



BTO Research Report No 290

**Investigation into the
causes of the decline of
Starlings and House Sparrows
in Great Britain**

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A report to the Department for the Environment, Food and Rural Affairs

by

A consortium led by the British Trust for Ornithology

Consortium Members:

**British Trust for Ornithology
Central Science Laboratory
Royal Society for the Protection of Birds/University of Oxford
&
WildWings Bird Management**

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Editors' Note [added after report was produced]

Starlings *Sturnus vulgaris* and House Sparrows *Passer domesticus* are amongst the most widespread and abundant bird species in the world. This is due, in large part, to the fact that both species are highly commensal with man and appear to benefit from the presence of towns and farms. For many years in Britain and elsewhere, both Starlings and House Sparrows have been considered as disease-carrying or agricultural pests and both species also gather in large urban roosts where fouling of pavements and buildings can be a significant problem.

In the 1990s, it became clear that both species were undergoing rapid declines (greater than 50% over 25 years) in Britain, such that they had become candidate species for inclusion on the Red List of Species of Conservation Concern and as Priority Species under Britain's Biodiversity Action Plan. The reasons for these declines in the wider countryside were unknown and there were indications that they were also declining in urban situations. Worries over these population declines began to spread to the wider public, such that a national daily newspaper instituted a £5000 reward for the discovery of the main cause of the decline of the House Sparrows.

The concern over declining farmland birds led to DEFRA adopting, as one of its eight Public Service Agreement (PSA) targets, the goal of reversing the long-term decline in the number of farmland birds by 2020. This is measured annually using the 'farmland bird index' which comprises population trend information for 20 species, including Starling but not House Sparrow. To meet this target, DEFRA has commissioned several research projects to identify ways in which the decline can be reversed. In October 2000, DEFRA commissioned a consortium, led by the BTO, to investigate the causes of the population declines of Starling and House Sparrow in Great Britain. A better understanding of the factors affecting breeding populations was required to ensure that legal control is not a contributory factor in their decline. DEFRA particularly wished to ensure that the urban and suburban populations of these species were embraced within the study, as very little was known about population trends in these habitats.

The report is available below. The Executive Summary provides a brief overview of the main results, for a more discursive summary, see Chapter 12 which pulls together most of the key findings from the individual chapters. See the individual chapters for the details of particular aspects of this work.

This report should be cited as: Crick, H.Q.P., Robinson, R.A., Appleton, G.F. Clark, N.A. & Rickard, A.D. 2002. (eds) Investigation into the causes of the decline of starlings and house sparrows in Great Britain. BTO Research Report 290. Defra, London.

Some of the Chapters have subsequently been published in revised form in the following papers.

Robinson, R.A., Siriwardena, G.M. & Crick, H.Q.P. 2005. Status and population trends of the Starling *Sturnus vulgaris* in Great Britain. *Bird Study* 52: 252-260. (Chapter 2).

Robinson, R.A., Siriwardena, G.M. & Crick, H.Q.P. 2005. Status and population trends of the House Sparrow *Passer domesticus* in Great Britain. *Ibis* 147:552-562. (Chapter 3).

Freeman, S.N., Robinson, R.A., Clark, J.A., Griffin, B.M. & Adams, S.Y. 2007. Changing demography and population decline in the Starling *Sturnus vulgaris*: a multi-site approach to integrated population modelling. *Ibis* 149:587-596. (Chapter 7).

Robinson, R.A., Siriwardena, G.M. & Crick, H.Q.P. 2006. The population decline of the Starling *Sturnus vulgaris* in Great Britain: patterns and causes. *Acta Zoologica Sinica* 52:S550-S553. (The Starling part of Chapter 12).

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1 INTRODUCTION

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Starlings *Sturnus vulgaris* and House Sparrows *Passer domesticus* are amongst the most widespread and abundant bird species in the World (Feare 1984; Summers-Smith 1988). This is due, in large part, to the fact that both species are highly commensal with man and appear to benefit from the presence of towns and farms. In addition, they have been intentionally introduced by man to North and South America, Africa and Australasia, as well as to a number of islands, where populations have undergone a rapid expansion colonising large areas from relatively small number of introduced individuals (Feare 1984; Summers-Smith 1990).

For many years in Britain and elsewhere, both Starlings and House Sparrows have been considered disease-carrying or agricultural pests. In the 18th and 19th centuries, most parishes had "Sparrow Clubs" formed with the aim of destroying as many sparrows as possible (Summers-Smith 1963) because flocks of thousands could destroy substantial areas of ripening grain. Such clubs, and the presence of bounties given for birds destroyed, were soon initiated in other areas of the World where they had been introduced. Large flocks of Starlings, too, in the past caused significant agricultural damage, primarily to newly sown cereal crops, orchards (particularly of cherries) and by taking cattle feed (Feare 1984; Feare *et al.* 1992). Both species also gather in large urban roosts where fouling of pavements and buildings can be a significant problem (Feare 1984; Summers-Smith 1963).

Because of the problems caused by large flocks of these species, both Starling and House Sparrow were placed on Schedule 2, Part II, of the Wildlife and Countryside Act (1981). Under Section 16, DEFRA has the power to issue licences to allow the control of certain species, at any time of the year, for specific purposes. Currently the Department has a general licence which permits authorised people to kill or take certain birds including the taking, damaging or destruction of their nests or the taking or destruction of their eggs, where there is no other satisfactory solution, for the purpose of preserving public health and public and air safety.

The British Government removed this provision because it did not meet the detailed derogation requirements of the European Directive on the Conservation of Wild Birds (EC/79/409). After securing a derogation under Article 9 of the Directive, the Government introduced a licensing system in January 1993, in which a general licence is issued, under Section 16 of the Wildlife and Countryside Act, for the taking of these species in the interests of health and safety or to prevent serious damage to livestock and crops, or for the protection of flora and fauna. This derogation entails a responsibility to monitor these species to provide data on indicated their population levels and trends. Monitoring of both Starling and House Sparrow has been carried out under the BTO's Common Birds Census (CBC) (Marchant *et al.* 1997) and more recently under the BTO/JNCC/RSPB Breeding Bird Survey (BBS) (Noble *et al.* 2001).

