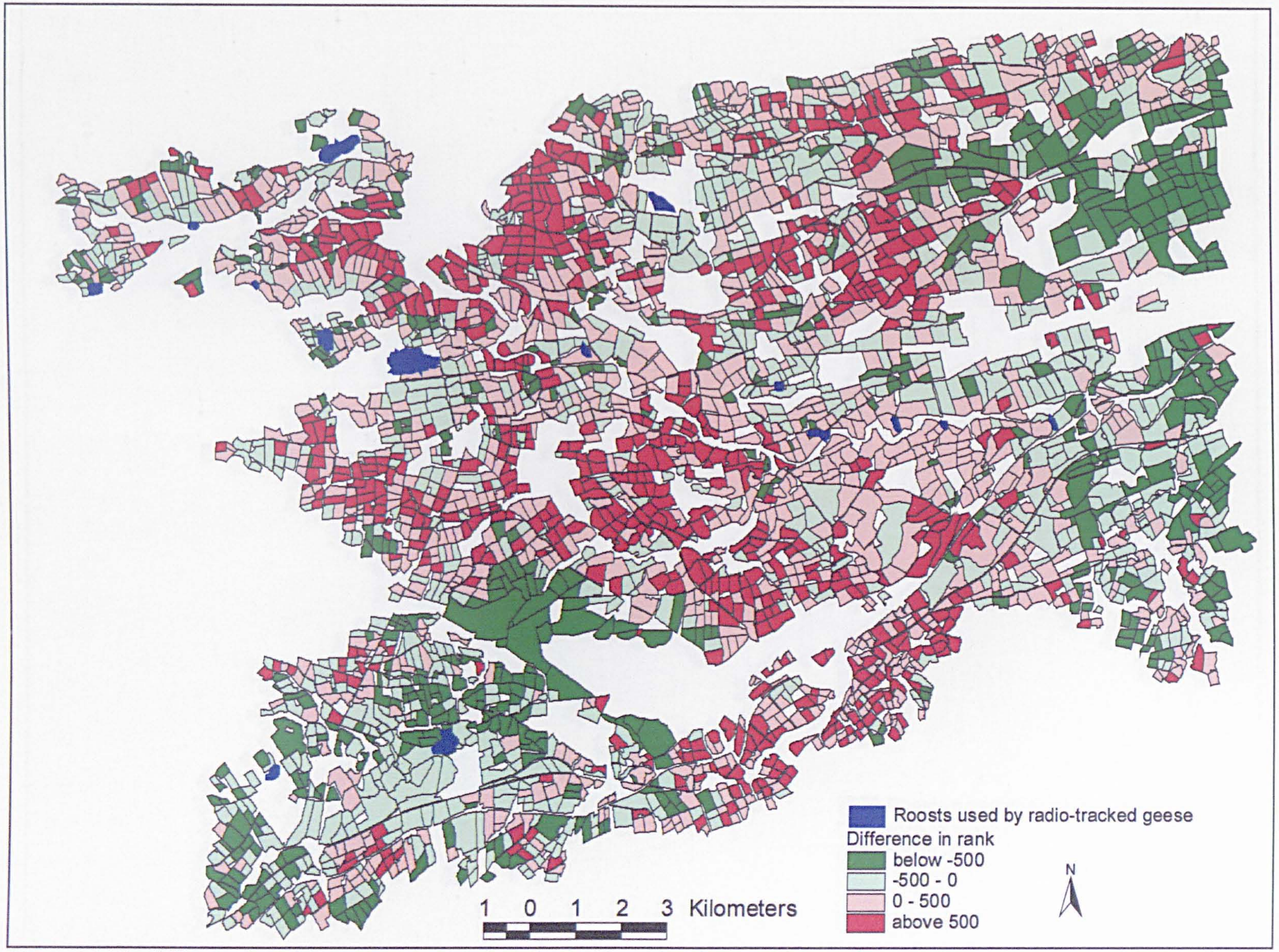

Figure 6.1 The difference in rank between **M-EQA** and **LR-2**. Positive values indicate high predicted use by model **M-EQA**, while negative values indicate higher predicted use by model **LR-2**. Rank values range from 1 to 3196.

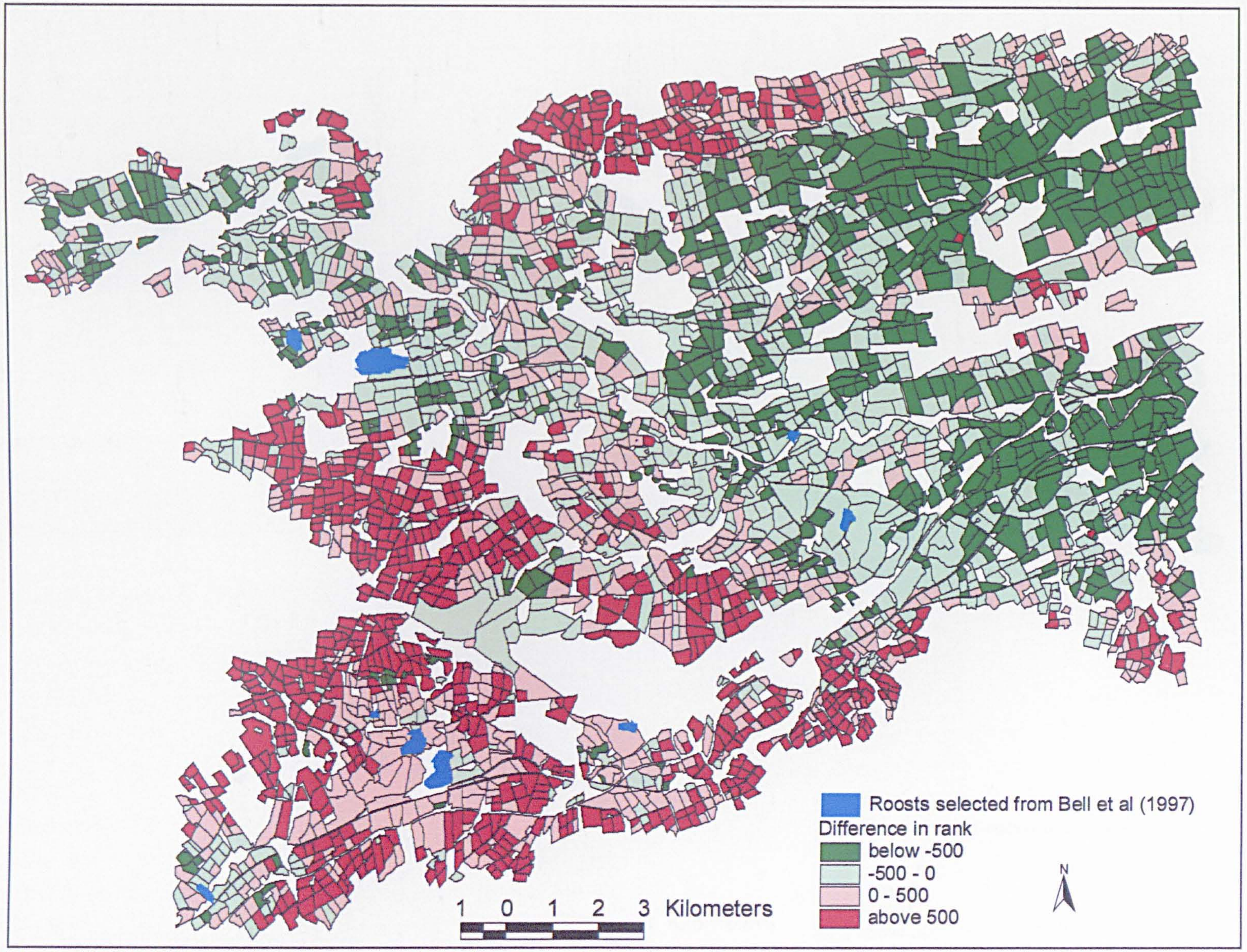

Figure 6.2 The difference in rank between M-2A and LR-O. Positive values indicate higher predicted use by model M-2A, while negative values indicate higher predicted use by model LR-O. Rank values range from 1 to 3196.

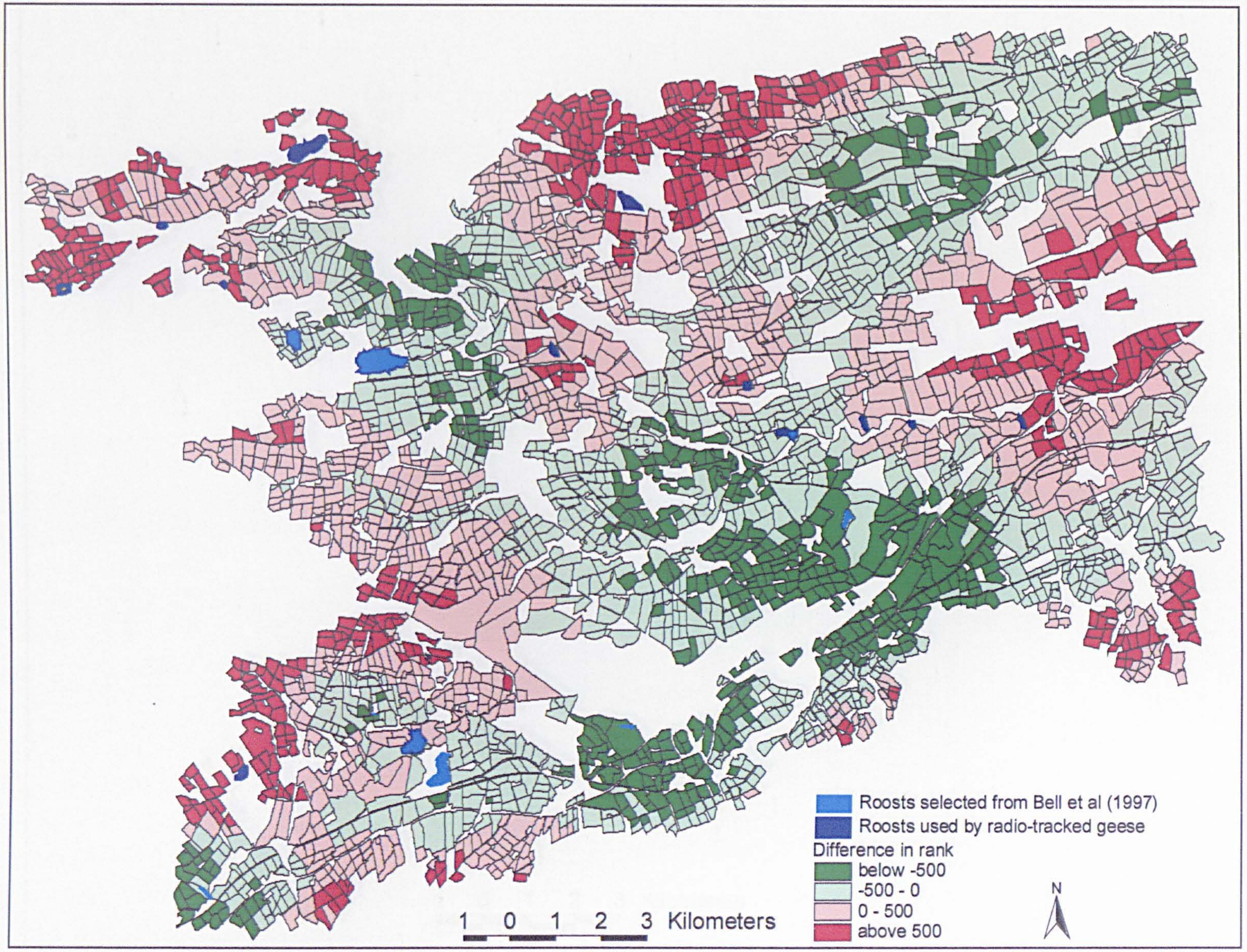

Figure 6.3 The difference in rank between LR-O and LR-2. Positive (red) values indicate higher predicted use by model LR-2, while negative (green) values indicate higher predicted use by model LR-O. Rank values range from 1 to 3196.

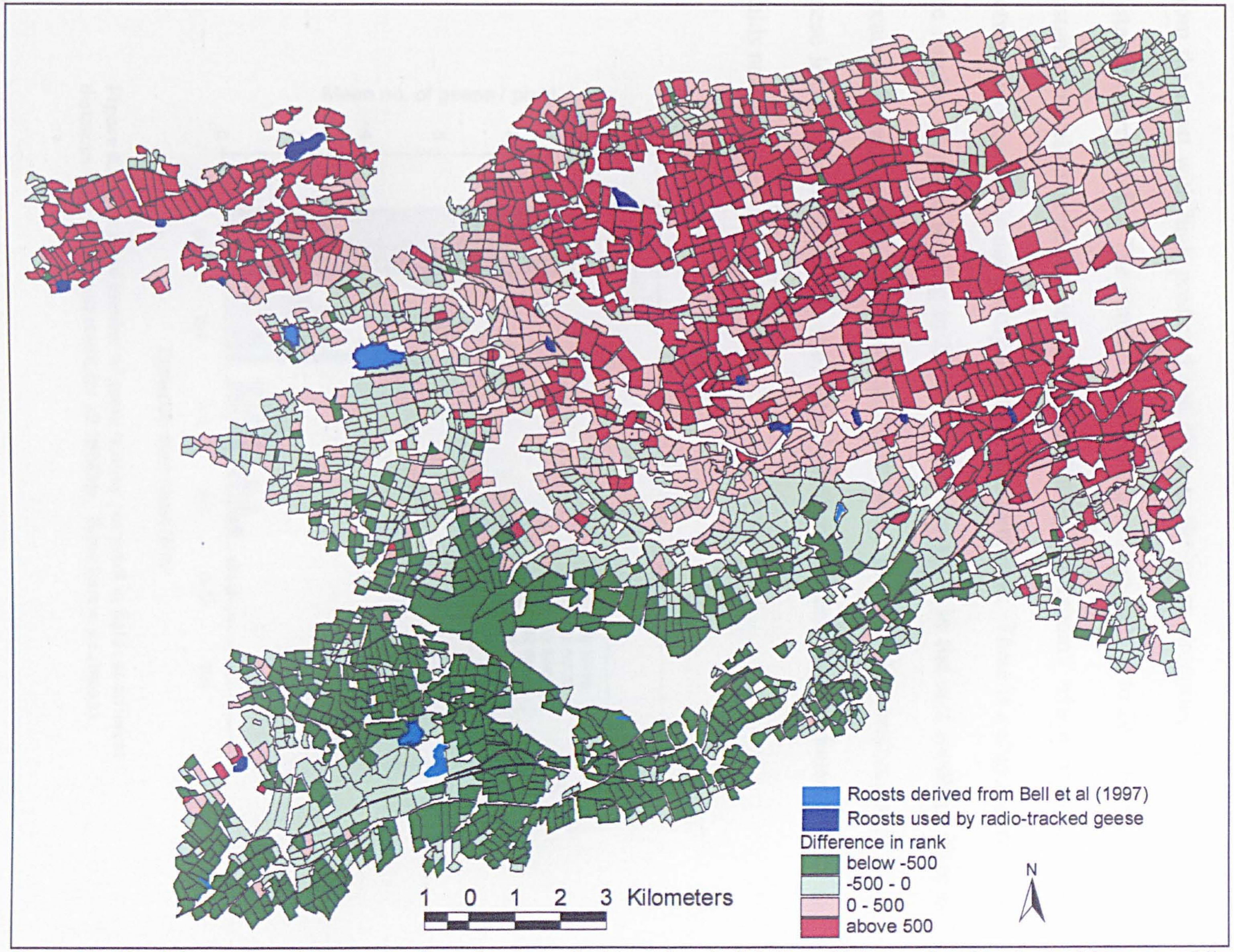

Figure 6.4 The difference in rank between M-2A and M-EQA. Positive values (red) indicate higher predicted use by model M-EQA, while negative values (green) indicate higher predicted use by model M-2A. Rank values range from 1 to 3196.

6.3.2 *Comparison of the relationships with predictor variables*

All IBMMs showed a very similar pattern of predicted goose use at varying distances from the roost with high predicted use close to the roost, dropping off quickly with distance (Figure 6.5). The similarity of the different models is to be expected as the distance travelled is dependent on the probability of landing which does not alter between models and is not greatly spatially autocorrelated. There is a slight increase in the number of geese feeding in fields close to the roost in the M-2 models. This is because the M-2 models are based on fewer goose roosts and, therefore, with more geese leaving from each roost site, larger numbers of geese are predicted to land in fields nearby.

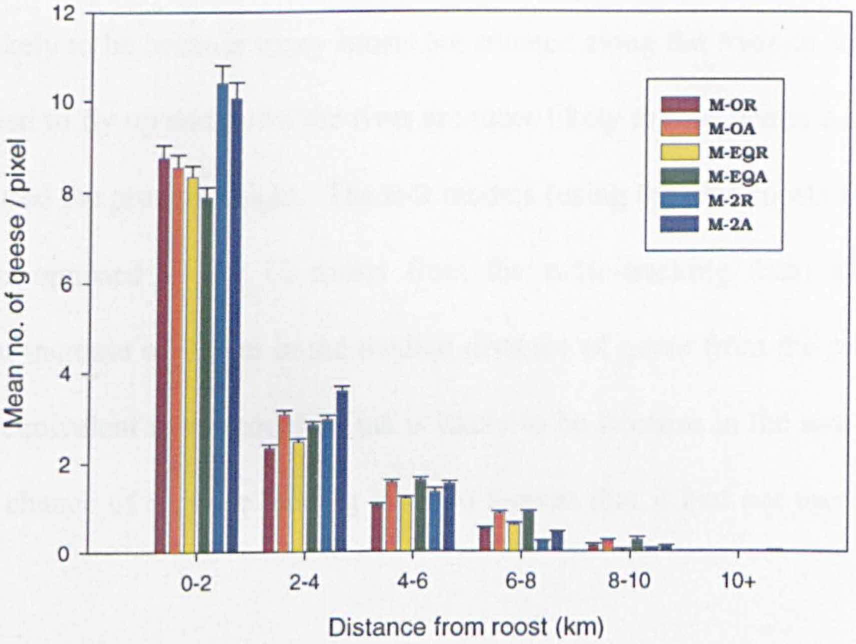

Figure 6.5 The mean number of geese landing per pixel in fields at different distances from the nearest roost, for all IBMMs. Error bars = s.e.(mean).

The form of the relationship expected when considering geese just using the first field in the day should approximate to:

$$P(D) = \lambda * EXP(-\lambda/D)/2\pi D$$

Where $\lambda \approx D/Q$, λ is the mean distance at which geese land from the roost (in pixels), D is the distance from the roost (in pixels) and Q is the mean probability of landing per pixel. The term $2\pi D$ accounts for the effect of the increasing number of pixels available to land in at greater distances from the point of origin. This relationship will be further complicated by goose movements throughout the day but will maintain its basic form. The median distance at which geese were predicted to feed from the nearest roost in the IBMMs ranged from 1.2 to 1.5km. Models with goose flight constrained by rivers had a median flight distance consistently 0.1km less that the equivalent altitude model. This is likely to be because many roosts are situated along the river so simulated geese constrained to fly up and down the river are more likely to land nearer a roost that they had not used the previous night. The **M-2** models (using the nine roosts from Bell *et al* (1997) as opposed to the 16 roosts from the radio-tracking data) also showed a consistent increase of 0.1km in the median distance of geese from the roost compared with the equivalent **M-EQ** models. This is likely to be because in the **M-2** models there was less chance of a goose landing close to a roost that it had not used the previous night.

The expected form of the relationship between the distance from the roost and the predicted probability of goose use from the logistic regression models is a logarithmic curve, as Ln (distance from roost) was the term incorporate in the model. This appears to be true for both logistic regression models (Figure 6.6). The relationship between predicted goose use and distance from the roost differs between modelling techniques. The logistic regression models predict higher use of fields further from the roost compared with the IBMMs. This effect can be seen when looking at the spatial pattern of the differences between the modelling techniques (Figures 6.1 and 6.2). Assuming that the predicted probability of goose use of a field was a measure of the extent of goose use, then the median distance from the roost of feeding geese from LR-O was 2.3km. For LR-2, using the roosts from radio-tracking data, the predicted median distance of feeding geese from the roost was 1.7km, much closer to the value predicted by the IBMMs.

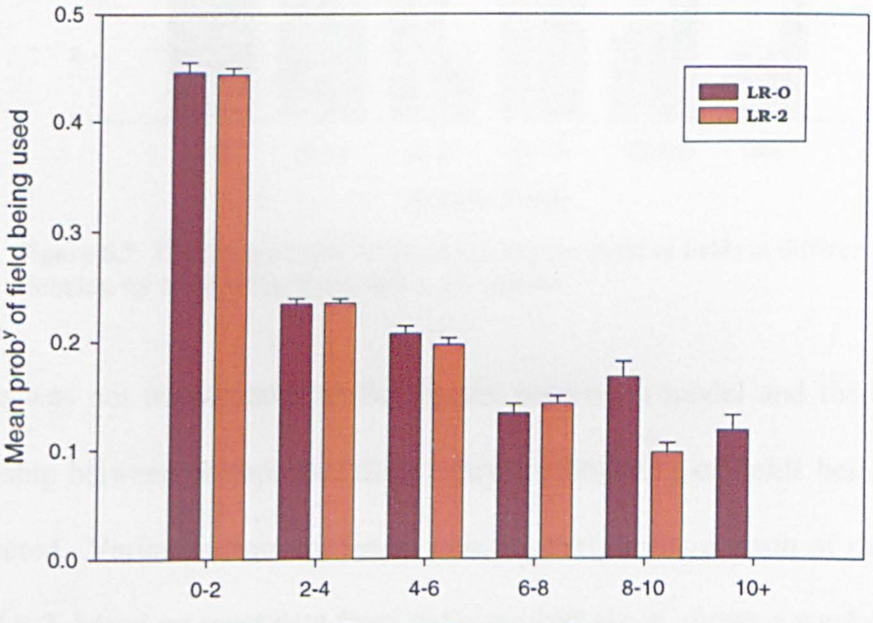

Figure 6.6 The mean predicted probability of field use at different distances from the nearest roost for all logistic regression models. Error bars = s.e. (mean).

Figure 6.7 shows the relationship between altitude and the predicted extent of goose use for the six IBMMs. There is relatively little difference between M-O and M-EQ models and between the altitude and river models, all showing greater predicted goose use of fields at lower altitudes. The M-2 models, however, result in a very different pattern reflecting the positions of roosts. High goose use will be predicted close to roost sites and therefore the altitude of roost sites will affect the altitude at which geese feed.