In the 1990s, it became clear that both species were undergoing rapid declines (greater than 50% over 25 years) in Britain, such that they had become candidate species for inclusion on the Red List of Species of Conservation Concern and as Priority Species under Britain's Biodiversity Action Plan (Gregory *et al.* 2000). The reasons for these declines in the wider countryside were unknown and there were indications that they were also declining in urban situations (e.g. Sanderson 1996). Worries over these population declines began to spread to the wider public, such that a national daily newspaper instituted a £5000 reward for the discovery of the main cause of the decline of the House Sparrows (McCarthy 2000).

Introduction

The concern over declining farmland birds led to DEFRA adopting, as one of its eight Public Service Agreement (PSA) targets, the goal of reversing the long-term decline in the number of farmland birds by 2020. This is measured annually using the 'farmland bird index' which comprises population trend information for 20 species, including Starling but not House Sparrow. To meet this target, DEFRA has commissioned several research projects to identify ways in which the decline can be reversed. In October 2000, DEFRA commissioned a consortium, led by the BTO, to investigate the causes of the population declines of Starling and House Sparrow in Great Britain. A better understanding of the factors affecting breeding populations was required to ensure that legal control is not a contributory factor in their decline. DEFRA particularly wished to ensure that the urban and suburban populations of these species were embraced within the study, as very little was known about population trends in these habitats.

The key questions that needed to be investigated were:

- Whether legal control was potentially important as a factor causing the declines.
- Whether habitats and regions are strongholds for the species and which are those where declines are steepest.
- Whether changes in breeding performance have had an important influence and how these are affected by environmental factors.
- Whether changes in survival have affected House Sparrow and Starling populations and whether there are regional variations in the changes in survival of Starlings.
- What are the key environmental factors that may be causing the declines?

1.1 THE AIMS AND OBJECTIVES OF THE STUDY

The key aims were to:

1. Investigate the trends in breeding populations of Starlings and House Sparrows in Great Britain.
2. Examine the trends regionally and according to habitat, particularly in relation to urban, suburban and rural habitats.
3. Investigate variations in breeding success and recruitment, as well as winter and summer survival.
4. Investigate human influences, in particular an assessment of the scale and impact of control activity.
5. Identify likely causes of the declines in Starling and House Sparrow populations and place these within a whole population context

To meet these aims the consortium undertook to:

1. Analyse data from the BTO's long-term population census data sets (Common Birds Census, Garden Bird Feeding Survey, Garden BirdWatch and BTO/JNCC/RSPB Breeding Bird Survey) in relation to environmental data sets, in order to identify periods of population decline and stability, and the environmental factors that may influence them at the national and regional level.
2. Analyse data from the BTO's national Bird Ringing and Nest Record Scheme to investigate trends and environmental factors influencing breeding performance and survival at the national and regional scale.
3. CSL RSPB/University of Oxford intensive data sets to investigate trends and environmental factors influencing breeding performance and survival at a local scale to provide important information to augment extensively gathered BTO data and variation in the numbers of breeding attempts per pair per year.
4. Undertake an extensive questionnaire survey of landowners/occupiers to collect information on the extent and scale of legal control activities of Starlings and House Sparrows on farms.

5. Combine information from censuses with estimates of survival and breeding performance from extensive and intensive studies to generate population models that will help identify the demographic and environmental factors contributing most to population declines.
6. Provide clear guidance to DEFRA on the likely causes of the declines and identify further research that would aid the understanding of how these causes operate.

1.2 THE CONSORTIUM

The consortium working on the project comprised the BTO, CSL, scientists involved in an RSPB/University of Oxford collaborative project and Wildwings Bird Management.

In addition to coordinating the project, the BTO provided and analysed extensive long-term datasets on bird numbers, breeding performance and survival, namely:

- The Common Birds Census (CBC), which monitored the populations of breeding birds on 200-300 farmland and woodland survey plots between 1962 and 2000 by means of territory mapping censuses.
- The Garden Bird Feeding Survey (GBFS), which monitors the numbers of birds feeding in c. 200 gardens in winter, starting in 1970. Data from this survey have never before been the subject of a rigorous statistical analysis.
- Garden BirdWatch (GBW), which monitors the numbers of birds in c. 10,000 gardens by weekly counts throughout the year. This survey started in 1995 and this is the first time it has been rigorously analysed.
- The BTO/JNCC/RSPB Breeding Bird Survey (BBS), which monitors the populations of birds in the breeding season in a stratified random sample of c. 2000 1-km squares. The project employs transect censuses and started in 1994.
- The national Bird Ringing Scheme, which provides information on the finding circumstances of retrapped and dead birds that have been ringed with uniquely numbered individual metal leg rings. Bird ringing started in 1909 in Britain, and analysis of the dataset provides information on movements and survival rates.
- The national Nest Record Scheme (NRS), which provides information on the breeding performance of birds from records of c. 30,000 individual nest histories submitted each year. The scheme began in 1939.

In order to understand the scale and potential impact of legal control activities on House Sparrows and Starlings, a national questionnaire survey of farmers/landowners and Local Authorities was required. The CSL has considerable experience in the design, execution and analysis of questionnaires of landowners and farmers and also holds a unique long-term dataset of a population study of suburban Starlings. CSL undertook the execution of the landowner questionnaire and the analysis of questionnaires sent to Local Authorities by DEFRA.

Analysis of CSL's intensive long-term study of Starlings was undertaken in collaboration with Professor Chris Feare of Wildwings Bird Management, who organised the study when formerly employed by CSL. This study not only provides detailed information at a local scale that complements the BTO's long-term datasets. Professor Feare also provided advice to the consortium on the basis of his studies of Starlings over the course of many years.

Joint research by RSPB and the University of Oxford has investigated the population ecology of individually marked populations of House Sparrows on three farms in Oxfordshire between January 1998 and the present. This RSPB/University of Oxford data set provides unique information to augment the extensive BTO data sets. House Sparrows on one of the study farms were the subject of intensive research during the 1960s and early 1970s - before the current phase of national population decline (and decline at this farm) began. This provided the opportunity for site-specific comparisons of ecological and demographic parameters between a phase of a high, stable population (1962-1972), and one of a low, declining population (1998-2000).

1.3 WORKPLAN AND OUTLINE OF THE REPORT.

The workplan was divided into five components and this is reflected in the structure of the report, detailed below.