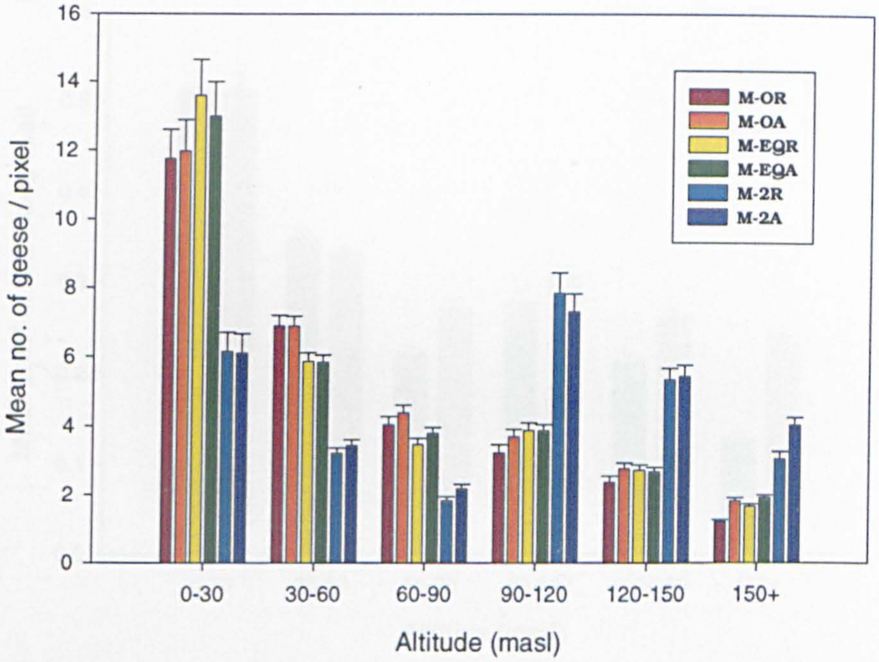

Figure 6.7 The mean number of geese landing per pixel in fields at different altitudes, for all IBMMs. Error bars = s.e. (mean).

Altitude was not transformed in the logistic regression model and therefore a linear relationship between altitude and the predicted probability of fields being used would be expected. Variation from the linear trend is likely to be a result of the locations of roosts. LR-**2**, based on roost data from radio-tracked geese, shows a weaker relationship between altitude and predicted goose use than LR-O (Figure 6.8). This result is reflected in the map showing the difference in predicted results between the two logistic regression models (Figure 6.3), with LR-**2** showing higher goose use at higher altitudes, compared with LR-O. This trend is the reverse of that found in the IBMM and is not a reflection of the altitude of roosts, as in general the roost locations used in LR-O were at greater altitudes that those used in LR-2. The difference between the two logistic regression models, caused by variation in the altitude co-efficient, is likely to be due to the relatively small sample size (n = 84).

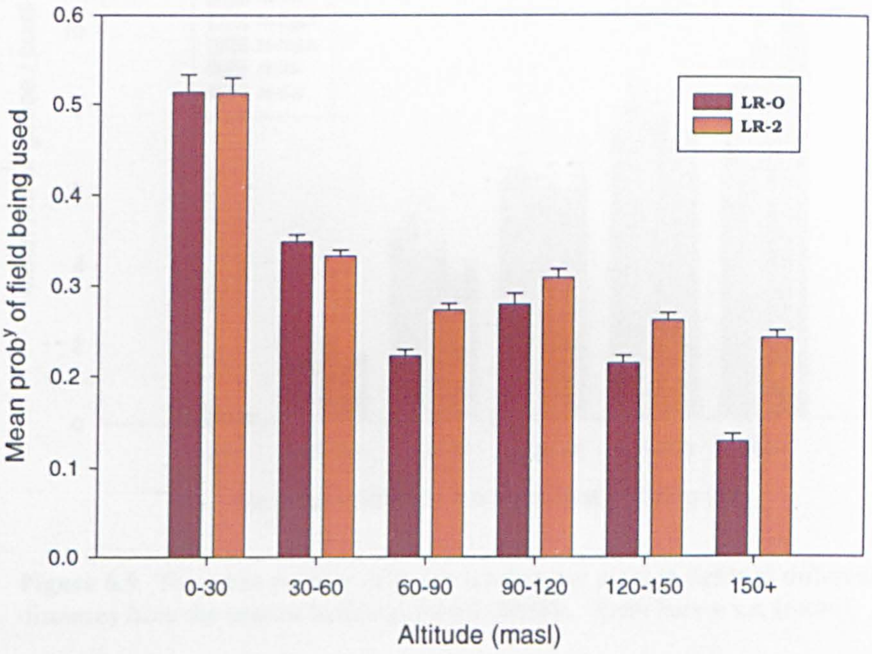

Figure 6.8 The mean predicted probability of fields use at different altitudes for all logistic regression models. Error bars = s.e.(mean).

All six IBMMs showed a similar linear relationship between maximum distance to the nearest building and the predicted extent of goose (Figure 6.9). This was expected as the probability of landing in the IBMM is a linear function of the distance from buildings. The M-2 models showed a slightly stronger relationship with distance from buildings than the other IBMMs with fields closer to buildings being less likely to be used. This is probably the result of more simulated geese roosting in Strathallan where there are relatively few buildings very close to the roost complex (Carsebreck Lochs) where geese are predicted to feed. The shift in predicted goose use towards Strathallan in the M-2 models when compared to the M-O and M-EQ models is shown in Figure 6.4.

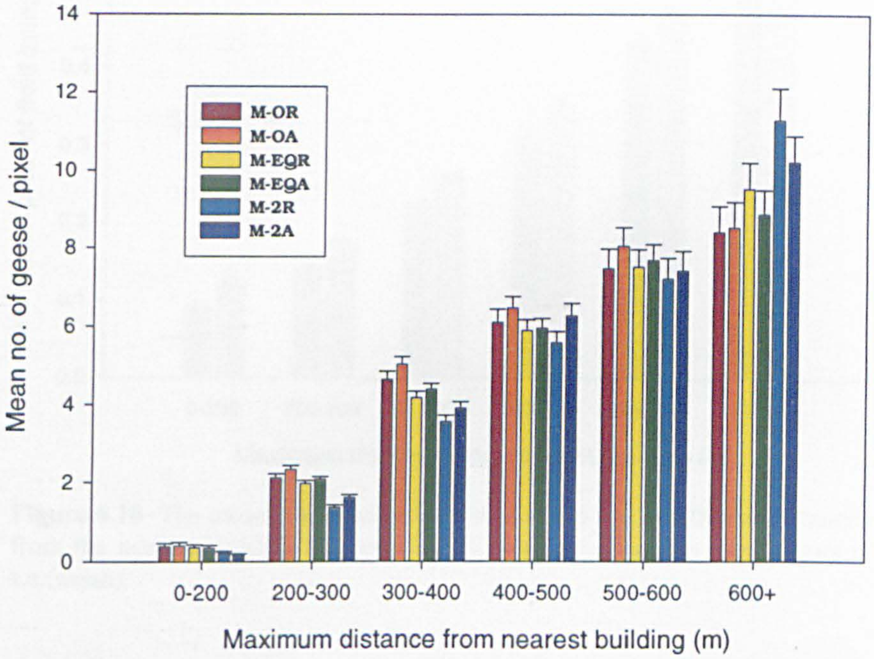

Figure 6.9 The mean number of geese landing per pixel in fields at different distances from the nearest building, for all IBMMs. Error bars = s.e. (mean).

There is a linear relationship between maximum distance from buildings and the predicted probability of goose use from the logistic regression models (Figure 6.10). Again, this was expected as maximum distance from buildings was not transformed in the logistic regression models. The close fit of the predicted results to the expected linear trend is a result of the distance from buildings was not greatly spatially autocorrelated. The relationship between goose use and distance from buildings did not appear to differ greatly between the two models although goose use of fields very close to buildings was lower in the IBMMs.

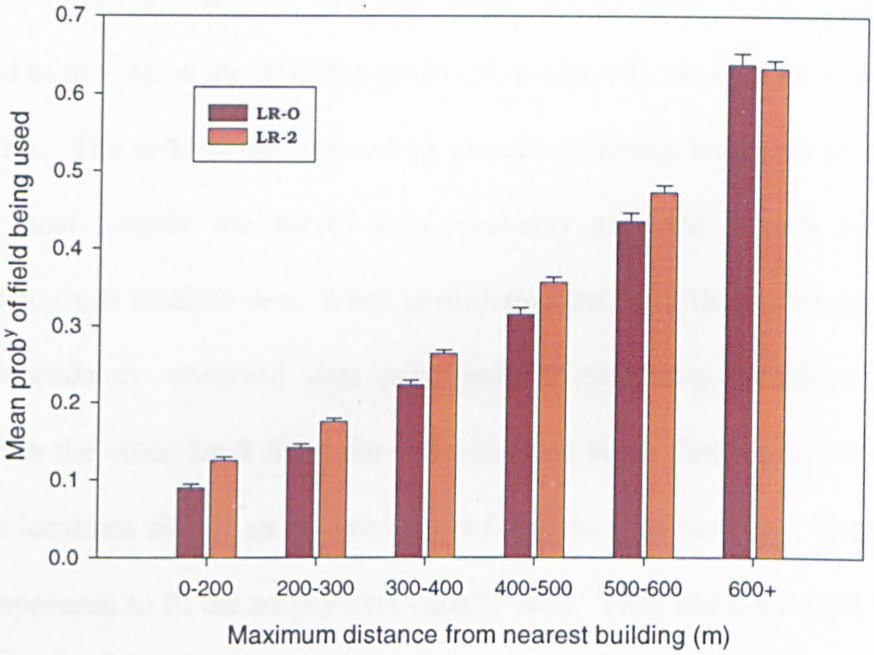

Figure 6.10 The mean predicted probability of field use at different distances from the nearest building for both logistic regression models. Error bars = s.e.(mean).

6.3.3 Comparison of models to observed data

The two data sets of observed goose distribution showed a good degree of agreement, especially considering the data were collected in different years and crop types could have changed. Radio-tracked geese used 32.6% of survey fields where flocks of Greylag were observed, while only 2.9% of survey fields where flocks were not observed were used by radio-tracked geese. The Chi-squared value for presence/absence of radio-tracked geese and observed flocks in survey fields was 60.94 (d.f. = 1, $p < 0.001$).

Table 6.3 shows the results of the Mann-Whitney U test which tested the difference in predicted results between fields where geese were observed and fields where they were not. The logistic regression models showed a better fit to the survey data while the

IBMMs showed a better fit with the radio-tracking data. These results are to be expected as they show the fit of the predicted results with the data on which the models were built. The **M-2** models proved an exception, fitting both sets of observed data poorly, most notably the survey data, probably as these models were based on incomplete roost location data. When considering the fit of the model predictions with the independently observed data sets, neither modelling technique appeared to outperform the other. **LR-2** fitted the radio tracking better than **LR-O**, probably because the roost locations used in **LR-2** were correct for radio-tracked geese. The **M-O** and **M-EQ** models appeared to fit the survey data equally well. They did not reflect the results of the fit with the radio-tracking data where river-based models showed a slightly closer fit than the altitude models. In general these results suggest that models using roost data derived from Bell *et al* (1997) (**LR-O**, **M-2R** and **M-2A**) predict goose distribution less well than models using roost data from radio-tracked geese.

Table 6.3. z-scores of Mann-Whitney U test. Shaded cells show the fit of the model with data on which the model was based. White cells show the fit of the model with an independent data set. *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, ns = $p > 0.05$.

Model	**Survey data (n = 422)**		**Radio-tracking data (n = 184)**	
	Z –score	**Sig.**	**Z-score**	**Sig.**
LR-O	5.427	< 0.001	3.948	< 0.001
LR-2	5.178	< 0.001	4.932	< 0.001
M-OR	4.538	< 0.001	5.645	< 0.001
M-OA	4.698	< 0.001	5.169	< 0.001
M-EQR	4.533	< 0.001	5.413	< 0.001
M-EQA	4.787	< 0.001	5.245	< 0.001
M-2R	1.649	0.099	4.520	< 0.001
M-2A	2.023	0.043	3.333	0.001

6.4 DISCUSSION

Comparison of the two modelling techniques showed that they gave relatively similar results when the same roost sites were used. Differences in the relationship between predictor variables and predicted goose use are likely to be a consequence of the data used for analysis as opposed to the modelling technique employed. The IBMM did not appear to out-perform the logistic regression model in predicting the feeding distribution of Greylag geese. The results of this chapter also emphasise the considerable effect of the roost locations used in the model on the resultant predicted distribution and highlights the need for accurate roost data.

In the IBMM predicted goose use is strongly centred around the roost sites of the geese. As the probability of landing was derived from observed goose movements, the distances at which IBMMs predict geese to feed from the roost are probably a relatively accurate representation of the real distances Greylag geese fly in Strathearn and Strathallan. A slight underestimation of the distance geese feed from the roost may have occurred because analysis of goose movements assumed geese flew in a straight line between their point of departure and landing location and the probabilities of landing were calculated accordingly. However, due to the algorithm used, simulated geese make some turns in their flight path. This results in both observed and simulated goose movements being of the same length and therefore the straight-line distance travelled by the simulated goose being somewhat shorter. As geese are predicted to feed close to the roosts in the IBMM, changes in roost location produce very different predicted goose use distributions.

In the logistic regression model the relationship between distance from the roost and predicted use by geese was not as strong as for the IBMM. As a result, the two logistic regression models using different roosts were much more consistent than the IBMM when the roost locations were altered. As we know that the distances travelled in the IBMMs are approximately correct, the median distance of feeding geese of 2.4 km from the roost obtained from the ordinary logistic regression model appears to be too great. This suggests that the roost data used to build the model were imperfect. The decrease of the median predicted distance of feeding geese from the roost to 1.7 km in **LR-2**, using roosts used by radio-tracked geese in the analysis, cannot be explained by the increased number of roosts in the model. The same change in roosts used caused only a 0.1km decrease in median distance from the roost in the IBMM. The decrease in median distance between **LR-O** and **LR-2** to one much closer to that obtained in the IBMMs suggests that the second model, based on roost locations of radio-tracked geese, was a more accurate reflection of the roosts used by the geese observed in the goose survey. This suggestion is supported by the results of the fit of models with observed data.

The models based on the radio-tracked goose roosts (**LR-2**, **M-OA**, **M-OR**, **M-EQA** and **M-EQR**) all showed a much better fit to the radio-tracking data than models based on the roosts locations derived from Bell *et al* (1997) (**LR-O**, **M-2A** and **M-2R**). This is because the roost data from radio-tracked geese gave information of the roost locations used during the period that data were being collected. Therefore the roost location data were obviously more accurate than the roost locations in the literature (Bell *et al* 1997) for the radio-tracked geese although not necessarily for the whole population of geese in Strathearn and Strathallan. There was also, however, a considerable reduction of the fit of the **M-2** models to the survey data compared with the **M-O** and **M-EQ** models. This suggests that the roost use recorded by radio-tracked geese was closer to the real roost use by geese observed in the survey than the roost data in literature (Bell *et al* 1997). These analyses highlights the need of both modelling techniques for accurate information about the locations of goose roosts, most especially the IBMMs. They also highlight the difficulty in obtaining such information. While major Greylag goose roosts are known throughout Britain, minor roosts may go unrecorded. Bell et al (1997) carried out a detailed investigation of the use of Greylag goose roost sites in Strathearn and Strathallan between 1987/88 and 1993/94. Radio-tracking, however, has highlighted roosts where no geese were observed by Bell *et al* (1997) while some roosts observed to be used by these authors appeared to have been abandoned, or used very little. Whether this is the result of a shift in roosting locations over time or because not all roosts were located in the studies, these results show the difficulty in obtaining adequate goose roost information.

The data collected from the radio-tracked geese was a better data set on which to test the accuracy of the model. Ninety-two fields were observed to be used by Greylag geese compared with 43 in the survey data. In addition the fields not used by radio-tracked geese were the same distance from the goose's previous location as the field to which the observed goose moved. Assessing the fit of model results to the radio-tracking data is a more rigorous test for the predictive power of the models than the survey data, in which fields where goose absence was recorded had no such criteria. Furthermore the results of the IBMMs were not as closely related to the field use by radio-tracked geese as that between the logistic regression models and the survey data. Therefore the radio-tracking data is likely to be better for comparison between modelling techniques.

The results of the fit of model predictions with observed data suggest that the simulation modelling technique is no better at predicting the distribution of Greylag geese in Strathearn and Strathallan than the logistic regression modelling technique. The logistic regression model was built on data collected in one season with only 43 fields used by geese and an equal number that were not. The data collection for the IBMM was much more time consuming, and although more data were collected, this does not appear to have improved the accuracy of the resulting models. Advantages of the IBMM are that the number of geese roosting at different sites can be altered, in contrast to the logistic regression model where goose use of roosts is considered uniform. This advantage may be slight. Altering the frequency of roost use appears to have very little effect on the fit of the model to observed data, even though goose use of roosts varied by up to 30 fold.

Comparison of the various IBMMs showed that **M-OR** and **M-EQR** models, with flight constrained by rivers, proved the closest fit to the radio-tracking data. The analysis of factors constraining goose flight direction found river to be the only consistently significant variable, with altitude only incorporated in the model to constrain goose flight when distance from the river was removed from the analysis (see Chapter 5). This suggests that the river model was a more accurate representation of how the radio-tracked geese moved. It does not, however, necessarily mean that it is a better model, as the river-based models did not give a better fit to the survey data than the altitude-based models.

Comparison of predicted and observed data was on a field basis and was not spatially explicit. Correctly predicted species presence or absence will be a conservative measure of model performance as no account is taken of the spatial element (i.e. predicting goose presence close to where geese were observed) (Austin *et al* 1996, Fielding & Bell 1997). In Chapter 3 the inclusion of autologistic terms, predicted and observed goose use in neighbouring fields, into the logistic regression models did not result in a significant improvement in the model. These results suggest that geese are no more likely to feed in fields close to others were goose presence is predicted. Therefore consideration of the spatial element when comparing observed and predicted goose distributions is unlikely to have a profound effect on the results.

6.5 SUMMARY

Both modelling techniques (logistic regression models and IBMMs) show very similar and clear relationships between distance from buildings and predicted goose use, and similar although less clear relationships between altitude and predicted goose use. Differences between the models in the distance geese were predicted to feed from the roost were most likely the result of incomplete knowledge of the goose roosts for the logistic regression models rather than an intrinsic difference between the modelling techniques. The two techniques have both resulted in models that appear to be based on real effects of the landscape within Strathearn and Strathallan on the feeding distribution of Greylag geese. Neither modelling technique appears to out-perform the other in its ability to predict goose distribution. Both models can be applied to other areas used by wintering Greylag geese relatively easily and require the same data to do so. It is apparent, however, that good knowledge of the location of goose roosts is essential for the models to produce realistic results.

CHAPTER 7 – PREDICTING GOOSE DISTRIBUTION FOR A DIFFERENT AREA: LOCH LEVEN

7.1 INTRODUCTION

7.1.1 Background

Two models were built to predict the distribution of goose feeding areas in Strathearn and Strathallan, Perthshire. First a correlative mapping technique, logistic regression, was used to predict the probability of geese using a field based on the field's landscape characteristics (Chapter 3). The goose distribution data on which this model was based were obtained by surveying 755 fields regularly for the presence of geese throughout the winter. Models were built for both Greylag and Pink-footed geese. The second model was an individual based behaviour model (IBBM), in which the movements of individual geese was simulated as they flew from the roost to fields, and from field to field throughout the day (Chapter 5). This model was built using movement decision rules based on data from radio-tracked Greylag geese and was used to predict the feeding distribution of Greylag geese only.

Large-scale ecology such as in this study exceeds the spatial scale of classical ecological experiments and therefore alternative methods to experimental manipulations are required to assess the accuracy of results (Ormerod & Watkinson 2000). The logistic regression models were tested on independent data in Chapter 3 by jack-knifing. In addition the results of both logistic regression models and IBMMs were tested on independent goose distribution data from the same area, Strathearn and

Strathallan (see Chapter 6). Habitat preference of species, however, may differ between regions (Fielding & Haworth 1995). Testing the ability of a model to predict species distribution in another area is therefore a more robust test of a model's performance (Verbyla & Litvaitis 1989). The performance of the two modelling techniques was therefore tested on another area.

It was necessary to test the models on an area where information about the feeding distribution of both Pink-footed and Greylag geese was available. There have been a number of studies on the feeding distribution of wintering Pink-footed geese in Scotland (Newton & Campbell 1973; Newton *et al* 1973; Bell 1988; Patterson *et al* 1989; Bell & Newton 1995; Hearn & Mitchell 1995; Hearn *et al* 1996). However, the only accurate data on the feeding distribution of Greylag geese, at a field scale, were collected at Loch Leven National Nature Reserve, Fife during the winters of 1968-69 and 1969-70 (Newton & Campbell 1973). The feeding distribution around Loch Leven was again surveyed during the winters of 1994-95 (Hearn & Mitchell 1995) and 1995-96 (Hearn *et al* 1996). Data for the distribution of Greylag geese were not sufficient in these later studies as the numbers roosting at Loch Leven have declined dramatically since the 1960's, with the November counts falling from 2500-5000 in the mid 1970's to fewer than 300 in the early 1990's (Boyd *et al* 1994). Furthermore, a large proportion of the wintering Greylag geese at Loch Leven was of feral origin by the time of the second survey (Hearn & Mitchell 1995). Therefore data from the earlier surveys (Newton & Campbell 1973) were used to test the predictive powers of the two modelling techniques.