1.3.1 Collation and preparation of data sets

In order to undertake the work outlined above, three important component data sets needed to be computerised at the BTO, namely:

- A seven-year block of uncomputerised data for the GBFS from the early 1970s;
- Nest Record Cards for the House Sparrow, and some additional records for Starling, to increase sample sizes as appropriate; and
- Ringing data for Starlings, to allow analysis of survival rates without the results being compromised by unknown trends in the reporting rates of ringed birds.

Further information on this aspect is given below in section 1.4.

1.3.2 The analysis of the population trends of Starling and House Sparrow nationally and in relation to habitats and regions

- The extensive census datasets held by the BTO (CBC, GBFS, GBW and BBS) were analysed to determine differences in population trajectories across broad habitats and regions, particularly emphasising the urban/suburban populations that have not been investigated systematically before.
- Long-term trends from the CBC and GBFS were analysed to determine the turning points in population trajectory using the methodology developed by Siriwardena *et al.* (1998a). This identifies periods of decline, stability and increase in the population trajectories of both species at both national, and for the first time, regional scales.
- BBS data were used to determine the population densities on each of the major habitats throughout Britain, using DISTANCE software (Thomas *et al.* 1998). This allows the calculation of the size and proportion of the population of each species occurring in each habitat, to determine their relative importance (e.g. Gregory & Baillie 1998).

These analyses form the basis of Chapters 2 and 3 in this report.

In addition, GBFS and GBW data were analysed to determine seasonal patterns of occurrence of each species in gardens to investigate how these have changed over time. If rural populations have become increasingly stressed over time, due to food shortages over winter, it was predicted that populations would increase progressively sooner in gardens over the course of winter. These analyses are described in Chapter 4 of the report.

1.3.3 The investigation of variation in the demography of Starling and House Sparrow populations

There are several different components to this analysis which was undertaken both nationally and in different large-scale regions and habitats to show how demographic changes relate to overall population trajectories and environmental factors.

- Breeding performance was calculated from information provided by the Nest Record Scheme (Crick & Baillie 1996). This scheme provides information on at least 150 Starling and House Sparrow nests annually. Changes in the timing of laying, clutch size, brood size, and nesting success at egg and nestling stages were investigated and related to other components of demography within integrated population models, to determine their

influence of population trajectories. These analyses are presented in Chapters 6 and 9 respectively.

- Information from intensive studies carried out by CSL (Starling) and RSPB/University of Oxford (House Sparrow) provide locally derived breeding performance measures for comparison with figures derived from the national Nest Record Scheme. In particular, the studies provide important information on numbers of breeding attempts per season by individual females; causes of nest loss; nestling growth rates, condition and fledging age. This information is not available from the extensive national datasets. These analyses are presented in Chapters 5 and 8 respectively.
- Survival rates were estimated nationally from the numbers of ringed birds subsequently found dead using the MARK software (White & Burnham 1999), which enables time- and age-specific survival rates to be calculated in the presence of variable reporting rates of dead birds.
- Information on recruitment is provided by the intensive mark-resighting studies of Starling and House Sparrow (CSL & RSPB/University of Oxford). It is also estimated as a product of the integrated population modelling process, which combines data on abundance, breeding performance and survival to model population dynamics.
- The populations of Starling and House Sparrow were modelled, using the changes in demography estimated from carrying out the above, in order to identify the demographic factors that have contributed most to the population declines. In addition, the project attempted to produce regional integrated population models for the first time. The analyses of survival and population modelling are presented in Chapters 7 and 10 for Starling and House Sparrow respectively.
- Many of the datasets to be used in this project have habitat data associated with them. The datasets were analysed in relation to national data sets on land use and climate: agricultural statistics from annual county-level summaries of DEFRA June census data; the Centre for Ecology & Hydrology's Landcover data for 1990, which provides information on the percentage cover in each 1-km square of remotely-censused habitat types; and meteorological data from the British Atmospheric Data Centre website.

1.3.4 National Survey of farmers and Local Authorities

A national survey of farmers (landowners/occupiers) was undertaken to ascertain whether the respondents considered that numbers of Starlings and House Sparrows had changed over the last five to ten years, whether they are perceived to be a problem and to provide information on the numbers controlled. The methodology was based on a survey of Badger (*Meles meles*) damage undertaken by CSL for (what was then) the Ministry of Agriculture, Fisheries and Food (MAFF) (Moore *et al.* 1998; 1999), and was stratified by region and farm type. After piloting the questionnaire on a small sample of farms, it was sent to *c.* 3,500 farms.

In addition, DEFRA designed and carried out a similar questionnaire survey of Local Authorities, which was then analysed in conjunction with the landowner questionnaire, to provide a greater understanding of the level of control that has been undertaken on each of the study species. The results of these surveys are reported on in Chapter 11.

1.3.5 Assessment of the factors that might be most influential in causing the declines of Starling and House Sparrow

The results from the data analyses and questionnaire surveys are brought together in the final chapter (12) to assess the most likely causes of the declines in Starling and House Sparrow populations.

In particular, the final chapter:

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- Assesses the results of the project, to review the relative importance of different demographic and environmental factors, particularly land-use and habitat, in affecting population declines and whether these factors operate on different components of the populations equally.
- Assesses the importance of licensed control in the context of other factors such as climate, factors affecting food supplies, predation, and redistribution.
- Provides guidance on the causes of declines and, if possible, likely actions that would lead to favourable conservation status for the two species.
- Makes clear recommendations for further work that is needed to better understand the causes of declines of Starling and House Sparrow populations.

1.4 DATA PROCESSING

As indicated above, in order to undertake the project, three important component data sets needed to be computerised at the BTO.

1.4.1 Garden Bird Feeding Survey (GBFS) data

Although this data set begins in 1970, there was a seven-year block of data from the 1970s that had not been computerised, a period when House Sparrow populations were believed to be stable. We needed to analyse these data in order to understand the variability in the House Sparrow population at this time, so that we could determine properly the size of the following population decline. This was of particular importance as the GBFS probably represents the best long-term data set for the House Sparrow which, being a highly sedentary species, means that wintering populations are indicative of resident breeding populations (Summers-Smith & Thomas, in press).

1.4.2 Nest Record Scheme (NRS) data

The majority of NRS data (11,645 records) had been computerised for Starling but, prior to this project, none were computerised for House Sparrow. To provide data for investigation of trends in breeding performance some 7,622 records for House Sparrow and 715 additional Starling records were computerised and added to the BTO's national Nest Record database.