7.1.2 Aims

The aims of this chapter are:

(i) To use both the logistic regression model and IBMM to predict the feeding distribution of geese around Loch Leven NNR

(ii) To assess the goodness of fit of predicted distributions with the observed goose feeding distributions in the late 1960s (Newton & Campbell 1973)

(iii) To draw conclusions about the ability of the two modelling techniques to predict goose distributions in different geographical areas

7.1.3 Study area

The study area consisted of farmland surrounding Loch Leven NNR, an area covering 476km^2 of east central Scotland (see Figure 7.1). The area lies within NO 0213 and NT 3096, the limits of the study area being chosen to include all goose feeding areas mapped in Newton & Campbell's study (1973). Approximately fifty-three percent of the area is classified as arable, 14.1% heather and grass moorland (upland areas corresponding to mountain and moorland classification in OS LandLine), 8.9% as wooded, 9.3% as improved pasture and 15.0% urban areas, roads, and other minor land uses (derived from Macaulay Land Cover of Scotland 1988). Loch Leven is the only roost in the study area; it covers some 14km^2 and is the largest eutrophic lake in Britain (Boyd *et al* 1994). The loch is renowned for its wildfowl and was one of the first sites designated by the United Kingdom under the Ramsar Convention (Owen *et al* 1986). During the winters of 1968/69 and 1969/70 the mean weekly counts of Pink-footed geese were 3418 and 3708 respectively while the mean numbers of Greylag geese were

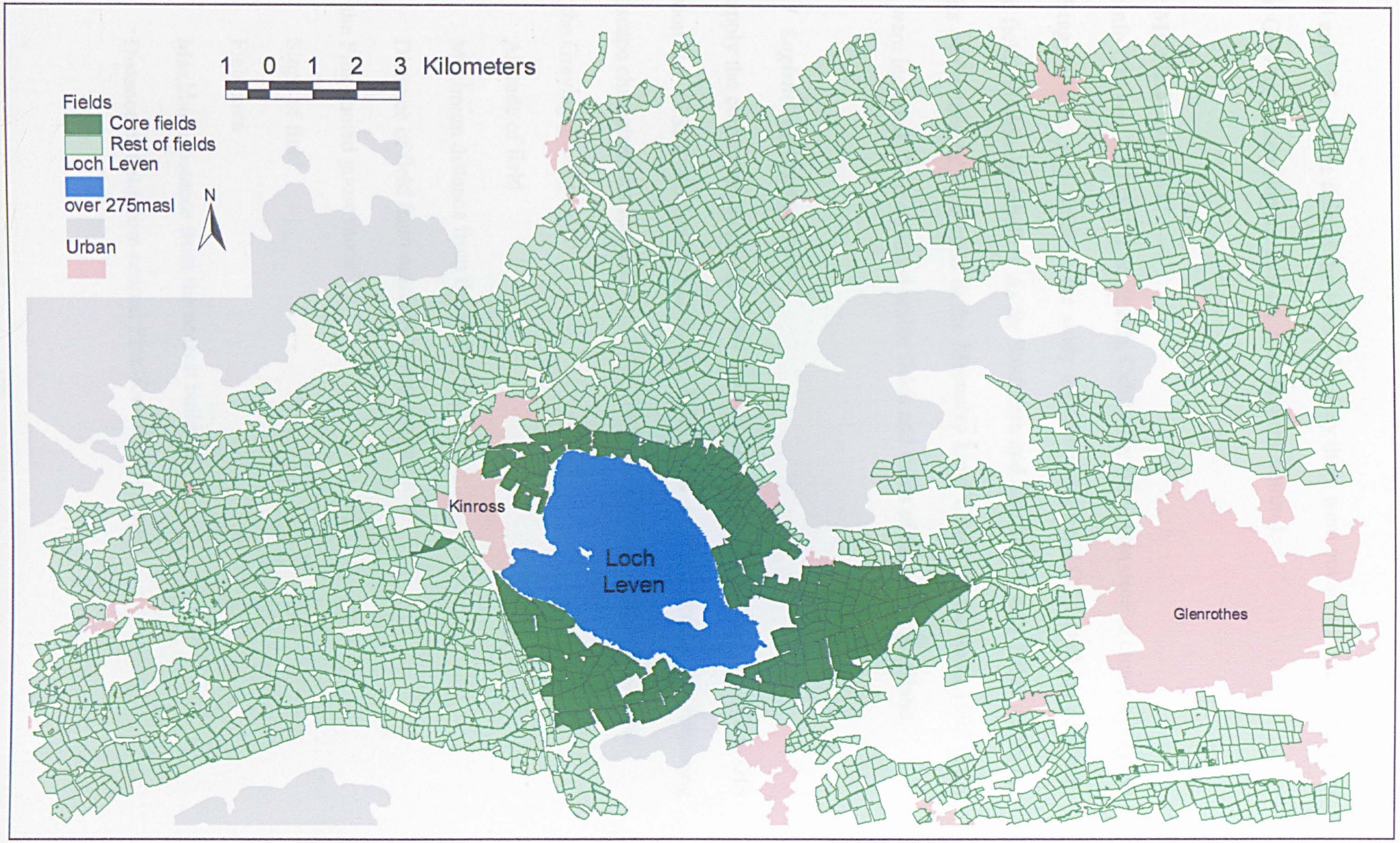

Figure 7.1 The study area around Loch Leven study, showing individual fields.

1638 and 906. At the time of the 1968-70 survey there were not significant numbers of feral Greylag geese using the loch (A. Lauder, pers. comm.).

7.2 METHODOLOGY

ArcInfo GIS ver. 7.2.1 (ESRI, Redlands, California, USA) was used to create a polygon coverage of the 3,445 fields in the study area from digitized OS LandLine data with each field individually labelled. As for Strathearn and Strathallan, only fields within the limits of the 'arable' land class in the Macaulay Land Cover for Scotland 1998 (LCS 88) were included. This included arable fields and fields of improved grassland.

7.2.1 Logistic regression model

To apply the correlative mapping model to Loch Leven for both species, ArcView GIS version 3.1 (ESRI, Redlands, California, USA) was used to derive the following landscape characteristics for each field from OS LandLine and OS Panorama data:

For the Greylag goose model:

- Altitude of field
- Maximum distance from the nearest building
- Distance of field from nearest Greylag goose roost

For the Pink-footed goose model:

- Slope of field
- Field area
- Maximum distance from the nearest building
- Distance of field from nearest Pink-footed goose roost

Only certain areas of Loch Leven are used by roosting geese. A map of the roost areas on the loch for both species by Newton and Campbell (1973) was digitised to enable the calculation of distance from the roost. The logistic regression equation was applied to all fields in the Loch Leven study area and the probability of geese landing in each field was calculated.

7.2.2 IBMM

The IBMM including distance to the river (Chapter 5) could not be applied to this study area. This was because there was no major river in the study area that would equate to the River Earn or Allan Water in Strathearn and Strathallan. Therefore the IBMM using altitude to constrain goose flight was applied to the Loch Leven study area.

To apply the individual based movement model to Loch Leven the study area was converted to a grid of 256 by 170 100m square pixels. For each pixel data on the following was required:

Pixel Property	**Effect on model**
Altitude of pixel	Constrain flight direction
Max. distance from building of underlying field	Constrain probability of landing
Whether Greylag roost site	Starting position

The altitude of each pixel was derived in ArcView from OS contour data. The logistic regression equations for both roost and non-roost movements, derived from Strathearn and Strathallan radio-tracking data were applied to the altitude data. This gave the probability of geese flying over each pixel which was rounded to one decimal place to create probability bands (see Chapter 5)

For all pixels the maximum distance from the nearest building of the field over which the pixel lies was derived. There were no data for pixels that did not lie over a field. The regression equations for the probability of a goose landing, derived from the Strathearn and Strathallan radio-tracking data for both roost and non-roost movements, were applied to each pixel. These were dependent on maximum distance from the nearest building and gave the probability of each pixel being landed in when flown over, for both roost and non-roost movements.

The location of pixels overlying Greylag goose roosts were derived from the roost map in Newton & Campbell (1973). When the IBMM was applied to Strathearn and Strathallan, the chance of geese leaving a roost was taken from the proportion of radio-tracked geese using the roost. There were no data available on the proportion of Greylag geese using each roosting area on the loch for the time when the test data were collected. As a result in the Loch Leven model simulated goose movements from the roost had an equal chance of being from any roost pixel. This was unlikely to have a great impact on the results of the model, as all roost sites were located on Loch Leven.

The model was run for 50,000 goose days. As with the Strathearn and Strathallan models, Arc-View was used to summarise for each field the total number of simulated geese using the field and the mean number of geese landing per pixel (density).

7.2.3 Calculating the distance at which geese were predicted to feed from the roost

The predicted extent of field use (IBMM) or probability of use (logistic regression models) was averaged for different distance categories from the roost. The median distance geese were predicted to feed from the roost was calculated. For the logistic regression model this assumed that the predicted probability of goose use of a field was a measure of the extent of goose use.

7.2.4 Comparison of results from the two models

The results of the two modelling techniques (for Greylag geese only) were compared by plotting the predicted probability of Greylag geese using each field against the total number of geese simulated to have landed in the field and the mean number of geese landing per pixel. The consistency of results between the two models was assessed both by Pearson's correlation and visually.

7.2.5 Comparison with observed goose distribution

Goose distribution data were obtained from a study carried out during the winters of 1968-69 and 1969-70 (Newton & Campbell 1973). For 324 fields situated around the loch (the core goose feeding area – see Figure 7.1) surveys were carried out on 301 days over the two winters. On some days more than one survey was performed. In such cases the largest flock in each field only was included. This was because if a goose lands in a field and remains in it all day, it has still only chosen the field once. For these fields the raw data were kindly supplied from the author (Prof. Ian Newton, CEH, Monks Wood) and the total number of each species over the two winters was calculated for each field.

The method of assessing the fit of models with observed data differs from that used in Chapter 6, where observed data was in presence / absence form. In the core fields at Loch Leven goose use was very high and there were few fields where geese were not observed, therefore predicted results were compared with the extent of use of these core fields. The accuracy of the two modelling techniques at predicting goose distribution for these 324 core fields surrounding the loch was assessed by the following methods. The predicted probabilities of field use from the logistic regression models for both Greylag and Pink-footed geese were plotted against the number of flocks observed in the field over the two winters. Linear regression was performed to assess the ability of the models to predict the observed extent of goose use of fields. In addition the results were summarised as bar charts with the mean number of flocks observed in groups of fields of differing predicted probabilities of goose use. These methods compare the results for individual fields but do not take into account the spatial pattern of goose use, therefore visual comparison of the observed and predicted results was also necessary. The same method of comparison was used to assess the results of the IBMM with both the mean number of geese landing per pixel and total number of geese compared with the number of Greylag goose flocks observed.

Outside the core area of 324 fields, goose feeding distribution was mapped but no accurate counts were taken during the 1968-70 survey. The raw data for goose use of the area outside the 324 core fields were not available; therefore the only information on goose distribution in these fields was from the map in Newton and Campbell (1973). The map in this paper showing the feeding distribution of Pink-footed and Greylag geese at Loch Leven, thought to include all areas where geese fed (I. Newton, pers. comm.), was digitized using ArcView and warped to fit the OS based maps using the ImageWarp extension ver 2.0. This enabled a visual comparison of the expected goose distribution from the two models with that observed.

7.3 RESULTS

7.3.1 Results of the logistic regression models for the whole study area

Figures 7.2 and 7.3 show the predicted feeding distribution around Loch Leven for Pink-footed and Greylag geese respectively from the logistic regression model, with the feeding areas for each species observed during the 1968-70 survey superimposed. For Pink-footed geese the predicted feeding distribution close to the roost fits observed data well. The extent of dispersal of the geese over the study area appeared consistent with observed data, although not all patches of high predicted distribution fitted those observed. The prediction of Pink-footed goose presence in fields further from the roost, especially to the north east of Loch Leven, appeared to be greater than observed. The observed feeding area to the south west of the study area should not be compared as a nearby town has expanded to cover some of the fields where geese fed during the 1968-70 survey and fields still present are likely be closer to buildings and subject to increased disturbance. As with Pink-footed geese, the predicted distribution of Greylag geese around Loch Leven roughly fits that observed during 1968-70, but patches of

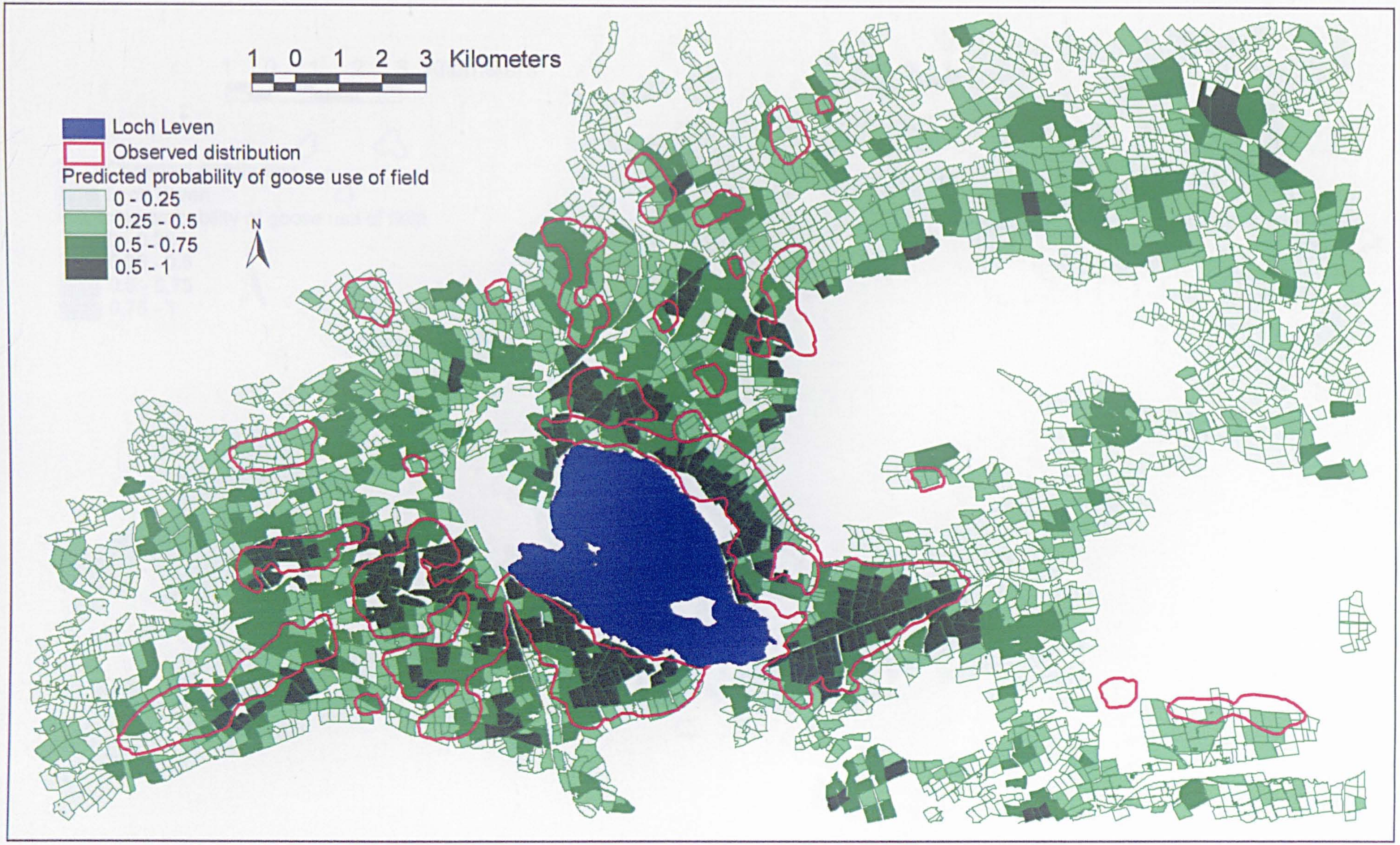

Figure 7.2 The predicted distribution of Pink-footed geese from the logistic regression model, with the observed distribution of feeding Pink-footed geese overlaid.

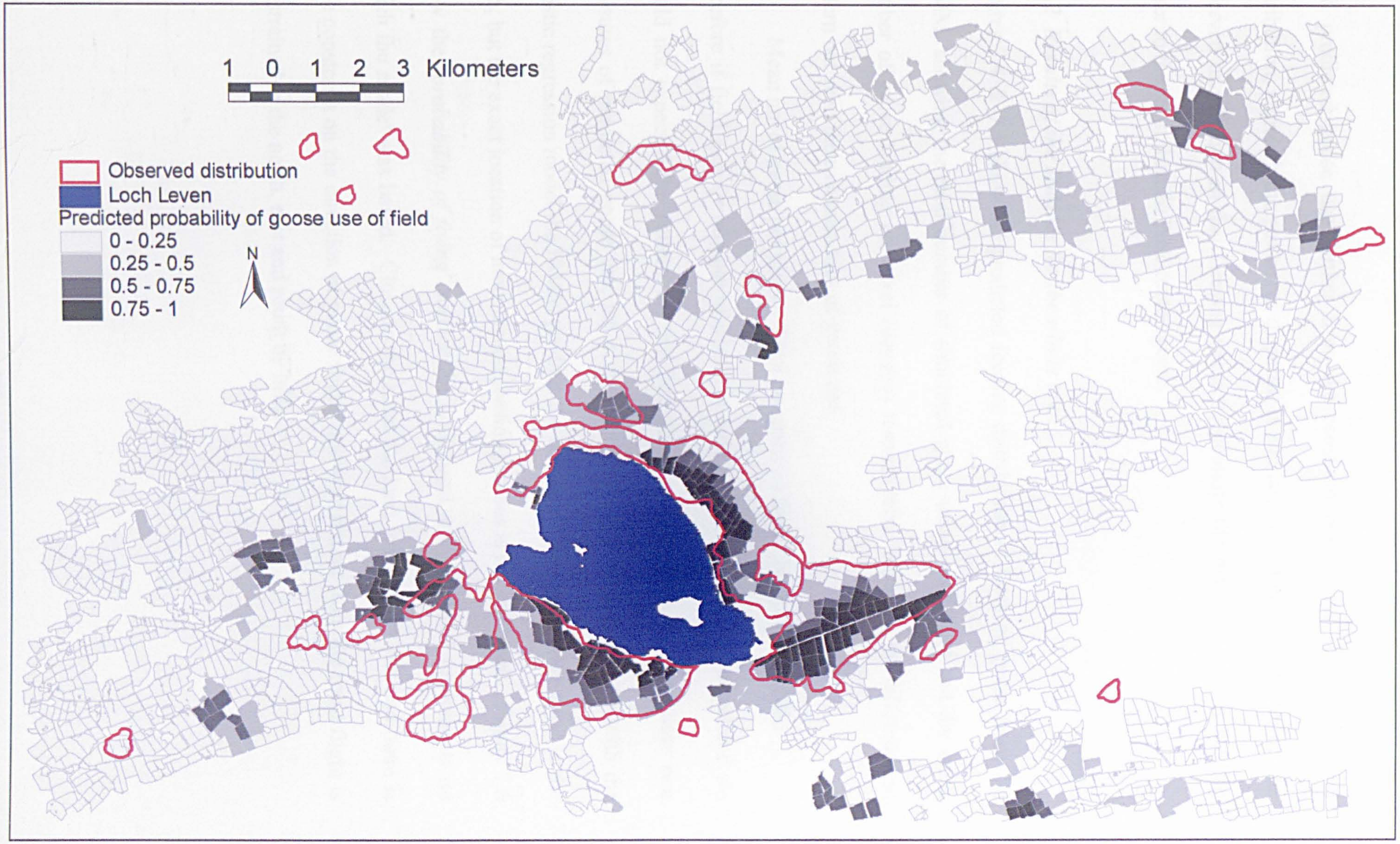

Figure 7.3 The predicted distribution of Greylag geese from the logistic regression model, with the observed distribution of feeding Greylag geese overlaid.

high predicted goose use further from the roost do not always fit the observed distribution, although the pattern of dispersal is similar. The model results reflect the observed distribution in that Greylag geese concentrate the majority of their feeding closer to the roost than do Pink-footed geese.

7.3.2 Results of the IBMMs for the whole area

Figures 7.4 & 7.5 show the predicted feeding distribution of Greylag geese from the IBMM, showing the total number of simulated geese using each field and the mean number of geese landing per pixel (density) respectively. There is no difference in pattern between the two measures of goose use.

Mean no. of geese per pixel = Total no. geese in field / No. pixels in field

therefore if field area (≈ number of pixels in field) is not spatially autocorrelated we would not expected the pattern of predicted goose use to differ between these two measures of predicted goose use, although individual values will vary. As with the logistic regression model the IBMM predicts the rough feeding distribution close to the loch, but the exact location of more distant feeding patches is not predicted. Figure 7.6 show the '*probability of flying*' surface for both roost and non-roost movements on which the model was based. Close to the roost the land is relatively flat and there is little constraint on the direction of goose flight, however further from the roost flight is constrained to the north, east and south by hills.

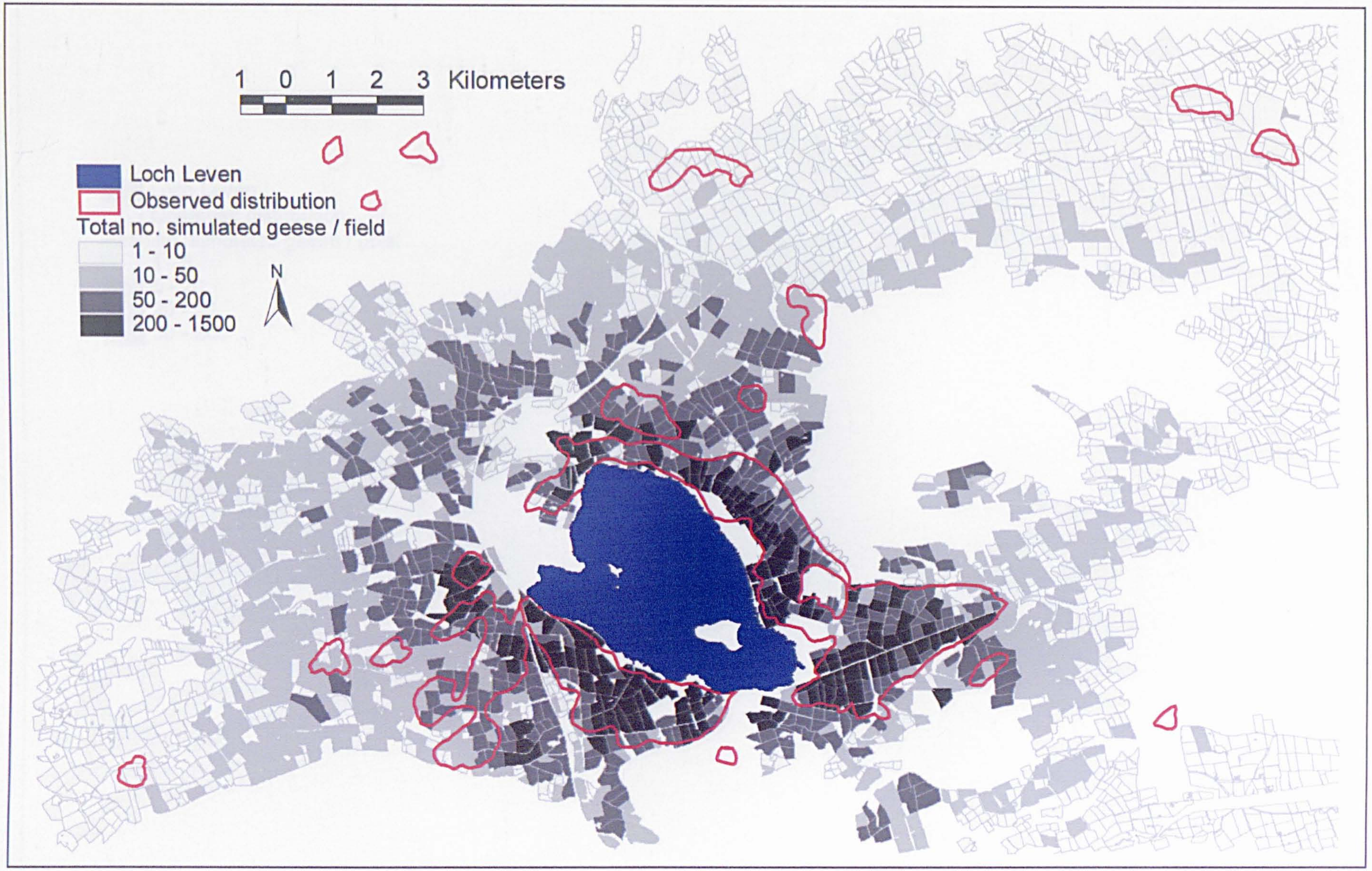

Figure 7.4 The predicted extent of Greylag goose use of each field from the simulation model, with the observed distribution of feeding Greylag geese overlaid.

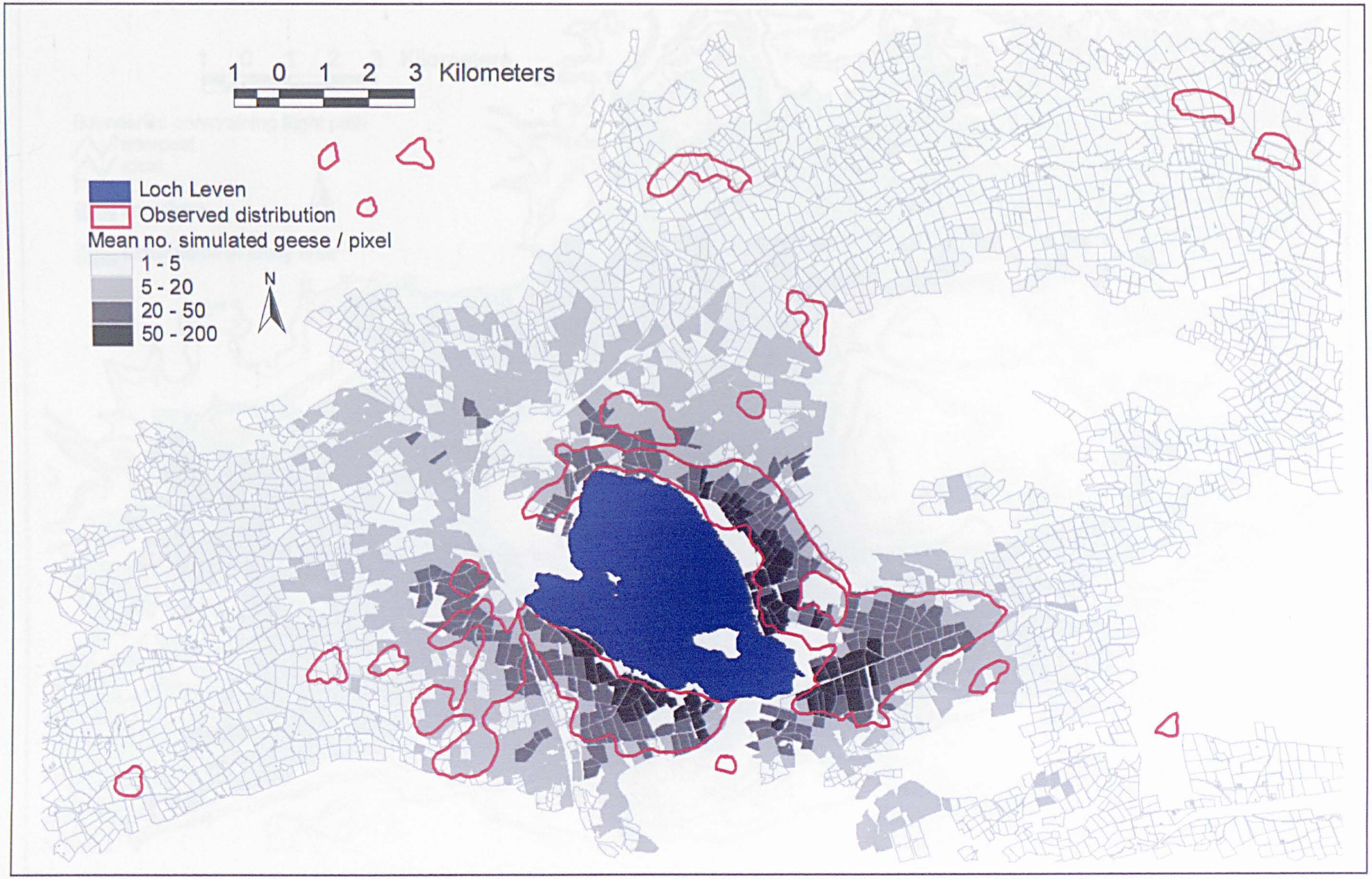

Figure 7.5 The predicted density of Greylag goose use of each field from the simulation model, with the observed distribution of feeding Greylag geese overlaid.

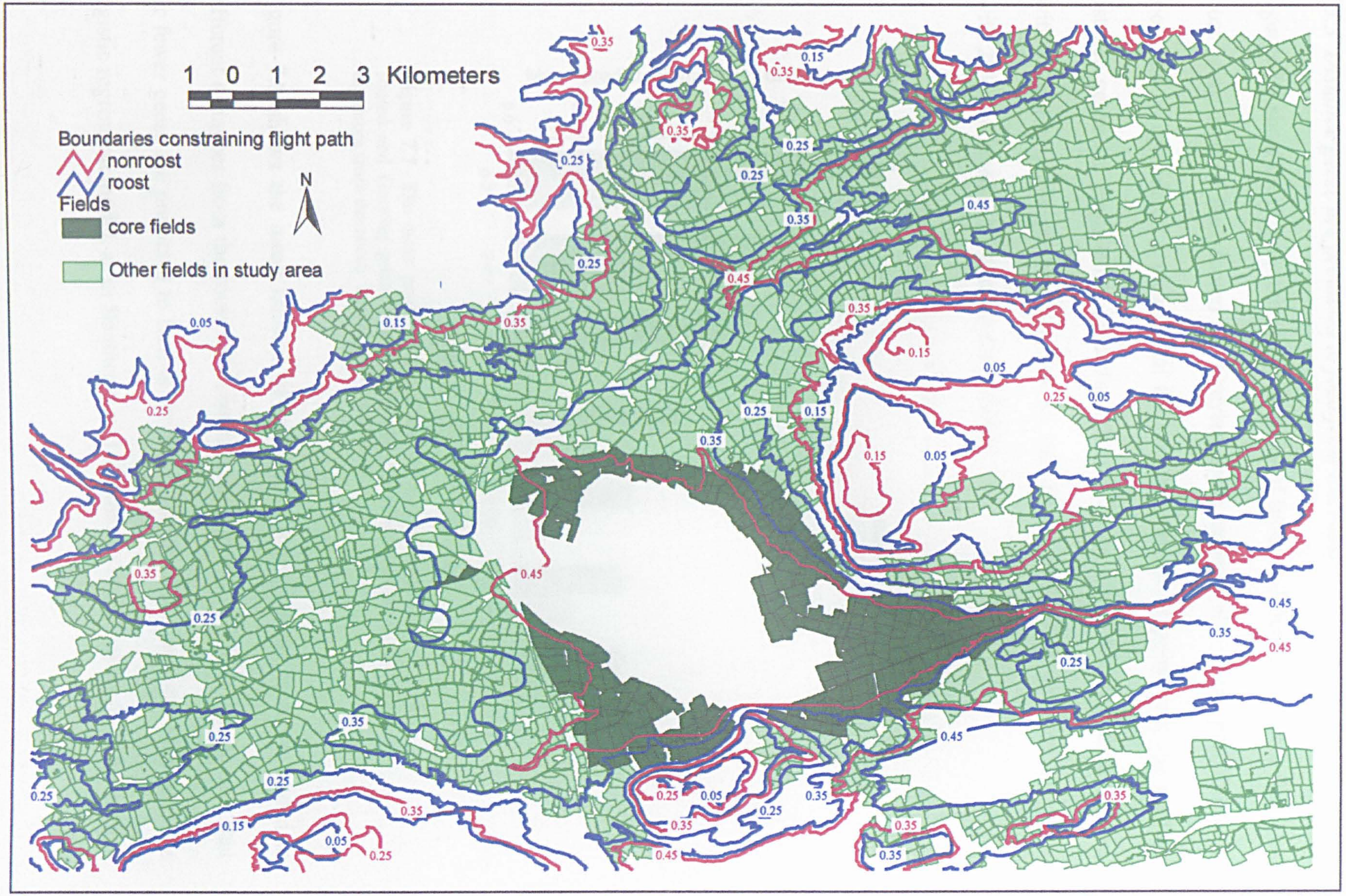

Figure 7.6 The boundaries of the probability bands constraining flight for both roost (blue) and non-roost (red) movements (i.e. flight is constrained by altitude only when considering movements at these boundaries)

7.3.3 Distance geese are predicted to feed from the roost

Figures 7.7 show the mean predicted probability of fields at different distances from the roost being used by Pink-footed and Greylag geese respectively. If the probability of goose use is considered a measure of the predicted extent of goose use, the median distance geese are predicted to feed from the roost was 4.4km for Pink-footed geese (with 17.6% of geese predicted to feed in core fields) and 3.7km for Greylag geese (with 29% predicted to feed in the core fields).

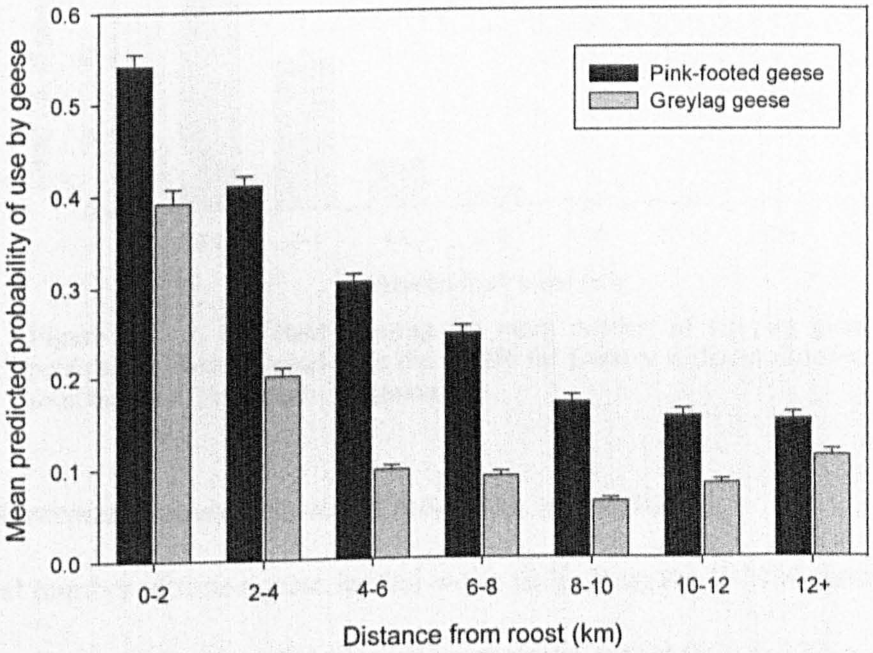

Figure 7.7 The mean predicted probability of a field being used by Pink-footed and Greylag geese from the logistic regression models at different distances from the roost. Error bars = s.e.(mean).

Figure 7.8 shows the mean number of simulated Greylag geese to have landed at different distances from the roost. By comparison with Figure 7.7, it can be seen that far fewer geese are predicted to land in the fields further from the roost than with the logistic regression model, as in Strathearn and Strathallan (see Chapter 6). The median distance geese were predicted to feed from the roost was just 1.7km with 53.8% of geese predicted to land in the core area.

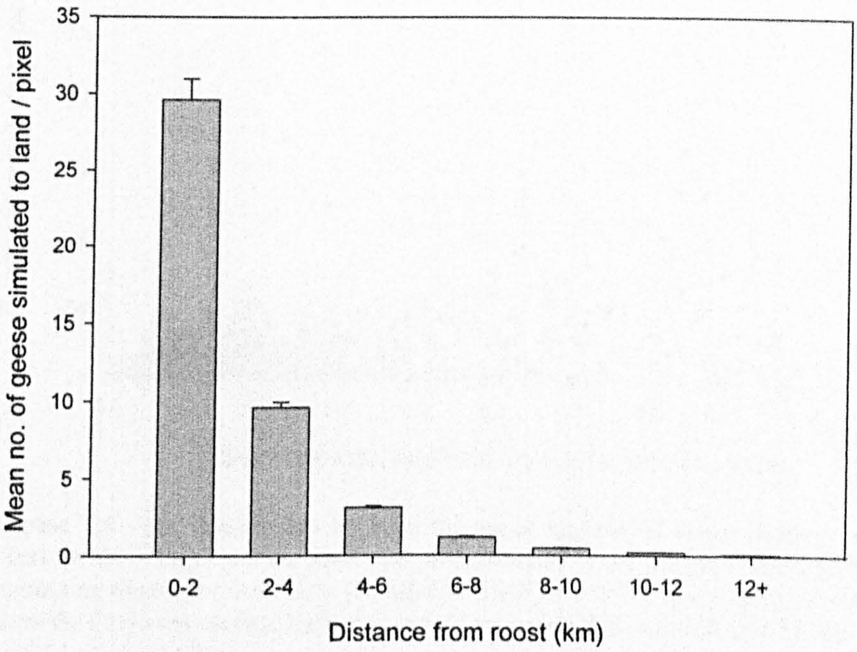

Figure 7.8 A bar chart showing the mean number of Greylag geese predicted to land per pixel from the IBMM for fields at different distances from the roost. Error bars = s.e.(mean).

7.3.4 Agreement between results of modelling techniques

The total number of times geese landed in the field, from the IBMM showed reasonable agreement with the results of the logistic regression model ($R = 0.677$, $p < 0.001$ for all 3,445 fields, $R = 0.682$, $p < 0.001$ for core fields) (Figure 7.9). The mean number of times pixels were landed in per field from the IBMM showed a better agreement, however, with an R-value of 0.746 ($p < 0.001$) for all 3,445 fields and an R-value of 0.825 ($p < 0.001$) for the core fields (Figure 7.10). The mean number of times a pixel is landed in for the IBMM is more consistent with the results from the logistic regression model than the total number of geese landed per field. This is because there is no measure of field area included in the logistic regression model.

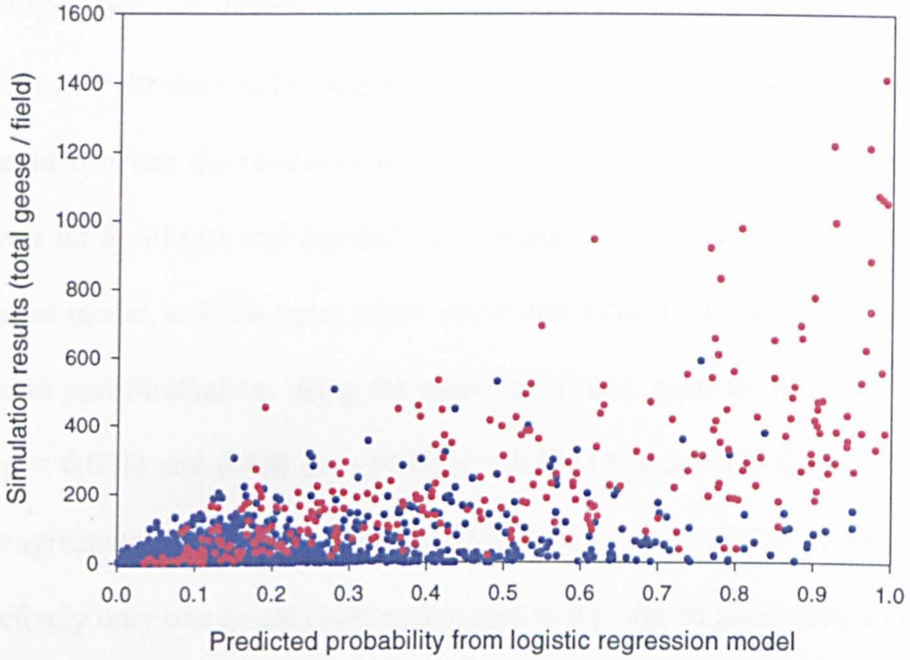

Figure 7.9 The relationship between the mean number of geese landing per pixel for the IBMM and the predicted probability of goose use from the logistic regression model for each field (R-value = 0.667, n = 3445, $p < 0.001$). Fields from the core area are highlighted in red (R-value = 0.682, n = 324, $p < 0.001$).

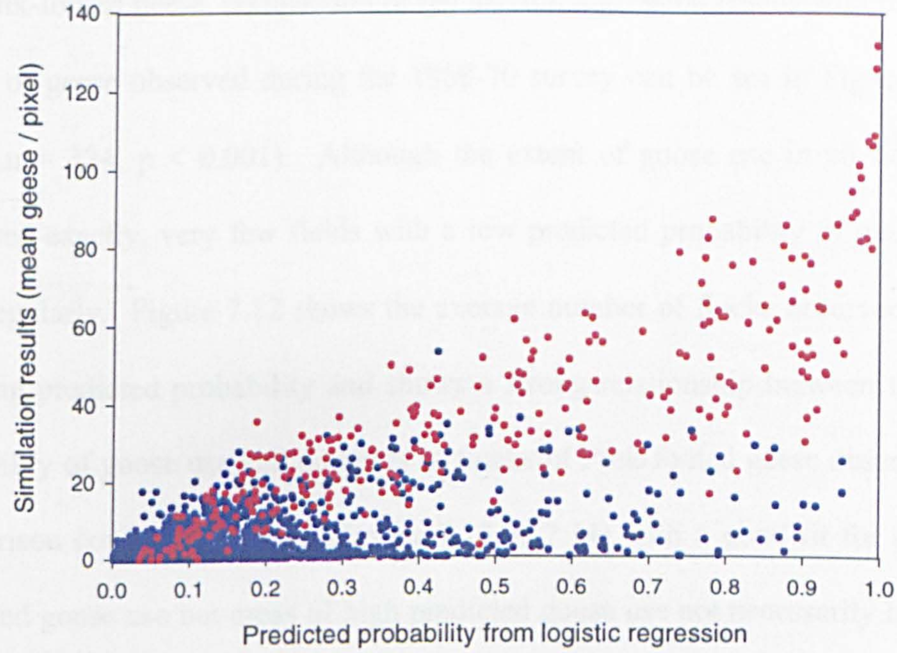

Figure 7.10 The relationship between the total number of geese landing per field for the IBMM and the predicted probability of goose use from the logistic regression model for each field (R-value = 0.746, n = 3445, $p < 0.001$). Fields from the core area are highlighted in red (R-value = 0.825, n = 324, $p < 0.001$).

In addition there is better agreement between the results of the two modelling techniques for the core fields than for fields further from the roost. There was greater agreement between the results of the two models for the Loch Leven study area than there was for Strathearn and Strathallan. Comparison between the results of the logistic regression model and the mean pixel value and total field value from the IBMM at Strathearn and Strathallan, using the same roost data, gave an R-value of 0.681 ($n = 3445$, $p < 0.001$) and 0.480 ($n = 3445$, $p < 0.001$) respectively (see Chapter 6). The greater agreement between the two models at Loch Leven probably arises because there is effectively only one goose roost as opposed to the nine in Strathearn and Strathallan, resulting in a simpler overall goose feeding pattern.

7.3.5 Results of the logistic regression models for core fields

For Pink-footed geese, comparison of the logistic regression results with the number of flocks of geese observed during the 1968-70 survey can be see in Figure 7.11 ($R^2 = 14.8\%$,$n = 324$, $p < 0.001$). Although the extent of goose use in all fields was not predicted exactly, very few fields with a low predicted probability of goose use were used regularly. Figure 7.12 shows the average number of flocks observed in fields of differing predicted probability and shows a strong relationship between the predicted probability of goose use and numbers of flocks of Pink-footed geese observed. Visual comparison confirms this (see Figures 7.13 & 7.14) with a good fit for areas of low predicted goose use but areas of high predicted goose use not necessarily holding large numbers of goose flocks.

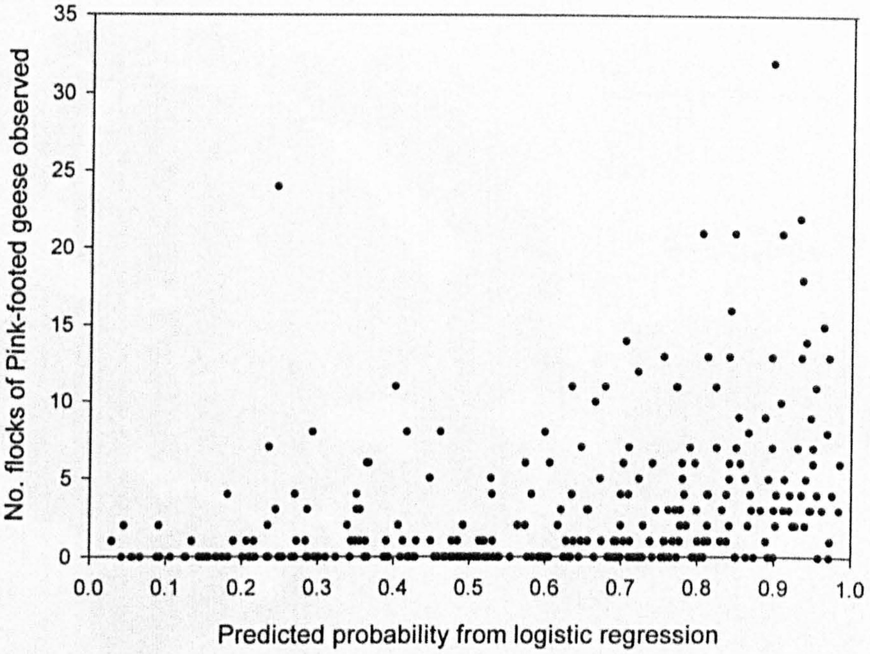

Figure 7.11 The relationship between the predicted probability of Pink-footed goose presence from the logistic regression model and the number of flocks observed for each of the core fields (R^2-value = 0.148, n = 324, $p < 0.001$).