1.4.3 Ringing data

To analyse long-term trends in survival rates of Starlings without the results being compromised by long-term trends in recovery rates, it was extremely important that the ringing information for all Starlings was computerised. This also allowed regional survival rates to be calculated. Small numbers of House Sparrows have been ringed annually, providing insufficient data to estimate survival and recovery rates simultaneously. These data were not, therefore, computerised.

For efficiency, all size 'C' rings were computerised as part of this project, with additional funding contributed by the BTO from its Blackbird Initiative to fund the computerisation of the Blackbird component of the dataset. A team of more than 20 outworkers were recruited and trained to input ringing data. A system was set up to extract data from the BTO ORACLE database and provide it to inputters electronically, to avoid double-inputting. The database already held details of some 70,000 Starlings. (The ringing details of 40,000 had been input when birds were found and reported to the BTO and details for a further 30,000 Starlings were input and submitted electronically by ringers themselves, using recently introduced home software). These details were provided to the inputters on Excel spreadsheets that included look-up tables and valid value ranges to assist inputting. Once data were returned to BTO, validity checks were made both before and during incorporation within the ORACLE ringing database.

In total, c. 2,500,000 ringing details were computerised, of which c. 780,000 were of Starlings. These totals considerably exceeded expected numbers.

1.5 THE SPECIES

As part of the introduction to this report, a brief overview of the biology and ecology of the species concerned are outlined below. Both species are highly commensal with man, and can occur in large flocks in towns and often near human habitation. The following accounts draw heavily upon the descriptions in Cramp & Perrins (1994), Summers-Smith (1988) and (Feare 1984).

1.5.1 The Starling

The Common Starling in Europe is a gregarious bird that can form huge flocks of millions of birds in winter. These flocks are familiar to many, as they wheel and move like some strange, amorphous super-organism above the place that they will roost that night. It is part of a successful Old World Family of Starlings, the Sturnidae, which comprise 24 genera and some 100 species. In the genus *Sturnus* there are 16 species that occur throughout Eurasia and Indonesia.

The Starling is a black bird with a glossy green/blue/purple iridescent sheen, but its body feathers, when freshly moulted in autumn, have grey/white tips that appear as distinct spots. These are gradually abraded through the winter, so they appear more black at a distance. The female appears more spotted in the winter, but less glossy than the male in spring, whereas the juvenile is a dull dun colour before moulting in the autumn.

Starlings are found throughout most of the Western Palaearctic and also occur through to Eastern China. The northerly and Eastern populations are fully migratory and fly South to winter in Southern Europe, North Africa, Arabia and Northern India. The British breeding population is more sedentary with most birds remaining within Great Britain throughout their lives. This breeding population is, however, augmented by substantial numbers of birds arriving from elsewhere in Europe during the winter (Feare, in press). They have been introduced into North America and have since spread throughout the continent; they have also been introduced into South Africa, South Eastern Australia, New Zealand and a number of oceanic islands.

Starlings nest in cavities in trees and buildings and take readily to nestboxes. They are usually colonial and show a high degree of synchrony of nesting activity within a colony. Nest holes are defended from other Starlings, but the species characteristically shows evidence of "egg-dumping", or the laying of additional eggs in the nests of other Starlings in a colony. In addition, males may attempt to defend several nest sites and may be successfully polygynous. Nests of dry grass and twigs are built by the male in the nest cavity, and these are then lined by the female. A clutch of five to six pale blue eggs is laid in the nest and incubation starts with the penultimate egg and takes c. 12 days. Incubation is mainly by the female, but the male will sit on the eggs for periods during the day to reduce heat loss when the female leaves the nest. After hatching, the female broods the chicks for the first five to eight days and she provides c. 70% of the food for the chicks, which generally consists of invertebrates. Fledging occurs at around 21 days and the parents feed the young for two weeks afterwards. A second clutch may be laid 40 to 50 days after the first clutch.

The young form feeding and roosting flocks, and may be joined by the breeders after the breeding season. These flocks can be highly mobile and occur in a wide range of habitats. They gather in communal roosts that grow in size through the autumn and winter. In Britain, these flocks are swelled by large numbers of wintering migrants from Scandinavia and Northern Europe. Departure from roosts is often in a series of waves that can be detected by radar (Eastwood 1967), occurring at three-minute intervals. Birds then scatter to feed in smaller flocks at distances from the roost sites. The formation of large wintering roosts can cause health and sanitation problems in urban areas, because of the large quantities of droppings that are deposited below such roosts.

The birds forage mainly on the ground in open areas of short grass. Their beaks are specially adapted for probing into the soil and tipulid larvae (leatherjackets) are a main prey item. Their pest status in

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agricultural areas derives from their feeding habits. In autumn they tend to feed on soft fruits and can thus be a horticultural pest, particularly of cherries. In addition they can dig up germinating cereal seed and take grain from livestock feeding areas, with the risk of spoiling and spreading disease to the foodstuffs.

1.5.2 The House Sparrow

The House Sparrow is probably the most numerous and certainly the most widely distributed member of the “true sparrows” of genus *Passer* (family Passeridae). There are 20 species of *Passer* and they originated in the Old World, with a centre of distribution in the Afrotropics (Summers-Smith 1988). Sparrows are essentially seed-eating birds with thick beaks. They generally feed on the ground, searching for seeds or insects (the latter especially for the young), often flocking and taking readily to bird tables and feeders.

Male House Sparrows are boldly marked in chestnut browns, blacks, greys and white, with a characteristic black bib, the size of which is a “badge” that signals the dominance status of an individual within a flock (Møller 1987). The females are plainer, giving a generally grey-brown appearance, and Juveniles resemble females in appearance. The species is markedly gregarious and can form large flocks in the late summer and autumn, when feeding on fields of ripening grain or where grain seeds are to be found concentrated in abundance.

The subspecies found in Britain, *Passer domesticus domesticus*, occurs throughout Europe and Scandinavia, with a distribution that stretches across to the Chinese coast opposite Northern Japan, and is found in Western North Africa. The other ten races are found in North Africa, Arabia, East Asia, India and stretch into Burma (Summers-Smith 1988). However, intentional introductions by man, particularly in the mid 19th Century, has allowed the species to spread into most of North, Central and South America, Southern Africa, the Eastern half of Australia, New Zealand, the Caribbean, as well as numerous smaller islands throughout the North and South Atlantic, Indian Ocean and Pacific Ocean (Summers-Smith 1990). This probably makes the species the world’s most successful introduced species, with a distribution that probably covers approximately two thirds of the World’s land area (Woodall 1996). It has been able to adapt well to a wide variety of different climates but is primarily associated with human habitations, whether in towns and villages or on more isolated farms.