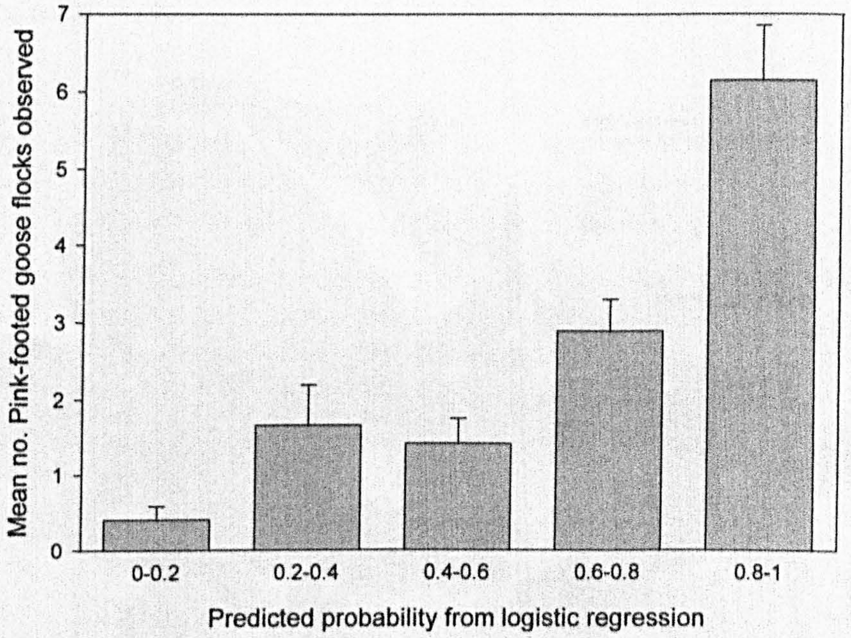

Figure 7.12 The average number of flocks observed in fields in different predicted probability bands for Pink-footed goose presence from the logistic regression model. Data for core fields only. Error bars = s.e.(mean).

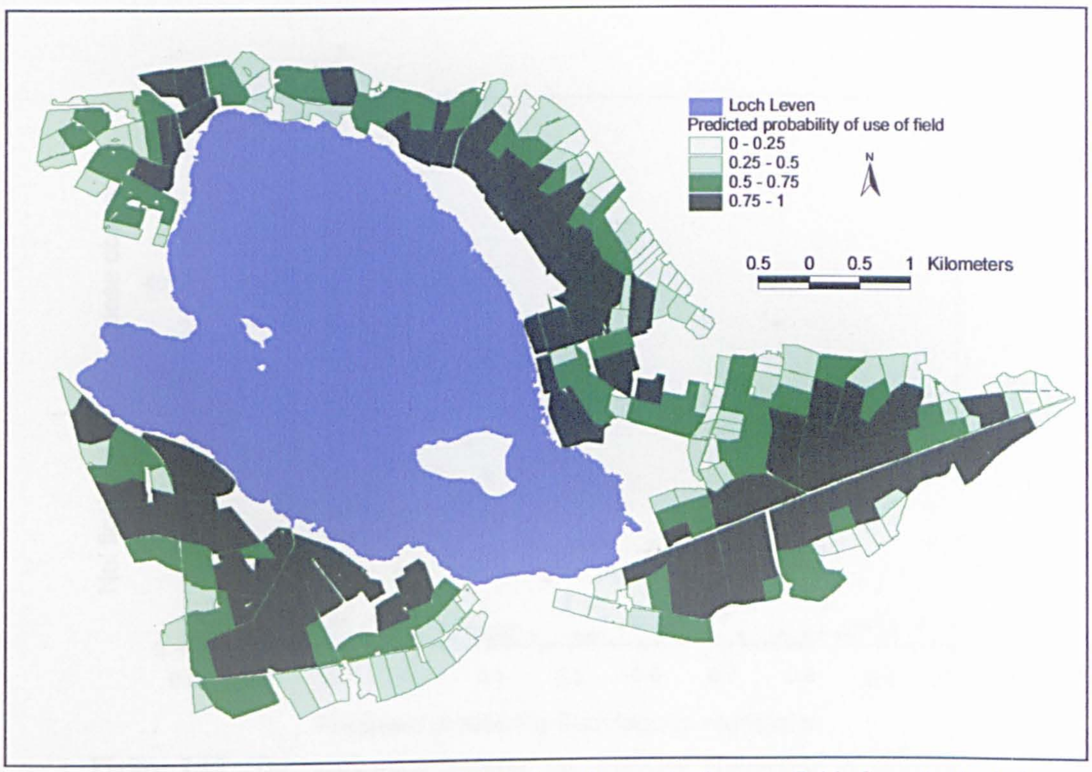

Figure 7.13 The predicted distribution of Pink-footed geese in the core fields from the logistic regression model.

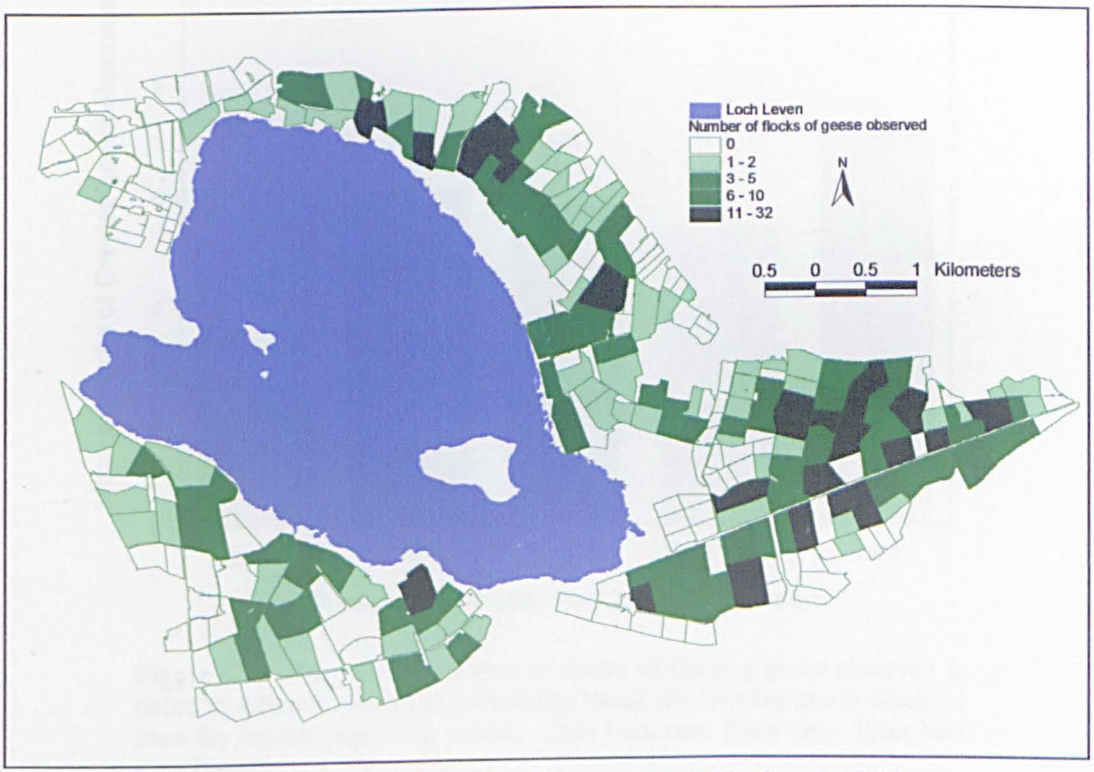

Figure 7.14 The number of flocks of Pink-footed geese observed in the core fields.

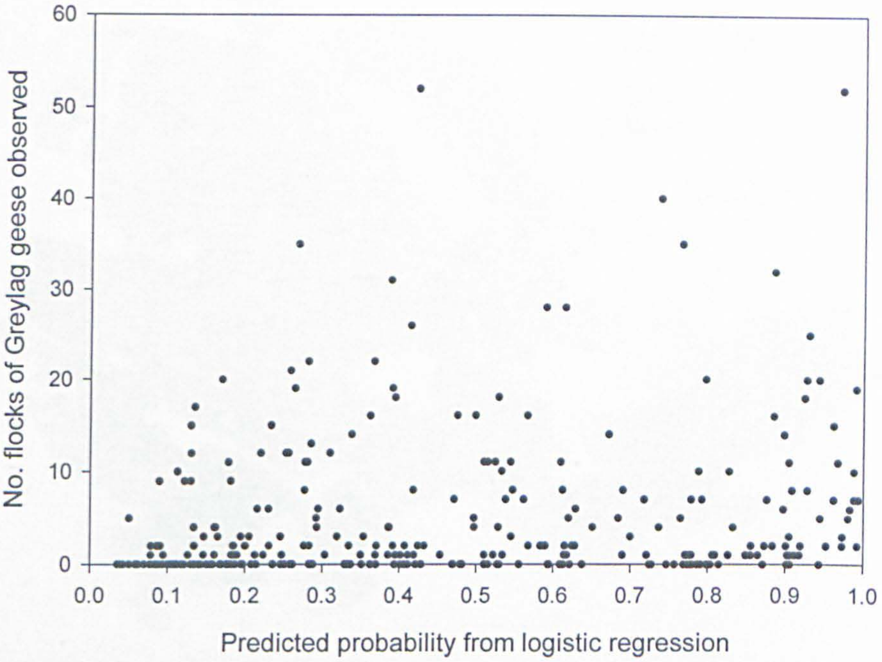

Figure 7.15 The relationship between the predicted probability of Greylag goose presence from the logistic regression model and the number of flocks observed for each field in the core area (R^2-value = 0.035,n = 324, p = 0.001).

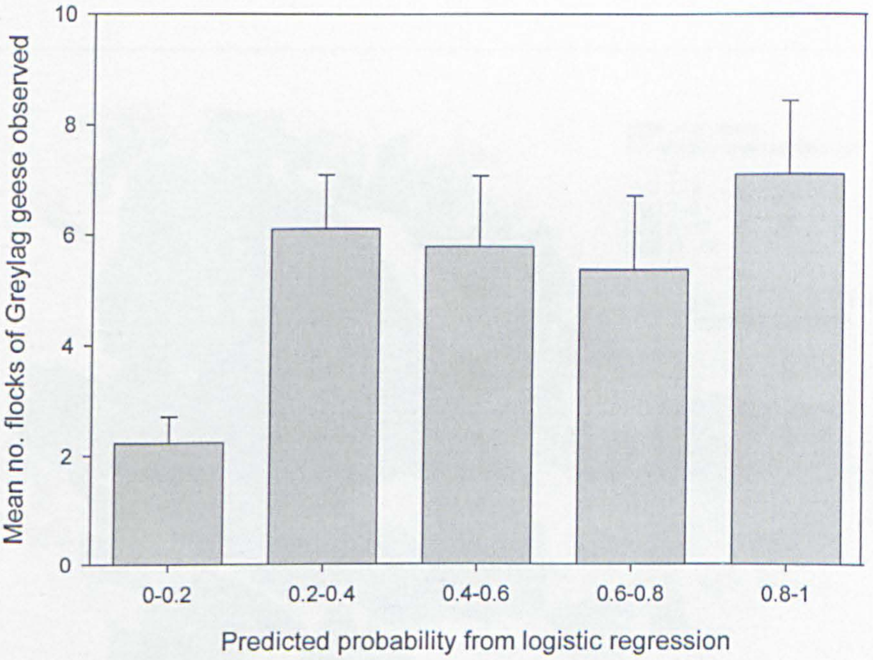

Figure 7.16 The average number of flocks of Greylag geese observed in fields in different predicted probability bands for Greylag goose presence from the logistic regression model. Data from core fields only. Error bars = s.e.(mean).

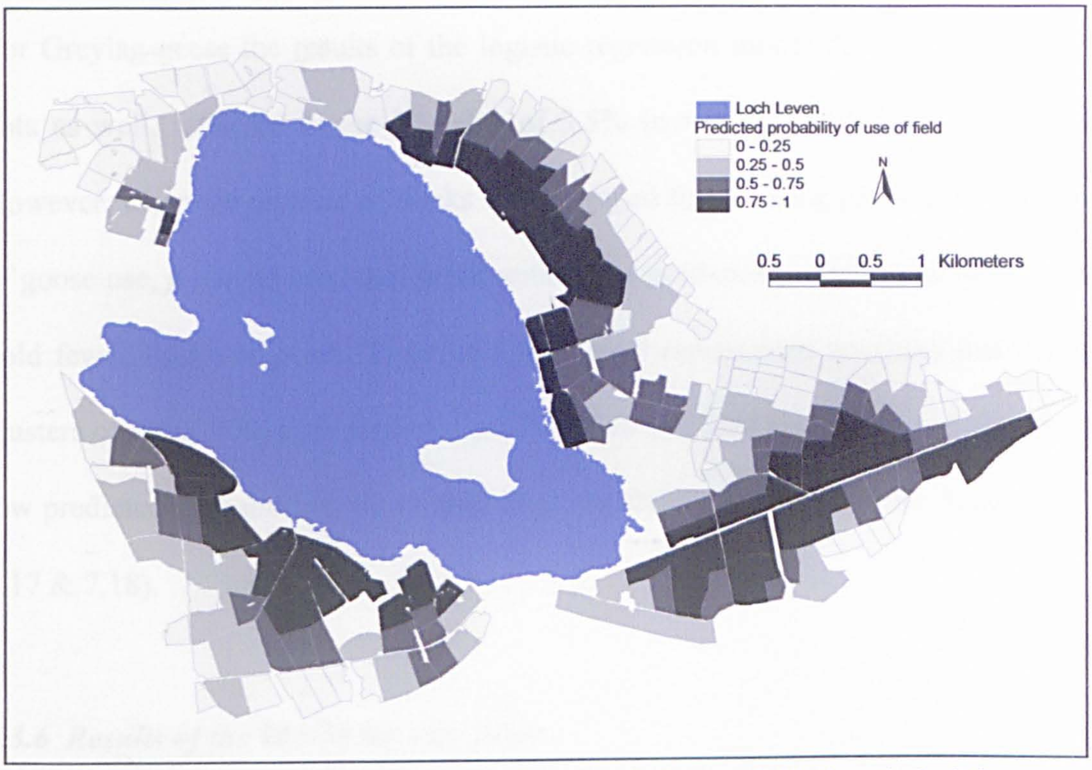

Figure 7.17 The predicted distribution of Greylag geese in the core fields from the logistic regression model.

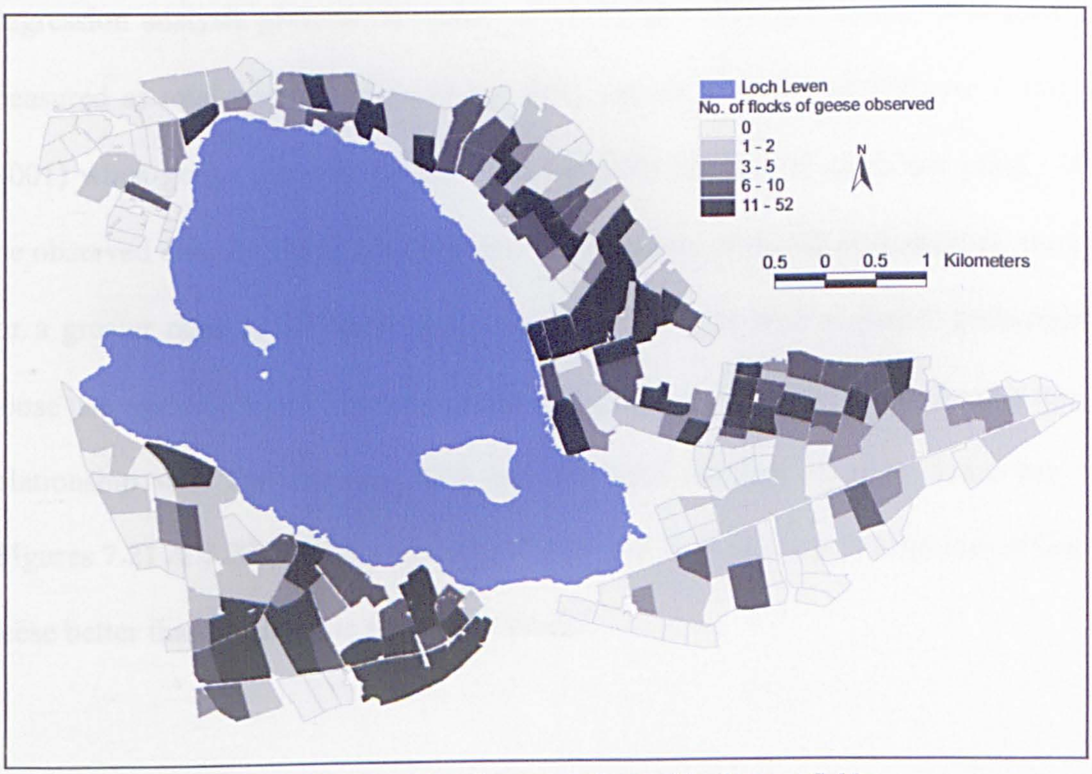

Figure 7.18 The number of flocks of Greylag geese observed in the core fields.

For Greylag geese the results of the logistic regression model do not fit the observed data as well, reflected in the R^2-value of 3.5% ($n = 324$, $p < 0.001$) (Figure 7.15). However, when the number of flocks was averaged for differing predicted probabilities of goose use, it can be seen that fields with lower predicted probabilities were likely to hold fewer flocks of geese (Figure 7.16). Visual comparison confirms that there are clusters of fields with high predicted probabilities that held few flocks and clusters with low predicted probabilities which held large numbers of Greylag goose flocks (Figures 7.17 & 7.18).

7.3.6 Results of the IBMM for core fields

The results for the core fields from the IBMM for Greylag geese are shown in Figures 7.19 & 7.20. The predicted results do not fit the observed data very closely. Regression analysis gives an R^2-value of 15.7% ($n = 324$, $p < 0.001$) with goose use measured as total number of geese per field and an R^2-value of 9.9% ($n = 324$, $p < 0.001$) when goose use was measured as the mean number of geese per pixel. When the observed data for fields was averaged for different predicted probabilities, the trend for a greater number of flocks being observed in fields with a greater probability of goose use could be seen. The total number of goose visits per field produced a stronger relationship with the observed data than the total number of goose visits per field (Figures 7.21 & 7.22), and both measures reflected the observed distribution of Greylag geese better than the logistic regression model.

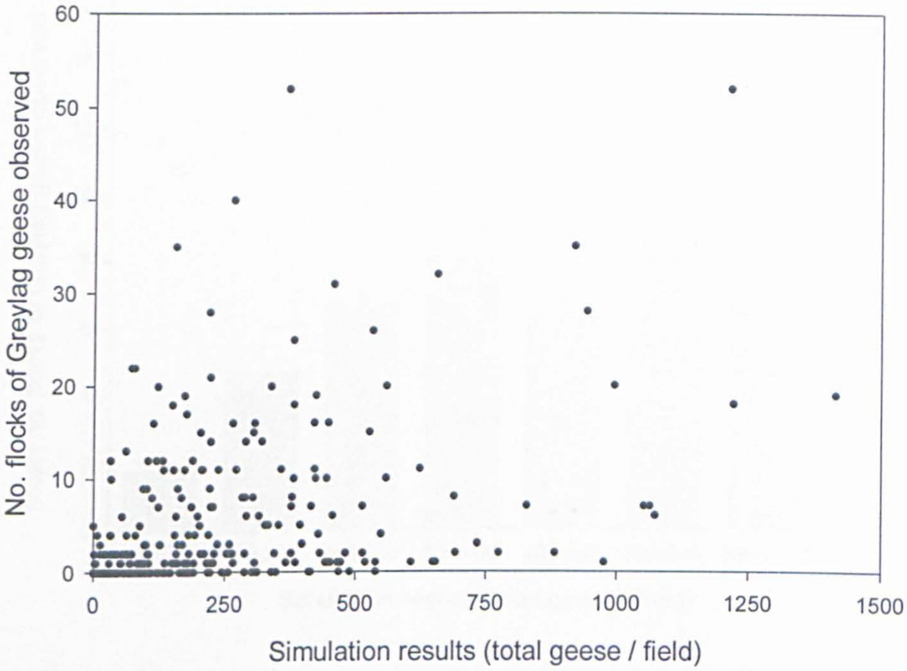

Figure 7.19 Comparison of the total number of geese simulated to land in each field with the number of flocks observed in the core fields (R^2-value = 0.157,n = 324, $p < 0.001$).

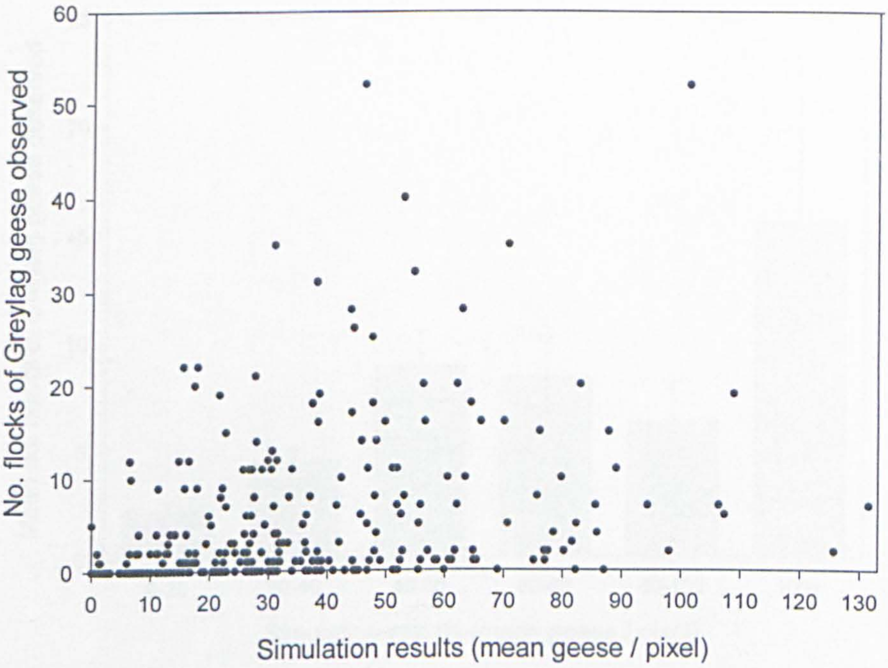

Figure 7.20 A comparison of the average number of geese simulated to land per pixel for with the number of flocks observed in the core fields (R^2-value = 0.099, n = 324, $p < 0.001$).

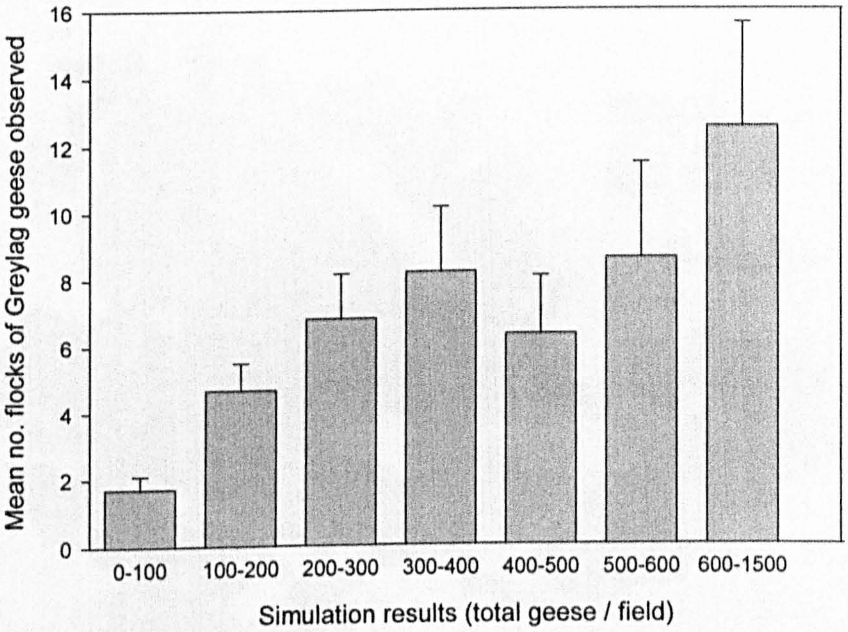

Figure 7.21 The average number of flocks of Greylag geese observed in fields in different bands of predicted goose use from the IBMM, using the total number of geese landing per field. Data from core fields only. Error bars = s.e.(mean).