In behaviour, House Sparrows are generally gregarious, living in colonies of 20 to 40 birds. They are highly social birds, breeding, roosting, feeding, washing and dust-bathing in groups, often calling vociferously with characteristic cheeps and chirrups. They are relatively sedentary birds, rarely moving more than 1km from their colony site, and usually substantially less than that, once adult. Only 3% of ringing recoveries in Britain are at distances greater than 20km, and the vast majority of these are of juvenile birds, undertaking dispersal from their natal colony (Summers-Smith & Thomas in press).

Pairs return to breeding colonies from local autumn foraging areas in the early winter. Although pairs are generally monogamous and faithful between years, there is competition for nest sites between males. The species is unusual in experiencing gonadal development and rising testosterone (and other reproductive hormone) levels in November (Hegner & Wingfield 1990). This is thought to reflect the need to establish nest site occupancy in early winter rather than the spring. Formation of new pairs may take place then or in early spring because of competition for suitable nest sites.

House Sparrows often nest in cavities, particularly under roof eaves, but can also build a domed woven nest of grasses, often in dense bushes, so are not apparently limited by the availability of nest holes. The male may start nest building but the nest is completed by both sexes once paired. Eggs are laid at daily intervals and incubation often starts with the penultimate egg. Although the female undertakes incubation at night, both sexes take turns to incubate during the day, with the female undertaking more than the male. Incubation lasts about 12 days, but its length is dependent to a

certain extent on the ambient temperature (Singer & Yom-Tov 1988). Once the eggs hatch, the young are brooded for six to eight days and are fed by males and females equally until near fledging, when the male switches to sexual displays that may help to stimulate the female to start a new brood. The parents feed their young at the rate of between 15 to 20 visits per hour and the fledging period (*c.* 14 days) is longer for larger broods. The food brought to chicks is largely invertebrate, starting initially with aphids, but moving onto larger items, particularly weevils, grasshoppers and caterpillars, as the chicks grow. At later stages, plant material is added to the diet. After fledging, the young are fed by their parents for seven days and then develop the ability to feed themselves over the next three to seven days.

Pairs may attempt to raise up to four broods per year, but the effort used in rearing a brood may impact on the next because both inter-clutch interval and brood sizes are dependent upon the brood size of the previous attempt (McGillivray 1983; Singer & Yom-Tov 1988). Like most multi-brooded species, clutch size shows a pattern of increase and decline over the course of the season (Crick *et al.* 1993), peaking at five mid-season, with an average of four during the early and later stages. There appears to be a slight sex-ratio bias towards males at fledging, but there is considerable evidence for the existence of both surplus females and males in healthy breeding populations. The loss of one member of a pair can be rapidly remedied, often within the space of a few days (e.g. Preiser 1957; Anderson 1990).

Once independent, the juveniles form into flocks and those from different colonies gradually coalesce into larger flocks that move 1 to 2km to feed on locally abundant sources of food. Adults that have finished breeding will join these flocks, which can grow to number several thousand birds, often on the edge of towns where they may feed on fields of ripening grain or areas where harvested grain is stored. This is where their pest status is achieved.

2 STATUS AND POPULATION TRENDS OF THE STARLING *Sturnus vulgaris* IN GREAT BRITAIN

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2.1 CHAPTER SUMMARY

1. Populations of Starling have declined throughout Europe over the last two to three decades.
2. In this chapter, we analyse data from extensive census schemes organised by the British Trust for Ornithology to determine the population size of the Starling in Britain, and the numbers occurring in different regions and habitats. We also assess long-term patterns of change, using generalised additive models, both in the wider countryside and in urban environments.
3. The national breeding population of Starlings was estimated at approximately 8.5 million birds, with a 95% confidence interval of 8.1-10.8 million. Most Starlings occur in Southern Britain and densities are greatest in suburban habitats.
4. Populations in both suburban areas and the wider countryside have declined by over 50%, with declines greatest in the South and West of Britain and in areas of livestock farming.
5. Changes in pastoral farming practices are likely to account for at least some of the decline in the wider countryside, probably related to changes in food resources, though these changes are unquantified.
6. The number of birds using rural gardens peaked in the mid 1980s, when annual winter temperatures tended to be low. A subsequent reduction in garden usage is likely to be attributable to less severe winters. Numbers using suburban gardens in winter have declined to a greater extent, though how this relates to breeding populations is unclear due to the large annual influx of birds from continental breeding populations.

2.2 INTRODUCTION

In Britain, and much of Western Europe, the Starling (*Sturnus vulgaris*) is a familiar bird of both farmland and towns. However, there has been a decline in population numbers over the last twenty years, both in Britain and in the rest of Europe (Baillie *et al.* 2001; Appendix 2.1). Declines in other farmland birds are well known (Fuller *et al.* 1995; Krebs *et al.* 1999), but most research has concentrated on the decline of arable specialists, in particular those that forage largely on seeds (Siriwardena *et al.* 2000c; Robinson & Sutherland 2002). Although changes in arable farming have been large (Chamberlain *et al.* 2000; Robinson & Sutherland 2002), changes in pastoral farming have been just as great (Vickery *et al.* 2001), and these may have affected Starling population numbers.

Two populations of Starling frequent Britain (Feare in press). The population that breeds in Britain is resident, with birds largely remaining in the same general area throughout their adult life. During the winter months, this population is augmented by a similar number of immigrant birds that

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breed primarily in Sweden and the Baltic states. These birds arrive in October and November and depart in March.