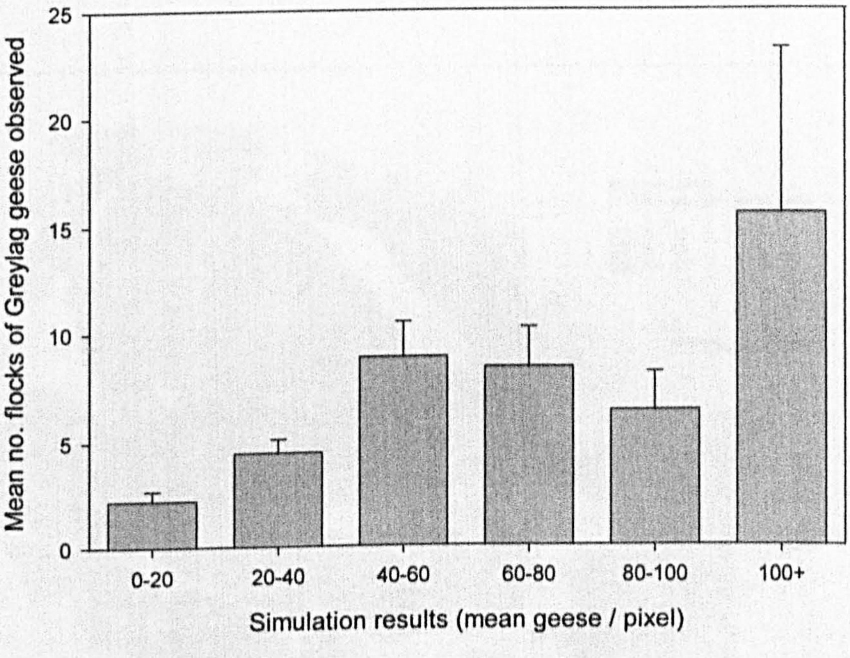

Figure 7.22 The average number of flocks of Greylag geese observed in fields in different bands of predicted goose use from the IBMM, using the mean number of geese landing per pixel. Data from core fields only. Error bars = s.e.(mean).

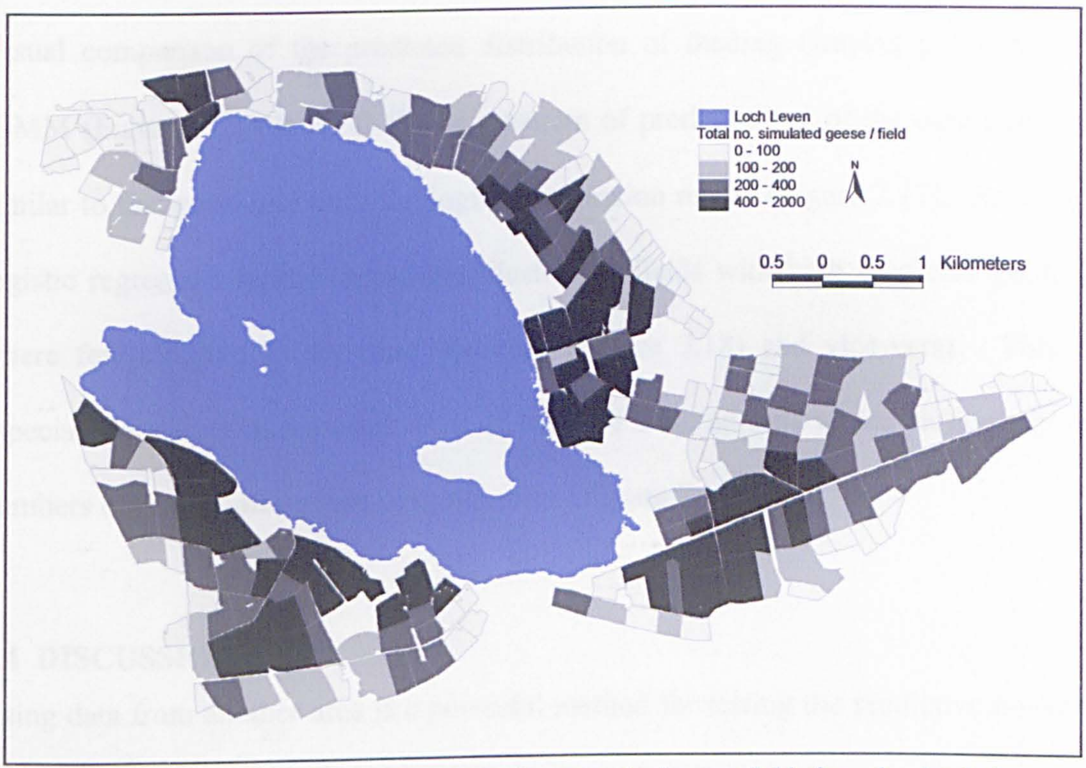

Figure 7.23 The predicted distribution of Greylag geese in the core fields from the simulation model, showing the total number of geese per pixel.

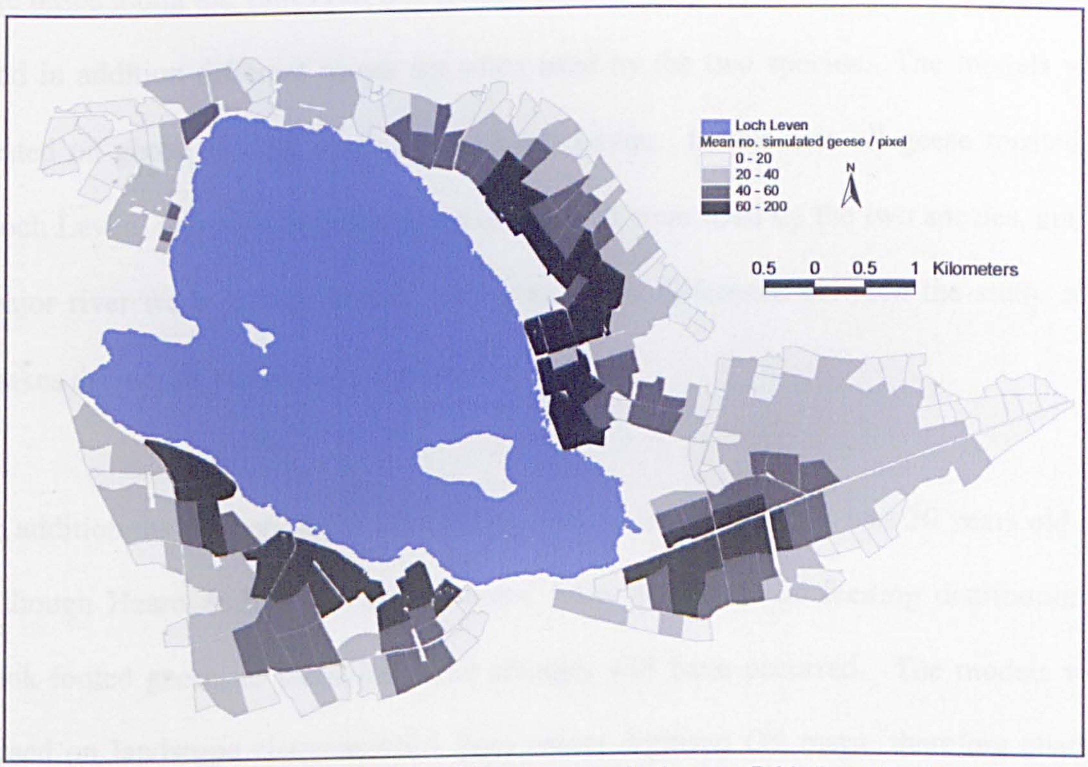

Figure 7.24 The predicted distribution of Greylag geese in the core fields from the simulation model, showing the mean number of geese per pixel.

Visual comparison of the predicted distribution of feeding Greylag geese from the IBMM (Figures 7.23 & 7.24) shows a pattern of predicted use of the core fields very similar to that predicted from the logistic regression model (Figure 7.17). As with the logistic regression model there were clusters of fields with high predicted goose use where few Greylag flocks were observed (Figure 7.18) and vice-versa. This was especially apparent in the south-west of the core area, an area where particularly high numbers of Pink-footed geese were observed (Figure 7.14).

7.4 DISCUSSION

Using data from another area is a powerful method for testing the predictive powers of models (Verbyla & Litvaitis 1989). For both modelling techniques models were built on data from Strathearn and Strathallan, an area where goose roosts and feeding areas are based along the valleys of two rivers. A number of roosts are used by each species, and in addition different roosts are often used by the two species. The models were tested on goose feeding areas around Loch Leven. In this area all geese roosted on Loch Leven, although different areas of the loch were used by the two species, and no major river were present in the study area. This difference between the study areas makes these tests particularly rigorous.

In addition the data on goose distribution used to test the models was 30 years old and although Hearn & Mitchell (1995) noted little change in the feeding distribution of Pink-footed geese, in that time some changes will have occurred. The models were based on landscape characteristics from recent digitised OS maps, therefore changes such as the alteration of field boundaries, building / demolition of houses will affect the predicted results. This is especially notable to the south west of the study area where areas previously used by geese are no longer farmland. In addition accurate counts of goose use of fields were only available for the core 324 fields, providing only a small number of fields for detailed comparisons, all with relatively high goose use due to their location so close to the roost.

For Pink-footed geese the results of the logistic regression proved a good fit to the observed data. Although goose feeding patches further from the roost were not predicted exactly, the general distribution of geese was realistic and the extent of the main feeding area around the roost well predicted. Within this core area the model again proved good at predicting the extent of goose use of individual fields. Fields with low predicted use were seldom used. Fields with high predicted goose use were not always observed to contain large numbers of geese. Such '*false positive*' errors (Fielding & Bell 1997) are frequently found in wildlife-habitat models (e.g. Osborne *et al* 2001). Undersaturation can be the cause of '*false positive*' errors (Fielding & Bell 1997), but this is unlikely to be the case in this situation as all core fields were situated close to a major goose roost. The errors in this study are more likely to be due to environmental variables such as fields not containing suitable food or being subject to high disturbance levels such as deliberate scaring by farmers. The models therefore predict areas of potential goose use as stressed in Chapter 3. The predicted probability of goose presence is a measure of the chance of geese occurring in a field, but analysis of the core fields shows that it can be considered as a measure of the extent of goose use of a field. As such the predicted median distance at which Pink-footed geese feed from the roost, 4.4 km, fits very well with results obtained from other studies in north-east Scotland where Pink-footed geese are observed to feed at a median distance of 3.9 – 4.8 km from the roost (Bell 1988; Giroux & Patterson 1995; Keller *et al* 1997). Newton & Campbell (1973) calculated that *c*.20% of Pink-footed geese fed within the core area while the model predicted 17.6% showing that the area over which Pink-footed geese were predicted to feed was realistic.

The results of the logistic regression model for Greylag geese predicted the general distribution of Greylag geese around the loch and correctly predicted Greylag geese to feed, in general, nearer to the loch than Pink-footed geese. As with Pink-footed geese, however, the location of feeding patches further from the loch were not predicted exactly. For the core fields the extent of goose use of fields was not accurately predicted and Greylag geese were observed to feed repeatedly in fields where low goose use was predicted, as well as being absent from fields where goose use was predicted to be high. In the core area altitude was fairly uniform and therefore distance from buildings and the roost were the landscape characteristics affecting the predicted pattern of Greylag goose use. The results therefore suggest that Greylag geese are feeding in fields closer to buildings than predicted from the Strathearn and Strathallan data. This could be due to a number of reasons. The logistic regression model may not have been an accurate representation of the relationship between landscape characteristics and the distribution of Greylag geese as only 84 fields were used to create the model compared with 234 for Pink-footed goose model. However, it is more likely that the behaviour of Greylag geese at Loch Leven differs from those in

Strathearn and Strathallan. Shooting pressure on Loch Leven was relatively light at the time of the 1968-70 survey with fewer than 200 geese being shot per year (Newton & Campbell 1973). In Strathearn, however, the recent increased shooting pressure is considered to have had an impact on the feeding distribution of Greylag geese (Bell & Newton 1995). As high shooting pressure can increase the response of geese to human disturbance (Gerdes & Reepmeyer 1983, Madsen 1984) differences in shooting pressure between the two study areas may mean that the tolerance of Greylag geese to human disturbance at Loch Leven was greater. Unlike at Strathearn and Strathallan, all Pink-footed and Greylag geese at Loch Leven roost at the same site resulting in competition between species for food in the core fields close to the loch. Observations of Pink-footed and Greylag geese in mixed flocks show that in any disputes Greylag are dominant (Kear 1965) but Madsen (1985a) found that when large numbers of Pink-footed geese where present in West Jutland, Denmark, Greylag geese shifted their field use. Greylag geese changed crop use away from that preferred by the Pink-footed geese and also avoided Pink-footed geese by feeding in fields closer to the road. Madsen (1985a) suggested that this was due to exploitative competition rather than interference competition where Greylag geese behaved optimally by selecting sub-optimal habitat as opposed to competing for grain with large numbers of Pink-footed geese. In contrast to the situation in West Jutland where Greylag geese arrive before the Pink-footed geese, at Loch Leven Pink-footed geese arrive first and numbers peak in early October when up to 10,000 geese are present (Newton & Campbell 1973). Therefore at Loch Leven Pink-footed geese have the opportunity to deplete resources in the most suitable fields before the majority of Greylag geese had even arrived, further increasing the opportunity for exploitative competition.

Simple attempts to control for competition with Pink-footed geese in the Greylag goose regression model proved unsuccessful. The probability of field use by Greylag geese from the logistic regression model was integrated with an inverse measure of Pink-footed goose presence, using Bayesian statistics. The resultant probability surface for Greylag geese, however, was not significantly related to the observed distribution of Greylag geese ($R^2 = 0.005$, $p = 0.23$).

The IBMM highlighted the core feeding area for Greylag geese near the roost. Although the IBMM was more successful at predicting the Greylag goose distribution than the logistic regression model, the fit between observed and predicted goose use was not very good. Differences between the observed and predicted Greylag goose distribution within the core area are likely to be due to factors discussed above.

The overall pattern of predicted goose distribution for Greylag geese differed between the two models. The simulation concentrated goose use of fields around the roost while in the logistic regression model, some fields over 15 km from the roost still had relatively high probabilities of goose use. This is clearly seen in the analysis of field use at different distances from the roost (see Figures 7.7 & 7.8) where the median distance of feeding geese from the roost was 3.7 km for the logistic regression model and 1.7 km for the IBMM, as observed for Strathearn and Strathallan (see Chapter 6).

The only published data on the median distance at which Greylag geese feed from the roost in north-east Scotland, showed a range from 2.4 km – 14.2 km dependent on the roost and time (Bell 1988) and was therefore of little use in establishing the most realistic model. Radio-tracked Greylag geese in Strathearn and Strathallan fed a mean distance of 2.0 km from the roost used the previous night (Chapter 4). Newton and Campbell (1973) found that *c.* 40% of Greylag geese fed within the core fields. This value lies in the middle of the 29% predicted from the logistic regression model and 54% predicted from the IBMM. The logistic regression model underestimated the percentage of geese feeding in the core area near the roost at Loch Leven. The result confirms suggestions in Chapter 6 that the logistic regression model overestimates the distance geese feed from the roost as the roosts used to build the model were not exactly those used by the geese observed. The IBMM, conversely, overestimated the percentage of Greylag geese feeding in the core fields. The IBMMs were built on data from geese in Strathearn and Strathallan where many more roosts were used and numbers of geese at each roost were relatively small so the effect of depletion in fields close to the roost was not great. At Loch Leven the large numbers of both Pink-footed and Greylag geese at the one roost may result in depletion of favoured fields close to the roost. The extremely high levels of goose use in fields close to the roost predicted by the IBMM at Loch Leven are unrealistic as these fields would not have enough resources to sustain such numbers of geese. Predicted goose use of fields close to the roost above their carrying capacity, due to the larger numbers of geese at Loch Leven, is therefore likely to account for the overestimation of the percent of geese feeding in the core fields.

The IBMM was better than the logistic regression model at predicting goose distribution in the core fields close to the roost. When predicting the entire feeding area, however, the IBMM did not predict geese feeding as far from the roost as they were observed, with the logistic regression model predicting a more realistic overall distribution. As discussed in Chapter 6, the logistic regression model overestimates the distance at which geese feed from the roost in Strathearn and Strathallan. The IBMM produced a more realistic pattern of goose use with distance from the roost for Strathearn and Strathallan as the probability of landing was derived from observed goose movements (see Chapter 6). At Loch Leven the situation differs in that only one goose roost is used by much larger numbers of both Pink-footed and Greylag geese. Larger numbers of geese will result in the depletion of resources in suitable fields close to the roost so that geese have to fly further to feed than at Strathearn and Strathallan. The apparent closer fit of the logistic regression model with the feeding distribution of Greylag geese at Loch Leven for areas further from the roost is therefore likely to be a chance result. It is also possible that some of the Greylag geese observed feeding further from Loch Leven were roosting elsewhere, as Greylag geese frequently roost at small roosts (Bell *et al* 1997, Chapter 4). The IBMM may be modified to include threshold values for field use, above which geese do not use a field. Although such modifications could take account of the numbers of Greylag geese, they could not take account of depletion by other species (i.e. Pink-footed geese).

In conclusion the logistic regression model proved fairly good at predicting the distribution of Pink-footed geese over the whole area and the extent of goose use in the core fields, although not all feeding patches further from the roost were predicted accurately. Predicting the feeding distribution of Greylag geese proved less successful possibly due to a habitat shift caused by competition by the more numerous Pink-footed geese. The IBMM predicted the use of core fields better than the logistic regression model, but underestimated Greylag goose use further from the roost.

7.5 SUMMARY

The predictive powers of the two modelling techniques developed in this study were tested on another goose feeding area, around Loch Leven. Data on goose distribution in this area were available from a previous study (Newton & Campbell 1973). The logistic regression model predicted Pink-footed goose distribution fairly well. The feeding distribution of Greylag geese were not as well predicted by either modelling technique, probably due to changes in behaviour at Loch Leven compared with Strathearn and Strathallan, caused by competition with Pink-footed geese. The IBMM predicted field use better than the logistic regression model close to the roost, but did not predict fields used by geese further from the roost.

CHAPTER 8 – DISCUSSION AND CONCLUSIONS

8.1 OVERVIEW

This study has looked at the effects of landscape characteristics on field selection by geese and used these relationships to predict the feeding distribution of geese using two different modelling approaches, a standard logistic regression technique (Chapter 3) and an individual based movement model (IBMM) (Chapter 5). The IBMM appeared to perform as well as, but not better than, the standard logistic regression model (Chapters 6 & 7).

The results of this study have implications for the management of wintering Greylag and Pink-footed geese in Britain. Radio-tracking data has highlighted differences in the way two species use their feeding grounds (Chapter 4). Predictive models have enabled the identification of potential areas for the siting of alternative feeding areas (AFAs) for both species in Strathearn and Strathallan. Both the logistic regression models and the IBMM's can be applied to any area used by wintering geese without the need for fieldwork, requiring only digitized OS LandLine data, OS Panorama data, Macaulay Land Cover for Scotland 1988 data and knowledge of the location of goose roosts.

8.2 THE EFFECT OF THE LANDSCAPE ON FIELD CHOICE BY GEESE

Various studies have shown that grey geese avoid feeding in proximity to landscape characteristics associated with disturbance, for example roads (Gill 1994, Keller 1991, Madsen 1984, Newton & Campbell 1973) and wind turbines (Larsen & Madsen 2000).

Landscape characteristics such as these can have a considerable influence on where geese feed as confirmed in this study where distance for buildings was a highly significant predictor variable in both Pink-footed and Greylag goose models. Topography also affects goose feeding distribution, although differently for the two goose species. Previous studies have noted that while Greylag geese have a tendency to feed along the river, Pink-footed geese prefer large fields in an open area, however far from the river (Newton *et al* 1973). This was confirmed by the results of this study, which showed that Greylag geese have a preference for feeding at lower altitudes, close to the river while Pink-footed geese selected fields dependent on both their size and their slope, preferring larger flatter fields (Chapters 3 & 5).

8.3 THE RESULTS OF PREDICTIVE MODELS

8.3.1 Introduction

Validation of models using independent data is necessary if the predictive powers of the two models are to be compared, the most rigorous test being to assess the ability of models to predict distributions in a different geographical area (Verbyla & Litvaitis 1989). The accuracy of the two modelling techniques developed in this study at predicting the feeding distribution of geese was tested with independent goose distribution data both within Strathearn and Strathallan and for another area, Loch Leven.

8.3.2 Logistic Regression models

The logistic regression models for Pink-footed and Greylag geese appeared to fit the jack-knifed results equally well (AUC's = 0.808 and 0.803 respectively) despite the Greylag goose model being based on a much smaller sample size (n = 86 as opposed to 234 for Pink-footed geese) (Chapter 3). When these models were applied to Loch Leven the Pink-footed goose model fitted the observed data fairly well, both within the core area and for the general distribution of feeding geese. The Greylag goose model, however, showed a much poorer fit, with heavy goose use of fields where geese were not predicted to feed (Chapter 7). It is possible that the small sample size used resulted in the Greylag goose model not reflecting the effect of the habitat on goose distribution accurately. It is more likely, however, that it is the result of differing behaviour of Greylag geese at the Loch Leven study area due to competition with con-specifics and large numbers of Pink-footed geese.

8.3.3 IBMM

There was no means of evaluating the IBMM on the data on which it was built. As with the logistic regression model, when tested on independent data, Greylag goose distribution was predicted well in Strathearn and Strathallan (Chapter 6) but relatively poorly predicted when the model was applied to Loch Leven (Chapter 7).

The major difference between the results of the two modelling techniques was that the simulation model predicted geese to feed much closer to the roost than the logistic regression model. As discussed previously (Chapter 6) the logistic regression model probably overestimated the distance that Greylag geese fed from the roost as analysis was based on inaccurate roost data. In the simulation model the probability of landing was based on real goose movements from known roosts. The probability of landing, and consequently the distance at which simulated geese land from the roost, is therefore an accurate reflection of observed goose behaviour. The distance that simulated geese flew in one movement may, however, have been underestimated. The distance that observed geese flew from the roost was approximated to a straight line while the path of a simulated goose, although having the same probability of landing in each pixel and therefore the same length, was not necessarily straight. This effect was unlikely to be great as simulated geese had relatively straight flight paths. The models could have been adapted to adjust for this effect by dividing the probability of landing for each pixel by

Mean (simulated path length) / Mean (straight-line distance of movement).

8.3.4 Additional factors affecting goose distribution

The distribution of animals is strongly affected by food availability (Sutherland 1996). However, neither of the predictive models developed in this study incorporated any measure of resource availability. Although Greylag and Pink-footed geese show strong preferences for particular crop types at certain times of the year (Newton & Campbell 1973, Forshaw 1983, Madsen 1984, Bell 1988, Patterson *et al* 1989, Giroux & Patterson 1995, Hearn & Mitchell 1995, Stenhouse 1996), crop preferences are less significant when averaged through the whole winter (Chapter 3). Data on crop type is much harder to obtain than for other predictor variables. Therefore inclusion of crop types into the predictive models would make them much more difficult to apply to other goose wintering areas. In addition, as crop types change annually, the predictive models would only be valid for one year. Although crop type categories were included as one of the landscape variables in the logistic regression analysis, they were not selected in the models for either Pink-footed geese or Greylag geese. The preferences of geese for certain crops varies through the winter as some foods are depleted (e.g. stubbles) while others become available (e.g. winter cereal) (Newton & Campbell 1973, Forshaw 1983, Madsen 1984, Bell 1988, Patterson *et al* 1989, Giroux & Patterson 1995, Hearn & Mitchell 1995, Stenhouse 1996). It is likely that by defining crop types for shorter periods (e.g. monthly), food availability could be better modelled, but such models would prove very difficult to apply to other areas as in addition to crop types, ploughing dates and sowing dates would be required. Neither does accurate crop data necessarily provide adequate information on the quality or quantity of food available. Geese show preferences for grass of different sward height (Andrews & Rebane 1994) and quality (Owen 1975) while the amount of spilt grain available in stubble fields is highly variable (Patterson *et al* 1989).

Additional factors such as scaring intensity and shooting pressure will also affect the distribution of feeding geese (Newton & Campbell 1973, Madsen 1985b). As with food availability these effects will vary over time, are difficult to quantify, and they are not permanent landscape characteristics like the variables included in the predictive models. If incorporated into the models such variables would reduce the transferability to other areas. **All models produced in this study therefore predict fields in which**

geese are likely to feed provided that adequate food is available and disturbance is below a critical threshold.

8.3.5 Comparison of the predictive powers of the two modelling techniques

Individual based movement models (IBMMs) can potentially outperform standard wildlife-habitat models at predicting the distribution of animals if the path of an individual is constrained by landscape heterogeneity, as this will affect the use of resources (Johnson *et al* 1992). Individuals may not encounter suitable habitat patches if there are barriers to movement to the patch, an effect that would be modelled in a movement model but not by wildlife-habitat models such as logistic regression (see Chapter 5).

The results of this study, however, showed no evidence of IBMMs proving more accurate at predicting the feeding distribution of geese than the standard logistic regression technique. Within Strathearn and Strathallan neither modelling technique out-predicted the other when applied to the independent data set (Chapter 6). When applied to the Loch Leven study area the simulation model showed a slightly better fit to the observed data than the logistic regression model (Chapter 7). However these results do not indicate that the IBMM was a superior method of predicting goose distribution. The agreement of model predictions with observed goose distribution data was low for both modelling techniques, probably due to competition as discussed above and in Chapter 7. Differences between the two techniques are likely due to chance differences in the relationships between predictor variables and the predicted goose use.

In the IBMM the direction of goose flight was constrained by either altitude or distance from the river (Chapter 5). There were no areas that were suitable for feeding geese, as predicted by the logistic regression model, but to which there were significant barriers to movement due to altitude or distance from the river in either study area. This is why the simulation model did not prove better at predicting the distribution of Greylag geese than the logistic regression model, despite being based on a larger amount of data and therefore on presumably more accurate relationships between goose feeding behaviour and landscape characteristics. Although there is some potential for using IBMMs to predict goose distribution in areas where there is a possibility of geese moving between valleys while feeding, this situation is unlikely to be common.

The IBMM assumed that geese move randomly and therefore do not have a pre-determined destination. Conversely the logistic regression model assumes that geese have perfect knowledge of the suitability of fields. Individual Pink-footed geese have been shown to return repeatedly to certain feeding areas (Hearn & Mitchell 1995) and Pink-footed geese have been shown to fly further to feed in fields of preferred crops (Giroux & Patterson 1995). Radio-tracking results suggest that Greylag geese feed in areas surrounding roosts but not necessarily by the roost that they had used (Chapter 4). This suggests that Pink-footed and Greylag geese do use prior knowledge when selecting a field to feed. It is not necessary that geese use the same mechanism for decision making as the simulated geese, as long as the patterns of movement are the same. If, however, Greylag geese favour feeding areas close to roosts, irrespective of whether it was the roost that they used or not, predicting geese to feed close to roosts (as with logistic regression) may be a more appropriate technique than modelling their movements (as with IBMMs).

8.4 IBMMs IN ECOLOGY

The IBMMs developed in this study did not out-perform the logistic regression model. However, such models could potentially predict animal distribution better than standard wildlife-habitat models, if animal movement is constrained by a heterogeneous landscape (Johnson *et al* 1992). IBMMs have an added advantage of being very flexible (Turchin 1991, Marsh & Jones 1988), enabling the incorporation of a whole range of features such as depletion (e.g. Turner *et al* 1993 & 1994), individual variation (e.g. Saarenmaa 1988), mortality (e.g. Dewdney 1984, Turner *et al* 1993 & 1994, Schippers *et al* 1996) and energetics (e.g. Turner *et al* 1993 & 1994) which cannot be incorporated into more standard distribution modelling techniques. Although IBMMs cannot be applied to all situations, as there needs to be a known starting position / distribution, there is a wide range of situations to which they could be applied. Despite their potential advantages, IBMMs have not been widely used in ecology. IBMMs have been primarily used to model dispersal and connectivity between populations. For example Boone and Hunter (1996) modelled the movement of Grizzly bears (*Ursus arctos horribilis*) constrained by habitat type and linear barriers (roads), and predicted the effect of proposed timber harvesting plans on the connectivity of bear populations. Similar work by Schippers *et al* (1996) modelled the dispersal of badgers (*Meles meles*) to assess the possibility of extinct populations being recolonised, again with movement constrained by habitat quality, roads and rivers. In most IBMMs the effect of landscape characteristics on animal movement are estimated (e.g. Schippers *et al* 1996) or interpreted from literature (e.g. Boone & Hunter 1996), which is far from ideal. There are few example of IBMMs based on analysis of observed animal movements, although Jones (1977) modelled the movement and oviposition of cabbage butterflies by analysing the observed movements of butterflies in experimental plots. There is considerable scope for analysing movement data from marked, and more specifically radio-tracked, individuals to derive rules on movement that can be incorporated into IBMMs, as shown in this study (Chapter 5, Boone & Hunter 1996). There are a variety of scenarios where IBMMs may prove more appropriate for modelling distributions than standard wildlife-habitat models for example:

(i) Predicting the spread of alien species, for example the Coypu (*Myocastor coypus*) in East Anglia (Reeves & Usher 1989) or Grey squirrels (*Sciurus carolinensis*) in mainland Europe (Rushton *et al* 1997).

(ii) Predicting the probability of animals colonising newly created habitat or returning to areas where local extinction has occurred. For example, the recolonisation of patches where stochastic local extinction has occurred in patchily distributed butterfly species (Thomas & Harrison 1992, Hanski *et al* 1995).

(iii) Predicting the feeding distribution of animals that moves out from a known roost / den locations. As this situation is uncommon, using IBMMs to predict feeding distribution is restricted to relatively few species, mainly wildfowl.

IBMMs may be particularly suitable at predicting the feeding distribution of scarce species, as the ability of standard methods such as logistic regression, discriminate analysis and artificial neural networks to predict distribution decreases as species rarity increases (Manel *et al* 1999) while a relatively small number of individuals are required to obtain parameters for models from radio-tracking.

8.5 IMPLICATIONS FOR THE MANAGEMENT OF WINTERING GEESE

8.5.1 Introduction

Considerable emphasis was placed on the damage caused by grey geese and methods of alleviating the goose-agriculture conflict during the 1980s and early 1990s (e.g. van Roomen & Madsen 1992) as the number of geese wintering in Britain and the whole Western Palearctic increased (Madsen 1992). Combining all goose species, Britain is subject to the highest goose grazing pressure in Western Europe at 70-90 million goose-days per year in the early 1990's (Madsen 1992). The two methods most widely recommended to alleviate goose-agriculture conflict are the implementation of a scheme to compensate farms for economic loss and the creation of Alternative Feeding Areas (AFA's) (Owen 1977, van Eerden 1990, Owen 1990, Jepsen 1991, Andrews & Rebone 1994, Giroux & Patterson 1995, Percival *et al* 1997).

8.5.2 Transferability of goose models

The predictive models developed in this study can only be used to target the management of wintering geese for areas outside Strathearn and Strathallan if they are transferable to other geographical regions. Although models can accurately predict species distribution in different areas (e.g. Austin *et al* 1996), owing to differences in animal behaviour, species composition and habitat, this is not always the case (Fielding & Haworth 1995).

Pink-footed geese are very mobile and move between feeding areas throughout the course of the winter (Fox *et al* 1989). Radio-tracking results from this study suggest that Greylag geese may be even more mobile (Chapter 4). It is therefore unlikely that goose behaviour will vary between wintering areas within Britain, except in response to differences in the environment.

The availability of resources will affect the feeding distribution of geese. The overall availability of food will be affected by agricultural practices or depletion of food, especially by geese. If, for example, models are applied to areas with larger numbers of geese than in the area where the models were created, model predictions are likely to be inaccurate as the effect of competition for resources may result in geese flying further from the roost to feed, or feed in sub-optimal fields (for example fields closer to buildings).

Higher intensities of shooting and scaring increases the response of geese to disturbance (Newton & Campbell 1973, Madsen 1985). Consequently, in areas subject to increased disturbance, geese may suppress their use of fields that are close to buildings more than geese in areas with less shooting and scaring. In addition, increased disturbance will probably result in geese making more frequent movements between fields However, this difference it unlikely to affect the overall feeding distribution of geese and therefore will not affect the accuracy of predictions made by the IBMMs.

The topographic features of the study area incorporated in the predictive models are unlikely to differ greatly in range from other goose feeding areas in eastern Scotland. When predicting the feeding distribution of geese in areas where topographical features are outside the range of those in the Strathearn and Strathallan study area, the relationship between goose use and topographical features may be less accurate, and the magnitude of predicted probabilities from the logistic regression models will be affected. However, there is no reason why the general pattern of goose use should not be predicted correctly.

In conclusion, differences between geographical areas could affect the accuracy of the models developed in this study if they were applied to other goose feeding areas. Farming and shooting practices, on a large scale, are unlikely to vary greatly over grey goose feeding areas in east Scotland, which are generally confined to lowland agricultural regions. Therefore these models are likely to be transferable to other goose wintering areas in Scotland, provided that the numbers of geese using individual roosts do not differ greatly from those in Strathearn and Strathallan. Predictions of the feeding distribution of geese in areas with very different farming practices and topography, such as East Anglia, or with different numbers of geese, and therefore increased competition, are likely to be less realistic.

8.5.3 Compensation payments

Although it is known that goose grazing does damage crops (Kear 1970, Owen *et al* 1986, Groot Bruinerink 1989, Patterson *et al* 1989, Ernst 1991) there is little knowledge of the scale or distribution of damage to crops in Britain (Mitchell *et al* 1999, Mitchell & Sigfusson 1999). If a threshold of goose-days were defined, over which significant damage to crops could occur, then predictive models such as those developed in this study could be used to define zones in which goose management plans could be considered. Such zones could be used to define areas in which compensation payments could be paid.

8.5.4 Locations for AFAs

The steady decline of Greylag geese since the early 1990s (Hearn 2000), if it continues, is likely to become an increasingly important conservation issue. While it is clear that the major cause to the population decline is the high levels of mortality due to hunting, mainly in Iceland (Hearn 2000), conservation measures to support the population while wintering in Britain may become increasingly desirable. Therefore AFA's may not only be an appropriate method of managing the goose-agriculture conflict for Pink-footed and Greylag geese, but the provision of refuges where Greylag geese can feed free of disturbance may improve the condition of geese, which has been shown to improve winter survival and reproductive success (Madsen 1995). While studies have suggested the appropriate size and spacing of AFA's from major roost sites for Pink-footed geese (Giroux & Patterson 1995), little attention has been focused on the requirement for Greylag geese in this respect.

For Pink-footed geese, studies suggest that AFA's should be relatively small (1km^2) and scattered throughout their feeding area (Giroux & Patterson 1995). The logistic regression model could identify fields, or areas, that are intrinsically attractive to Pink-footed geese due to their landscape characteristics and therefore good potential sites for AFA's. For example Figure 8.1 shows all patches in Strathearn and Strathallan that have high predicted goose use from the logistic regression model (greater that the arbitrary cut-off value of 0.75) and are larger than 1km^2, and which therefore could be considered good locations for AFAs. Indeed the predictive models are better suited to identifying fields for the creation of refuges than for predicting goose distribution which is dependent on additional factors such as hunting pressure, food availability and quality. These are factors that can be manipulated in an AFA and therefore permanent landscape characteristics, such as those developed in the models developed in this study, should be used to define the suitability of sites for refuge placement.

For Greylag geese there are few published recommendations for refuge placement. Greylag geese use a wide range of smaller roost sites (Bell *et al* 1997), and feed a mean distance of just 0.7km from roost sites, although geese frequently fly between feeding areas (Chapter 4). These results suggest that Greylag geese are likely to benefit from AFA's that are situated close to roost sites as opposed to being scattered throughout the extended feeding area as for Pink-footed geese. There is no reason to expect the size of

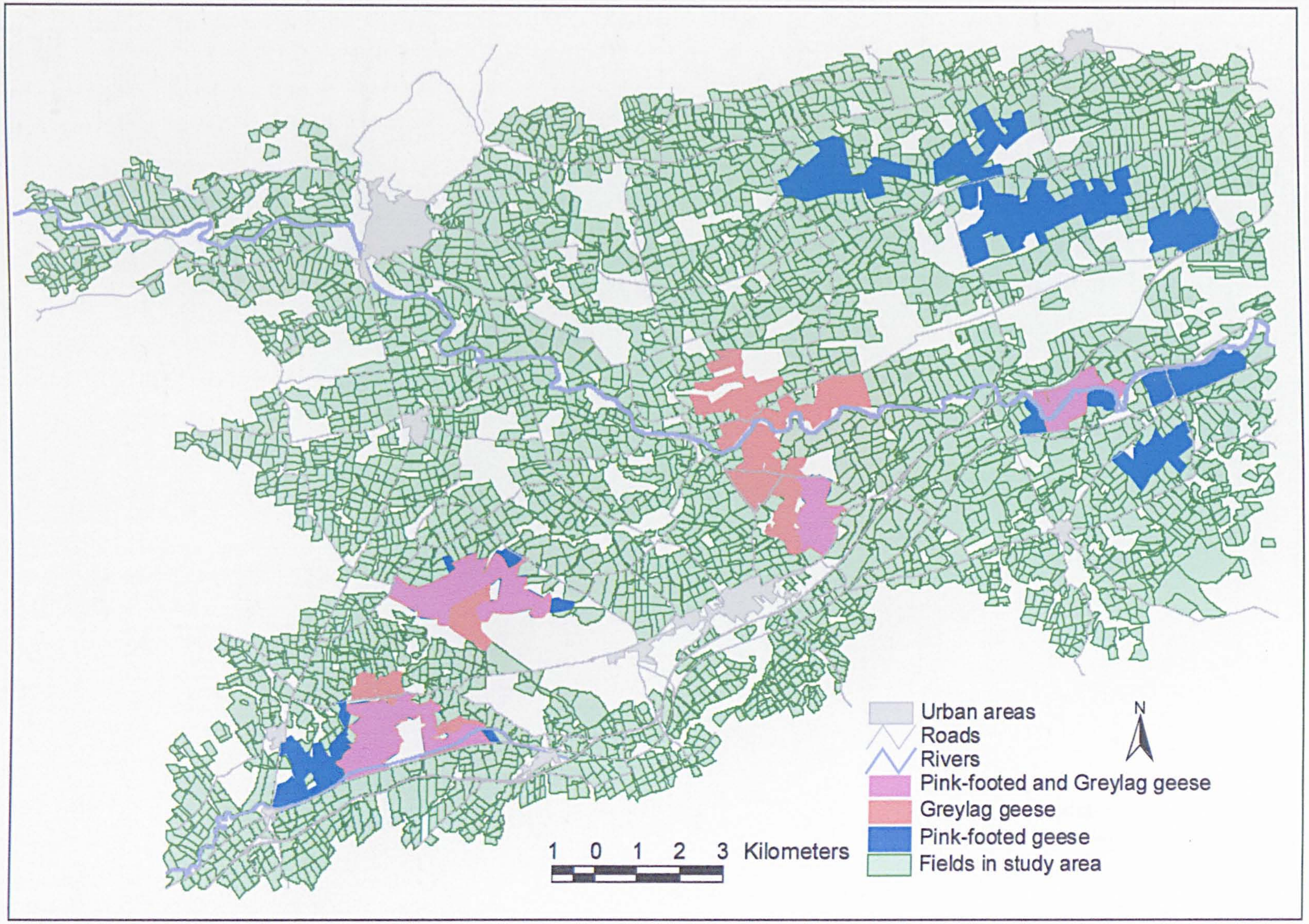

Figure 8.1 Potential sites for the location of AFA's in Strathearn and Strathallan for Pink-footed and Greylag geese, derived from the results of the logistic regression model

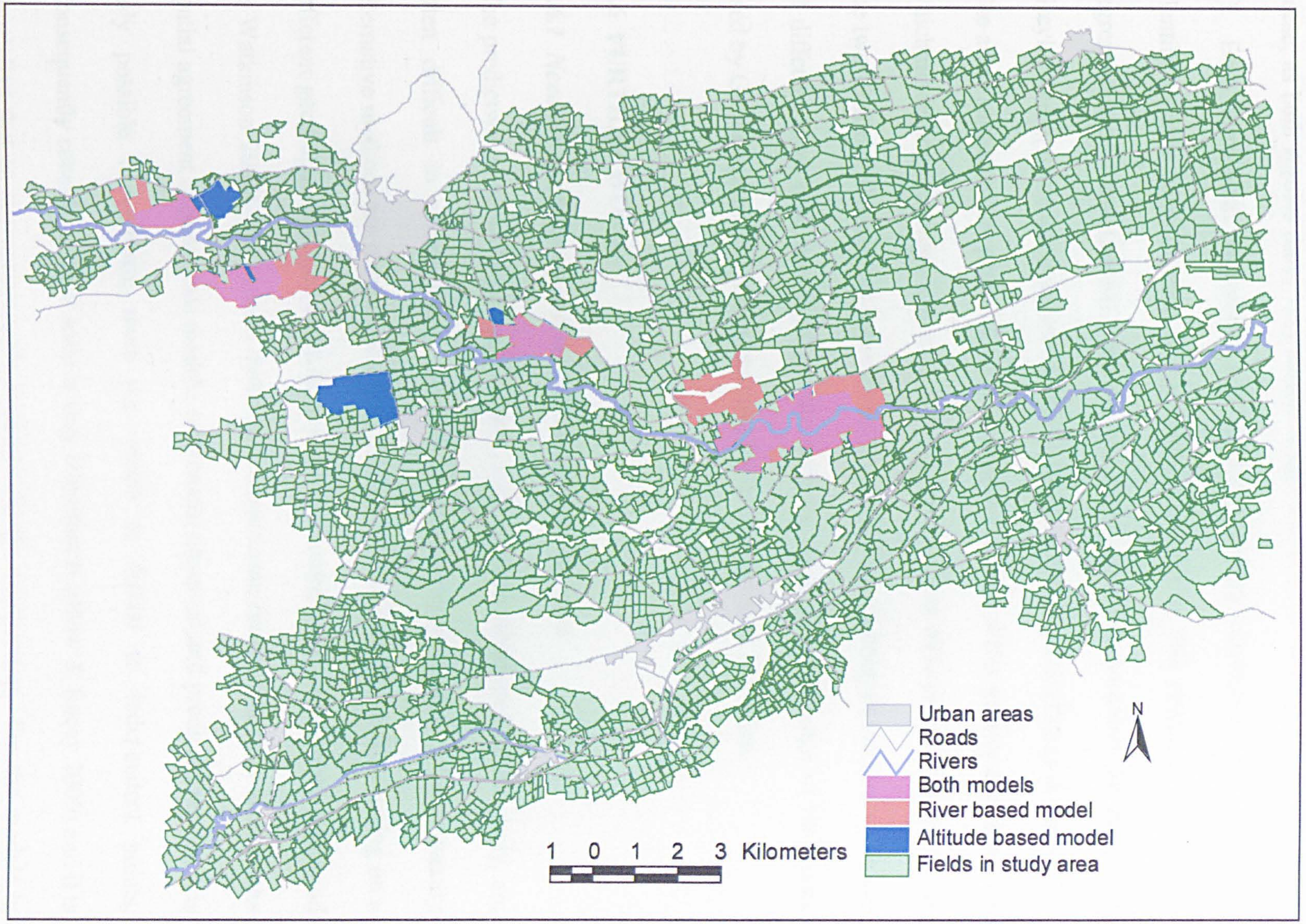

Figure 8.2 Potential sites for the location of AFA's in Strathearn and Strathallan for Greylag geese, derived from the results of two IBMMs, one with flight constrained by altitude, the other by distance from the river.

AFAs required for Greylag geese to differ from that recommended for Pink-footed geese, as both species make very similar length movements during the day (Chapter 4). Both the logistic regression and IBMM modelling techniques could be used to identify suitable fields or areas for the creation of AFA's. The results of the logistic regression model and IBMMs were used to identify possible locations for AFAs for Greylag geese, using the same criteria for as for Pink-footed geese (Figure 8.1 and 8.2). The areas suggested for potential goose management plans differ greatly depending on which modelling technique was used, although there is little difference in the results for the two IBMMs. Differences between the two modelling techniques are due to the use of different roost data, and highlight the need for complete knowledge of the roosts used by Greylag geese if suitable locations for AFA's are to be identified.