In Britain, the control of wild bird numbers for economic, health or other reasons must be specifically licensed. However, the control of certain common “opportunistic” species is permitted under a general licence, for which specific approval for individual measures is not required. This licence is permitted under a derogation from the EC Wild Birds Directive (EC/1979/409), which requires that monitoring be undertaken to ensure that the conservation status of the species concerned is not affected. Of the nine species covered by the general licence and monitored by the BTO’s survey schemes, only two, House Sparrow *Passer domesticus* and Starling, have undergone appreciable population declines over the last few decades (Wilson *et al.* 1998). In this chapter, we present a comprehensive analysis of the changes in Starling abundance, using historical data from the BTO’s Common Birds Census (CBC) and Garden Bird Feeding Survey (GBFS), together with the BTO/JNCC/RSPB Breeding Bird Survey (BBS). The CBC monitors populations in the wider countryside, being particularly representative of farmland in South East England (Fuller *et al.* 1985); its coverage of gardens, and human habitats in general, is poor. The CBC monitored numbers of Starlings between 1962 and 2000 and has since been replaced by the BBS, which commenced in 1994 and has a wider and more representative geographic and habitat coverage. The GBFS has, since 1970, monitored the number of birds feeding in gardens during the winter.

We use these data sources to examine the long-term population trends across the regions and habitats and to investigate the use of gardens over time. This is the first time that extensive data on abundance in gardens at a national scale have been analysed. These data also allow us to distinguish between suburban and rural gardens. Whilst population trends in rural gardens might be expected to mirror those in the wider countryside, trends in suburban areas have been poorly documented, being only peripherally covered in the standard monitoring schemes (with the exception of the relatively recent BBS). We also analyse the data regionally and with respect to particular habitat types, with the aim of addressing the following hypotheses:

- Do population trends differ between broad habitat types? Woodland habitat in particular is regarded as sub-optimal since, although birds breed there, few forage there (Feare 1984).
- Have changes been greater in pastoral or arable systems?
- Foraging Starlings are often associated with livestock though rearing practices have changed markedly. Are declines greater on farms with livestock?
- During the autumn, large flocks of Starlings can be seen foraging on coastal saltmarsh, particularly in Southern England where most saltmarsh occurs in Britain (C.J. Feare pers. comm.). This habitat has not undergone the extensive changes seen on farmland, so declines in areas close to saltmarsh might be expected to be less than elsewhere.

Finally, we produce an estimate of the number of Starlings breeding in Britain, and quantify the number and density of birds breeding in each region and habitat. This will enable us to determine which populations are the greatest contributors to the national population trend, and yield information on the relative quality of different areas as Starling breeding habitat.

2.3 METHODS

2.3.1 Data Sources

2.3.1.1 Common Birds Census

Until the inception of the BBS (below), the CBC was the mainstay of terrestrial bird monitoring in Britain (Marchant *et al.* 1990). Between 1962 and 2000, between 200 and 300 plots were visited eight to 12 times each year and territories of all breeding species were mapped by volunteer observers. CBC plots were characterised as farmland, woodland or “special” (the latter consisting of areas dominated by nature reserves, lakes, coastal habitat, etc.). On average, Starlings were recorded on

146 plots each year. Some more detailed habitat information was also recorded for each CBC plot, along with location and altitude data. Cropping patterns on farmland CBC plots have been shown to be representative of those across Southern and Eastern Britain (Fuller *et al.* 1985). We use both the complete CBC plot sample, and plots from farmland and woodland separately, to investigate long-term trends in breeding abundance. Due to a sparseness of data, it proved impossible to calculate a woodland index for 1962 or 1963.

2.3.1.2 Garden Bird Feeding Survey

Since 1970, the GBFS has provided annual information on the numbers of birds using artificial food and water sources during winter in a sample of rural and suburban gardens in Britain. Rural gardens are defined as being situated in an area consisting of more than 50% open country, while suburban gardens are surrounded mostly by other houses and gardens (this includes, both suburban and urban gardens, which are often not clearly differentiated). Suburban gardens constitute around 60% of the sample. Volunteer observers record the maximum number (the “peak count”) of each species using garden bird feeding stations in their gardens in each week of the winter (26 weeks from October to March, inclusive). The sample of gardens has changed over time, as observers have entered and left the scheme, but an average total annual coverage of around 190 sites with Starlings has been maintained. Throughout the life of the GBFS, efforts have been made to ensure that gardens are broadly representative of a range of garden types (large, small, rural, suburban, etc.) with a consistent, national spatial distribution. If an observer leaves the scheme, another observer with a similar garden and feeding regime is sought as a replacement. The amount of food provided for garden birds has generally increased across Britain during the life of the scheme and this is likely to apply to the food provisioning in GBFS gardens too.

Annual indices of abundance in rural and suburban gardens and reports on long-term trends are produced regularly (e.g. Glue 2001), but GBFS data have generally been under-utilised in the monitoring of Britain’s birds. Although British breeding Starlings are relatively sedentary, around half of the wintering population is composed of continental immigrants (Feare in press). Clearly, the number of birds using gardens will vary from year in response to, for example, severe weather conditions and productivity in the breeding areas from which these immigrants originate. Thus, changes in numbers on GBFS plots will reflect not just the changes in numbers of birds resident on the plots. The GBFS is the only long-running survey with wide geographical coverage in Britain of both wintering terrestrial birds in general and birds in gardens in any season and, thus, represents the best available data source; however, the caveats relating to immigrant birds should be borne in mind when interpreting the analysis of data from this scheme.

2.3.1.3 Breeding Bird Survey

The BBS was introduced in 1994 as a long-term replacement for the CBC. It was designed to improve on the CBC by providing wider, randomised spatial coverage that is representative of bird populations and habitats across the country. The BBS is based on 1×1km square survey units across which two 1km transects are walked by volunteer observers twice between the beginning of April and the end of June each year; any birds seen or heard are recorded in distance bands on either side of the transects (Noble *et al.* 2001). Habitat is also recorded; the 2km length of recording transect is divided into ten 200m sections in each of which the habitat is characterised in terms of habitat descriptions drawn from the standard BTO habitat coding system (Crick 1992), which identifies broad habitat type. The BBS protocol allows the estimation of densities in specific habitats through distance-sampling analysis (Bibby *et al.* 1992; Buckland *et al.* 1993; Thomas *et al.* 1998).

2.3.2 Statistical Models

The basic statistical framework employed is that of generalised linear and generalised additive modelling, each employing a log link function and a Poisson error distribution, as is appropriate for count data (ter Braak *et al.* 1994; Thomas 1996; Fewster *et al.* 2000). Generalised linear models (GLMs) allow the modelling of annual variation and simple linear and quadratic (etc.) trends, as well as analyses of the strength of relationships between abundance and various predictor variables, such as habitat characteristics. Generalised additive models (GAMs) allow the estimation of non-parametric smoothed trends, with a level of smoothing defined by the degrees of freedom, providing the best description of a long-term trend without imposing constraints on its shape (unlike linear, quadratic or other parametric function; Fewster *et al.* 2000).

2.3.2.1 CBC and GBFS

We fitted GLMs using the GENMOD procedure of SAS and compared models using likelihood-ratio tests (SAS Institute, Inc. 1996). Confidence intervals were derived from the analytically estimated standard errors produced by SAS. GAMs were fitted using the program GAIM (Hastie & Tibshirani 1990), models being fitted using ten degrees of freedom (recommended by Fewster *et al.* 2000) to produce smoothed trends and $T-1$ degrees of freedom, where T is the number of years in the analysis, to produce unsmoothed trends (Fewster *et al.* 2000), and confidence intervals were calculated by bootstrapping from a matrix of 199 replicates generated from re-runs of each model on new samples generated by re-sampling survey sites with replacement.

Both the GLM and GAM analyses of CBC data modelled number of birds counted as a function of a categorical plot effect and year, the latter being parameterised as either a categorical variable or as a continuous (parametric or non-parametric) predictor. Further predictor variables or interactions between these variables were introduced to make specific comparisons or to test hypotheses. GLM analyses of GBFS data used basic models of peak weekly count as a function of a categorical garden effect, a year effect and two continuous variables describing the cyclical pattern of counts through the winter. This cyclical pattern was modelled using a combination of sine and cosine functions (Fisher 1993). The latter were calculated as the sine and cosine of the week of the year (week number divided by 52: week sine effect = $\sin(2 \times \pi \times (\text{week}/52))$, cosine effect = $\cos(2 \times \pi \times (\text{week}/52))$). In order to account for the much repeated counts made on GBFS (each year had up to 26 weekly counts), we included an auto-correlated covariance matrix within the GLM specification. In this, within each site and each year, weekly counts (Y_i) were correlated in an autoregressive manner, such that $\text{corr}(Y_i, Y_{i+1}) = \alpha^1$, where α is constant across site-year combinations. This was necessary to take into account the fact that counts from adjacent weeks were likely to be more similar than those separated by greater time intervals.

Analyses of the weekly patterns of variation in abundance over the entire GBFS survey period showed that peak abundance occurred between weeks 11 (mid December) and 20 (late February) inclusive, where week one is the first week in October each year. Consequently, we averaged the weekly peak counts over this period to produce a single estimate of numbers in each garden in each year. These averaged counts were then entered into the GAMs with a categorical garden effect and a year effect as predictors (Fewster *et al.* 2000).

To identify significant turning points in the smoothed CBC and GBFS trends, we employed the methods of Siriwardena *et al.* (1998a) and Fewster *et al.* (2000), slightly adapted to consider changes in population growth rate rather than in abundance. Thus, we estimated the second derivatives (rates-of-change of the rate-of-change) of the population trends in each year (on the log scale), together with their 95% confidence intervals, using the smoothed GAM trends and the matrix of 199 bootstrapped replicates of these trends. Years where the 95% confidence interval of the second derivative did not overlap zero could be considered to be years in which there was significant curvature in the original trend being analysed (Siriwardena *et al.* 1998a; Fewster *et al.* 2000). These turning points then provided both an intrinsically useful tool for describing trends and an objective means of dividing the

population index time series into units with homogenous trends (e.g. Siriwardena *et al.* 1998b; 2000c).

Smoothed CBC trends were produced for five regions of Britain and for each of arable-dominated, grass-dominated and mixed CBC plots. The five regions were based on those used by Chamberlain *et al.* (1999) to compare intensive arable farming (in Eastern England) with other agricultural types and were defined as follows:

East -	Hertfordshire, Bedfordshire, Northamptonshire, Nottinghamshire, Humberside and eastwards;
North -	Merseyside, Manchester, South Yorkshire and areas to the North;
West -	Gloucestershire, Warwickshire, Leicestershire, Derbyshire, Cheshire and areas to the West;
South West -	Avon, Wiltshire, Dorset and areas to the West;
South East -	London, Buckinghamshire, Oxfordshire, Berkshire, Hampshire and areas to the South and East.

Other tests took the form, as appropriate, either of comparisons between linear year effect terms for different plot classifications or with respect to a continuous modifier of trend slope. We compared CBC and GBFS trends using annual plot and garden counts (i.e. the simplified garden data also used to fit GAMs), testing whether simplified, underlying long-term trends (either linear or quadratic) differed between the two schemes, by using log-likelihood ratio tests as before, to test whether a year \times scheme interaction term significantly reduced the residual deviance.

In the autumn, large flocks of, mostly juvenile, Starlings are often seen foraging on salt marshes. Thus, we hypothesised that coastal pasture and salt marsh would provide additional foraging resources for Starlings and that numbers on CBC plots in close proximity to salt marsh should have declined less than more inland sites. This pattern should be particularly evident in Southern and Eastern England, where intensive farming predominates. To test this hypothesis, we compared trends on CBC plots in 10km squares containing salt marsh, identified with reference to the Centre for Ecology and Hydrology's Land Cover data set (Fuller & Parsell 1990). We also tested for differences between farmland and human habitation at two levels, by comparing trends on CBC plots with and without buildings and comparing trends on CBC plots and in GBFS gardens.

2.3.2.2 BBS

BBS data were used to assess densities of Starlings with respect to habitat and region, using a distance-sampling approach (Bibby & Buckland 1987; Buckland *et al.* 1993; Thomas *et al.* 1998). This method incorporates modelling of how the probability of detection of a bird falls as distance from a transect line increases and allows these detection functions to be calculated on a habitat-specific basis (detectability is likely to vary between habitats due to differences in visibility and the efficiency of sound transmission). We calculated habitat-specific densities using the methods of Gregory & Baillie (1998), with the refinement that abundance-habitat relationships were assumed to be uniform only within each of the ten regions in Britain rather than across the whole country. In addition, we assumed that the random geographical coverage of the BBS (stratified by observer density: Gregory & Baillie 1997) allowed us to use BBS habitat records to estimate the area covered by each habitat category in each region and thus to produce estimates of regional and national population sizes by combining the area of each habitat in a region with region- and habitat-specific densities.