8.6 FURTHER WORK

8.6.1 Need for spatially explicit model validation techniques

The predictive power of large-scale models, such as those developed in this study, are often difficult to assess using classical ecological experiments. Consequently alternative methods are required to assess the accuracy of models, such as testing on a different geographical region or by large-scale environmental manipulations (Ormerod & Watkinson 2000). At present statistical comparisons cannot take into account the spatial agreement between two models, or between observed and predicted results; it is only possible to compare units (i.e. pixels or fields) as independent points. Consequently consideration of scale is very important (Caldow & Racey 2000) and it is imperative that an appropriate scale is chosen for the comparison. For the models in this study comparisons were made between fields as this was considered to be the scale at which geese make choices on where to feed. Even if an appropriate scale is used, difficulties occur when techniques assume independence of data points as species distribution and landscape characteristics are often spatially autocorrelated (Legendre 1993). If species distribution or landscape characteristics are spatially autocorrelated the assumptions of many statistical analyses (e.g. logistic regression) will by broken, resulting in an overestimation of the degrees of freedom and therefore the possibility of false significance in statistical tests (Legendre 1993, Augustin *et al* 1996, Fielding & Bell 1997). In addition no account is taken of how far species were recorded from areas where presence was predicted (i.e. the distance of false positives from real positives) when models are evaluated (Austin *et al* 1996, Fielding & Bell 1997), whereas a model which predicts presence close to where animals are observed is clearly preferable. Due to the recent increase in large-scale ecological modelling (Ormerod & Watkinson 2000) it is clear that new techniques for model validation and testing are now required that take into account the spatial distribution of both observed and predicted results.

8.6.2 Possible improvements to the IBMM predicting goose distribution

The IBMM could be extended to include the effects of depletion, either dependent on crop type (as discussed in Chapter 5) or more simply by giving all pixels a uniform threshold of goose days above which the resources were assumed to be depleted and geese could no longer land. If the model was adapted for Pink-footed geese then it would be possible to incorporate depletion caused by both species. Such models will predict differences in field selection by geese due to inter-specific and possibly intra-specific competition, and therefore are likely to be more transferable to different situations.

8.6.3 Effective targeting of goose management plans

When creating refuges for mobile species such as geese, there is a danger that, instead of relieving goose-grazing pressure on surrounding farmland, the provision of improved wintering conditions may encourage larger numbers of individuals to use the area, possibly even increasing existing conflict between geese and agriculture locally (Miere & Kuijen 1991). Therefore there is a need for field trials to assess the impact of AFAs on both damage to surrounding farmland and on goose condition (e.g. abdominal profile) to see if the creation of AFAs will have the desired effect.

8.7 CONCLUSIONS

1. The main landscape characteristics affecting the feeding distribution of Pink-footed and Greylag geese in Strathearn and Strathallan are distance from the roost and distance from buildings. Topography also affects which fields geese choose for feeding.
2. Using information on these landscape characteristics from existing digitised data sources it is possible to predict where geese are likely to occur.
3. Movement models, although advantageous in certain situations, did not consistently predict Greylag goose distribution more accurately than the logistic regression.

4. Greylag geese use many small roosts in addition to main roosts, some of which may not be documented. Knowledge of these is required if the Greylag goose distribution is to be predicted correctly.

The predictive models created can be applied to other areas used by wintering geese. Within goose feeding areas in Scotland the behaviour of geese and landscape characteristics are unlikely to vary greatly from those in the Strathearn and Strathallan. The models developed in this thesis therefore have the potential of being used to identify zones for where farmers can be compensate for economic loss caused by geese, or to identify locations which are suitable for the creation of Alternative Feeding Areas.

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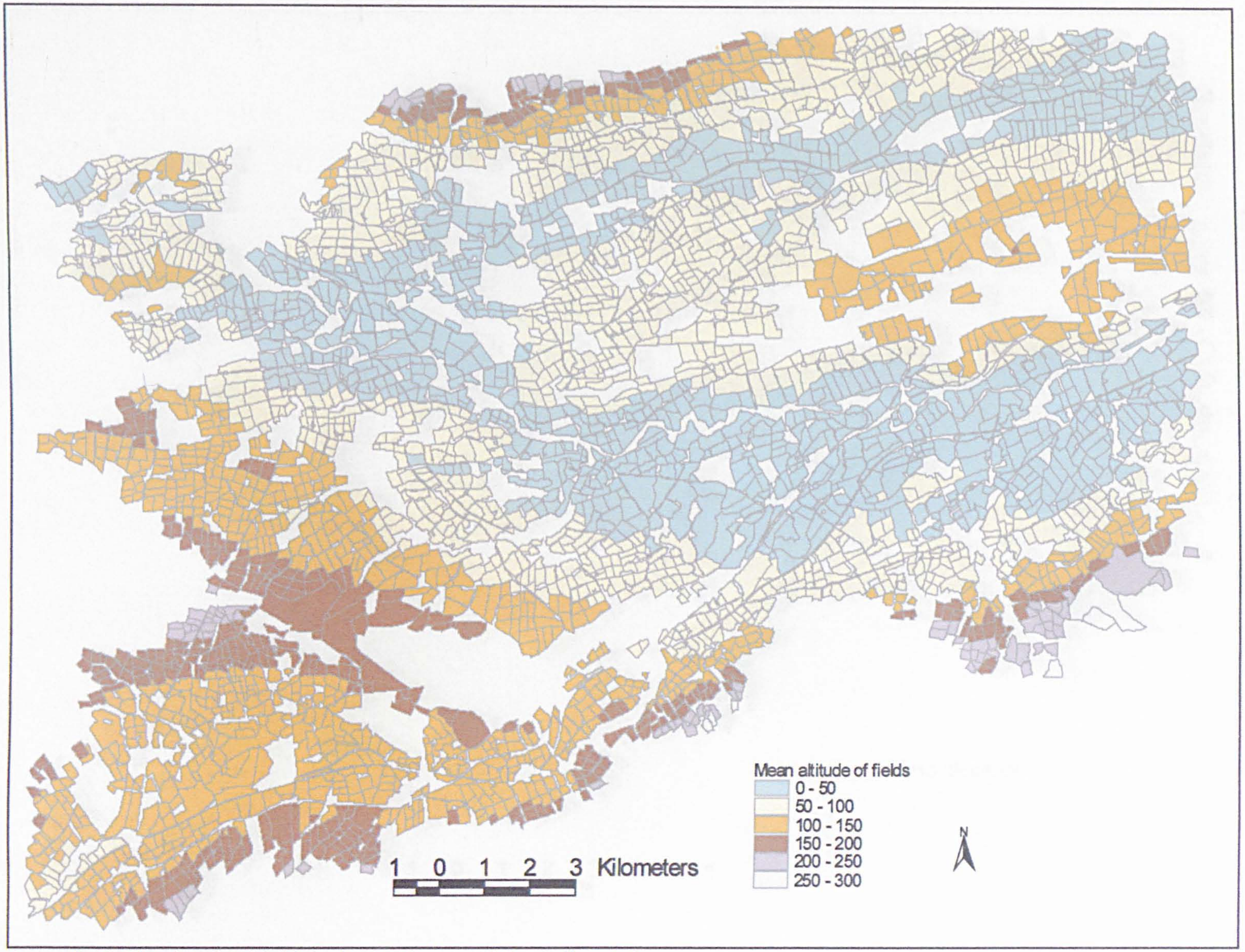
APPENDICES

Appendix 1. Descriptive statistics of landscape variables used in the analysis.

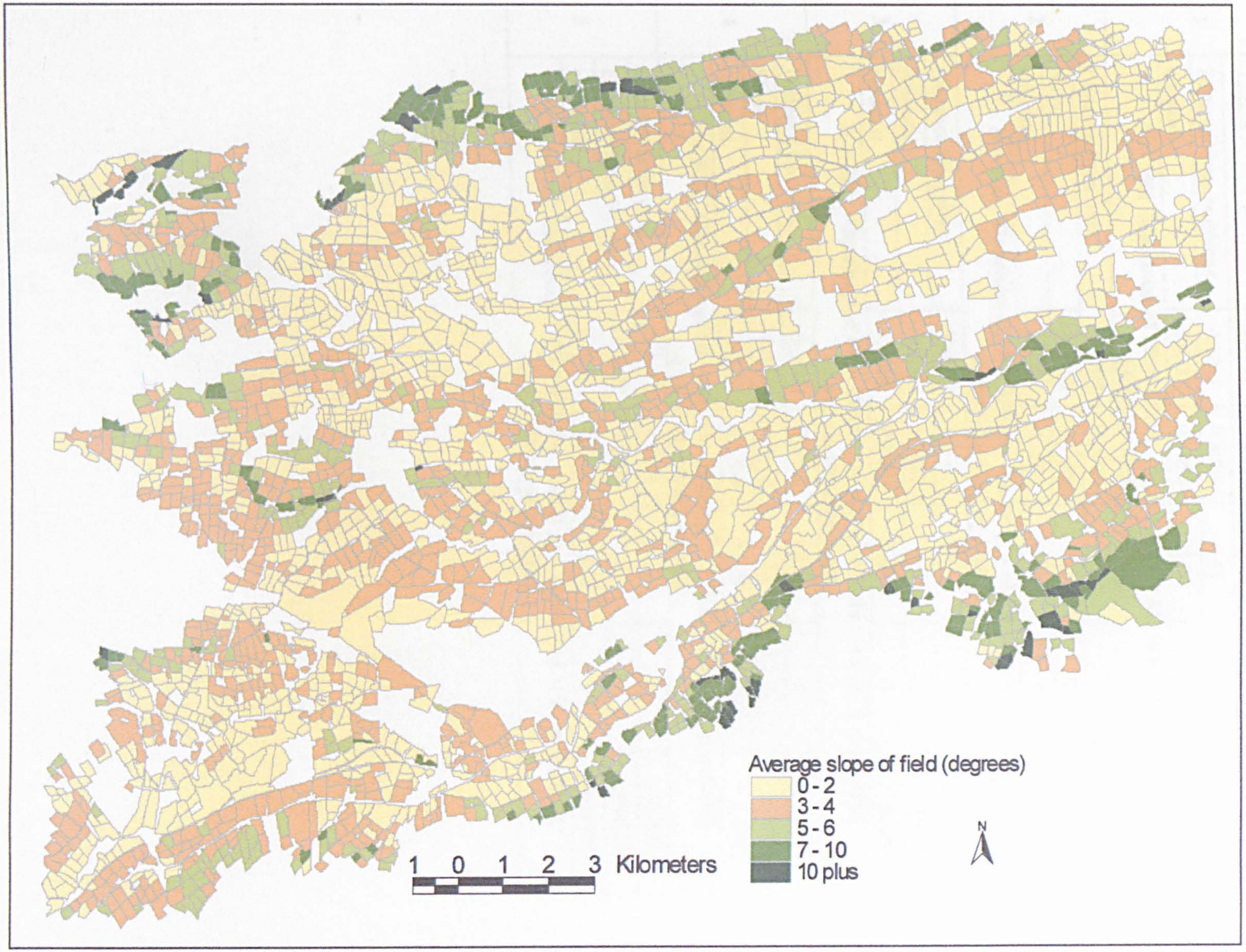
Variable	Sample size	Mean	SD	SE of Mean	Minimum	Maximum	Median
Distance from greylag roost	3599	4521.4	3268.1	54.5	5.8	14426.3	3519.7
Distance from pink-footed goose roost	3496	6191.4	3116.4	52.7	20.1	14133.9	6132.0
Area	3599	73979	59260	988	2656	1127153	62304
Slope	3599	3.2	2.3	0.0	0.0	18.8	2.6
Altitude	3599	91.1	49.8	0.8	5.1	267.7	81.0
Mean distance from building	3599	261.7	153.7	2.6	9.8	1304.5	225.7
Minimum distance from building	3599	116.7	133.8	2.2	0.0	1064.0	60.0
Maximum distance from building	3599	383.1	163.3	2.7	60.0	1539.4	362.5
Mean distance from road	3599	250.1	197.6	3.3	17.4	1423.0	181.7
Minimum distance from road	3599	122.4	181.2	3.0	0.0	1282.7	0.0
Maximum distance from road	3599	384.6	217.3	3.6	30.0	1603.8	335.4
Distance from permanent water	3498	145.9	95.0	1.6	0.0	719.2	124.0
Distance from river	3599	2780.9	1946.1	32.4	36.9	8233.1	2567.6
Distance from urban areas	3599	1686.2	929.6	15.5	0.0	4642.1	1613.1
Distance from wood	3599	433.3	321.3	5.4	0.0	1897.2	350.7

Appendix 2. R-values of correlations between all landscape characteristics (n = 3599).

	Dist. to Greylag roosts	Max. dist. to building	Slope	Altitude	Dist. to water	Average dist. to building	Field area	Minimum dist. to building	Minimum dist. to road	Maximum dist. to road	Average dist. to road	Dist. to river	Dist. to urban area	Dist. to woodland	Dist to Pink-foot roost
Dist. to Greylag roosts	1.000														
Max. dist. to building	0.059	1.000													
Slope	0.017	-0.053	1.000												
Altitude	-0.155	0.079	0.398	1.000											
Dist. to water	0.052	0.082	-0.059	-0.014	1.000										
Average dist. to building	0.046	0.919	-0.043	0.091	0.054	1.000									
Field area	0.070	0.441	-0.101	-0.087	0.175	0.290	1.000								
Minimum dist. to building	0.011	0.770	-0.004	0.147	-0.014	0.891	-0.006	1.000							
Minimum dist. to road	0.062	0.339	0.042	0.073	-0.035	0.350	-0.026	0.385	1.000						
Maximum dist. to road	0.093	0.519	-0.007	0.029	0.040	0.443	0.332	0.347	0.856	1.000					
Average dist. to road	0.080	0.449	0.017	0.053	0.007	0.414	0.168	0.378	0.954	0.965	1.000				
Dist. to river	0.525	-0.031	0.175	0.279	0.038	-0.009	-0.043	0.007	0.091	0.071	0.083	1.000			
Dist. to urban area	0.051	0.219	0.013	0.057	-0.066	0.179	0.102	0.155	0.120	0.168	0.149	0.056	1.000		
Dist. to woodland	0.034	-0.037	-0.174	-0.279	0.056	-0.047	0.075	-0.087	-0.007	0.030	0.012	-0.101	-0.172	1.000	
Dist to Pink-foot roost	-0.128	-0.208	0.168	-0.235	0.017	-0.173	-0.088	-0.149	0.032	-0.001	0.014	0.128	-0.129	0.007	1.000



Appendix 3 The altitude of fields in the Strathearn and Strathallan study area



Appendix 4 The slope of fields in the Strathearn and Strathallan study area.

Appendix 5. Statistics of the five logistic regression models investigating where geese fly for movements from the roost, using different random 10% samples of pixels.

Run	Independent variable	B	s.e (B)	Wald statistic	Degrees of freedom	Significance
1	Distance from river	-0.0006	0.0001	19.54	1	< 0.0001
	Altitude	-0.0090	0.0025	13.36	1	0.0003
	Distance from buildings	0.0011	0.0005	4.41	1	0.0358
	constant	0.9533	0.1968	23.47	1	< 0.0001
	N = 500, Goodness of Fit = 487.99, model $\chi^2 = 71.43$, d.f. = 3, $p < 0.0001$ **63.8% classified correctly**					
2	Distance from river	-0.0007	0.0001	43.36	1	< 0.0001
	Slope	-0.0432	0.0189	5.21	1	0.0224
	constant	1.0370	0.1707	36.92	1	< 0.0001
	N = 500, Goodness of Fit = 485.18, model $\chi^2 = 65.14$, d.f. = 2 $p < 0.0001$ **61.8% classified correctly**					
3	Distance from river	-0.0007	0.0001	26.12	1	< 0.0001
	Altitude	-0.0069	0.0025	7.37	1	0.0066
	constant	1.2888	0.1880	47.00	1	< 0.0001
	N = 500, Goodness of Fit = 480.41, model $\chi^2 = 90.20$, d.f. = 2, $p < 0.0001$ **64.6% classified correctly**					
4	Distance from river	-0.0010	0.0001	62.82	1	< 0.0001
	Slope	-0.0376	0.0172	4.78	1	0.0288
	constant	1.3121	0.1784	54.09	1	< 0.0001
	N = 500, Goodness of Fit = 484.63, model $\chi^2 = 103.41$, d.f. = 2, $p < 0.0001$ **67.6% classified correctly**					
5	Distance from river	-0.0009	0.0001	52.59	1	< 0.0001
	Distance from woods	-0.0008	0.0003	5.31	1	0.0213
	constant	1.3817	0.2423	32.52	1	< 0.0001
	N = 500, Goodness of Fit = 482.25, model $\chi^2 = 77.80$, d.f. = 2, $p < 0.0001$ **63.6% classified correctly**					

Appendix 6. Statistics of the five logistic regression models investigating where geese fly for non-roost movements, using different random 10% samples of pixels.

Run	Independent variable	B	s.e (B)	Wald statistic	Degrees of freedom	Significance
1	Distance from river	-0.0003	$9.3*10^{-5}$	13.58	1	0.0002
	Distance from woods	-0.0007	0.0003	4.23	1	0.0396
	constant	0.7687	0.2556	9.05	1	0.0026
	N = 340, Goodness of Fit = 339.45, model χ^2 = 15.81, d.f. = 2, p = 0.0004 **60.3% classified correctly**					
2	Altitude	-0.0136	0.0025	28.56	1	< 0.0001
	Slope	0.1006	0.0313	10.36	1	0.0013
	Distance from building	0.0016	0.0006	8.10	1	0.0044
	constant	0.1205	0.2016	0.36	1	0.5502
	N = 340, Goodness of Fit = 339.99, model χ^2 = 38.35, d.f. = 3 p < 0.0001 **65.0% classified correctly**					
3	Distance from river	-0.0006	0.0001	29.58	1	< 0.0001
	Distance from woods	-0.0008	0.0003	6.41	1	0.0114
	constant	1.0878	0.2579	17.79	1	< 0.0001
	N = 340, Goodness of Fit = 346.80, model χ^2 = 36.26, d.f. = 2, p < 0.0001 **65.9% classified correctly**					
4	Distance from river	-0.0005	0.0001	24.41	1	< 0.0001
	Slope	0.0759	0.0308	6.08	1	0.0137
	constant	0.3681	0.1723	4.56	1	0.0327
	N = 340, Goodness of Fit = 340.08, model χ^2 = 31.61, d.f. = 2, p < 0.0001 **60.0% classified correctly**					
5	Distance from river	-0.0002	$9.2*10^{-5}$	6.70	1	0.0096
	constant	0.2620	0.1477	3.15	1	0.0761
	N = 340, Goodness of Fit = 340.98, model χ^2 = 7.01, d.f. = 1, p = 0.0081 **58.2% classified correctly**					

Appendix 7. Statistics of the five logistic regression models excluding distance from river, investigating where geese fly for movements from the roost, using different random 10% samples of pixels.

Run	Independent variable	B	s.e (B)	Wald statistic	Degrees of freedom	Significance
1	Attitude	- 0.0141	0.0022	39.43	1	< 0.0001
	Distance from buildings	0.0010	0.0005	4.20	1	0.0403
	constant	0.7510	0.1899	15.63	1	0.0001
	N = 500, Goodness of Fit = 508.00, model χ^2 = 48.35, d.f. = 2, p < 0.0001 **63.0% classified correctly**					
2	Attitude	- 0.0143	0.0023	40.30	1	< 0.0001
	Distance from buildings	0.0017	0.0005	10.21	1	0.0014
	constant	0.5849	0.2009	8.48	1	0.0001
	N = 500, Goodness of Fit = 501.43, model χ^2 = 46.80, d.f. = 2 p < 0.0001 **63.6% classified correctly**					
3	Attitude	- 0.0165	0.0024	47.72	1	< 0.0001
	Distance from buildings	0.0010	0.0005	3.92	1	0.0478
	constant	0.9070	0.2015	20.25	1	< 0.0001
	N = 500, Goodness of Fit = 518.20, model χ^2 = 61.03, d.f. = 2, p < 0.0001 **65.8% classified correctly**					
4	Attitude	- 0.0162	0.0023	48.39	1	< 0.0001
	Distance from buildings	0.0014	0.0005	6.93	1	0.0085
	constant	0.8321	0.1984	17.58	1	< 0.0001
	N = 500, Goodness of Fit = 498.93, model χ^2 = 58.05, d.f. = 2, p < 0.0001 **62.6% classified correctly**					
5	Attitude	- 0.0140	0.0022	40.49	1	< 0.0001
	Distance from buildings	0.0016	0.0005	8.47	1	0.0036
	Distance from roads	- 0.0011	0.0005	5.27	1	0.0216
	constant	0.8669	0.2090	17.21	1	< 0.0001
	N = 500, Goodness of Fit = 497.00, model χ^2 = 50.08, d.f. = 3, p < 0.0001 **62.0% classified correctly**					

Appendix 8. Statistics of the five logistic regression models excluding distance from river, investigating where geese fly for non-roost movements, using different random 10% samples of pixels.

Run	Independent variable	B	s.e (B)	Wald statistic	Degrees of freedom	Significance
1	Altitude	- 0.0064	0.0020	10.79	1	0.0010
	Distance from woodland	- 0.0007	0.0003	3.95	1	0.0468
	constant	0.7967	0.2764	8.31	1	0.0039
	N = 340, Goodness of Fit = 337.77, model $\chi^2 = 13.11$, d.f. = 2, p = 0.0014 **54.1% classified correctly**					
2	Altitude	-0.0136	0.0025	28.56	1	< 0.0001
	Slope	0.1006	0.0313	10.36	1	0.0013
	Distance from buildings	0.0016	0.0006	8.10	1	0.0044
	constant	0.1205	0.2016	0.36	1	0.5502
	N = 340, Goodness of Fit = 339.99, model $\chi^2 = 38.35$, d.f. = 3 p < 0.0001 **65.0% classified correctly**					
3	Altitude	- 0.0111	0.0028	16.33	1	0.0001
	Slope	0.0667	0.0287	5.39	1	0.0202
	Distance from woodland	- 0.0008	0.0003	5.34	1	0.0209
	constant	0.9515	0.3092	8.88	1	0.0029
	N = 340, Goodness of Fit = 341.69, model $\chi^2 = 21.56$, d.f. = 3, p = 0.0001 **61.8% classified correctly**					
4	Altitude	- 0.0095	0.0024	16.22	1	0.0001
	Slope	0.1025	0.0331	9.62	1	0.0019
	Distance from buildings	0.0013	0.0005	6.97	1	0.0083
	constant	- 0.0933	0.2161	0.19	1	0.6660
	N = 340, Goodness of Fit = 340.63, model $\chi^2 = 23.60$, d.f. = 3, p < 0.0001 **60.6% classified correctly**					
5	Altitude	- 0.0060	0.0022	7.80	1	0.0052
	Distance from buildings	0.0012	0.0006	3.86	1	0.0495
	constant	- 0.0043	0.2356	0.00	1	0.9854
	N = 340, Goodness of Fit = 340.07, model $\chi^2 = 9.72$, d.f. = 2, p 0.0077 **57.4% classified correctly**					