Following Gregory & Baillie (1998), we estimated Starling densities from BBS data for each of 15 habitat categories: deciduous woodland, coniferous woodland, mixed woodland, scrub, semi-natural grassland, heath, improved grassland, unimproved grassland, mixed farming, arable farming, urban human sites, suburban human sites, rural human sites, areas adjacent to water bodies and miscellaneous areas. In a separate analysis, we also divided the data into the ten British geographical

regions used by the European Community for statistical purposes. We conducted these analyses for each year for which BBS data were available, i.e. 1994-2000, calculating 95% confidence intervals for the region - and habitat-specific densities using a bootstrapping procedure in which survey squares were re-sampled, with replacement, 400 times (after Gregory & Baillie 1998). This enabled us to examine the variation in population trends among the regions and habitats occupied by Starlings to identify any population strongholds and problem areas for conservation.

2.4 RESULTS

2.4.1 How many Starlings are there?

BBS data suggest that there are approximately 8,860,000 starlings present in the breeding season (averaged over the period 1994-2000, 95% confidence limits: 8,140,000-10,820,000); however, these were not distributed evenly throughout the country (Table 2.4.1.1). Around a third (36%) of all birds were recorded in the Southernmost counties of England (South of a line from Essex to Gloucestershire), whereas Scotland (representing 33% of the land area) held only 21% of the population. These regional differences reflect, to some extent, differences in landscape character, the bulk of the population (73%) being found in only two habitats: gardens and areas of unimproved grass.

The greatest densities of birds occurred in urban and suburban areas, with the density of birds in agricultural areas being an order of magnitude lower; densities in rural areas (i.e. villages) are intermediate (Table 2.4.1.2). There is no consistent geographical variation in the density in any habitat between regions, though the density of birds in Wales is low across all habitats and densities in suburban Scotland are particularly high.

2.4.2 Long term trends

In the wider countryside of Great Britain, i.e. away from human settlements, Starlings have declined by 68% since 1962 (Figure 2.4.2.1, figures for population change are based on the GAM trends). The decline has been much greater in woodland CBC plots (92% since 1965) than farmland plots (66% since 1962) but because Starlings are more widespread on farmland plots, the latter figure more closely resembles the overall trend. While the decline in woodland plots appears to have been largely continuous, a period of relative stability punctuated the decline in farmland populations in the 1970s. There are insufficient early data to determine whether the early period of population increase on farmland plots (1962-65) occurred on woodland plots too.

Population trends also differ regionally (Table 2.4.2.1). In the West and North of the country, the decline has been more or less continuous, following a transient peak in the early 1960s (Figure 2.4.2.2). In both areas, farmland plots represent about 60% and woodland plots about 25% of the sample (*cf* the trends in Figure 2.4.2.1). A similar pattern is observed in the South East, without the early peak, perhaps reflecting a more even distribution of farmland (44%) and woodland (37%) plots. Declines in the South West (early 1980s) and Eastern (mid 1980s) parts of England appear to have started later. Although, the population decline started later, the overall decline in numbers has been greater (population decline in South West 86%, in East 77%) though not significantly so (95% confidence limits overlap).

Table 2.4.1.1 Population estimates by region and habitat for Starling as measured from BBS. For each habitat and region combination, the first column gives the percentage of the British population supported and the second column gives the mean annual percentage change during the period 1994-2000, changes in bold are significant at $P < 0.05$. Population change was not calculated for wood or 'other' habitats, which represented a heterogeneous range of scrub, heath and coastal habitats. For the final line, habitats were ranked within each region according to the severity of decline (one being most severe) and these rankings averaged across the regions.

	Unimp. Grass ¹		Imp. Grass ²		Arable		Wood		Rural Human		Suburban		Urban		Other		All Habitats	
Scotland	4.33	+10.8	1.46	+14.1	1.80	-2.62	0.36	-	2.08	-1.09	5.36	-0.62	1.19	-2.75	4.32	-	20.9	+8.1
Northern England	1.08	-8.03	0.43	-12.0	0.41	-13.1	0.17	-	0.11	+0.93	1.71	-23.8	0.54	+26.4	0.42	-	4.87	-0.3
North East England	1.29	-9.53	0.64	+8.99	0.64	+2.42	0.24	-	1.64	-1.43	2.03	+12.9	0.72	-6.82	0.35	-	7.55	-26
North West England	1.48	-2.21	0.11	+2.18	0.53	-32.3	0.01	-	0.76	-4.97	2.13	+2.23	0.42	+7.27	0.51	-	5.95	-20.2
Wales	0.92	-41.8	0.03	+1.98	0.25	+20.8	0.04	-	0.47	+9.64	1.38	+18.8	0.31	+43.9	0.31	-	3.71	+8.8
Central-West England	0.98	-16.6	0.48	-2.95	0.63	+9.48	0.10	-	0.71	+3.08	2.93	-8.58	0.85	-23.4	0.58	-	7.26	-26
South West England	2.57	+8.27	0.52	-11.9	0.67	-8.19	0.05	-	1.56	+1.87	2.71	-7.75	1.52	-8.71	1.05	-	10.65	-17.8
Central East England	0.89	+5.29	1.21	+0.29	0.24	-8.03	0.06	-	1.54	+2.62	3.15	+0.45	0.84	+0.95	1.46	-	9.39	+13.6
East Anglia	0.11	-6.80	1.02	-6.93	0.15	-1.94	0.06	-	0.09	-1.28	0.84	-2.19	1.10	+20.1	0.47	-	3.84	-36.3
South East England	2.10	-2.79	1.74	-8.62	0.89	-10.7	0.41	-	4.90	-0.52	11.17	-2.55	2.33	-2.31	2.31	-	25.85	-31.5
All Regions	15.75	-6.53	7.64	+3.02	6.21	-0.53	1.50	-	13.86	-1.40	33.41	-1.20	9.82	-0.60	11.78	-	100	-6.03
Mean Rank of Decline		3.3		3.0		2.9		-		4.2		3.7		3.9				

¹ Unimproved Grassland; ² Improved Grassland

Table 2.4.1.2 Density estimates by region and habitat for Starling as measured from BBS. For each habitat and region, estimates of density (km^{-2}) \pm 1 standard error are given, for the years 1994-2000.

	Unimproved Grass	Improved Grass	Arable	Rural Human	Suburban	Urban
Scotland	36.9 \pm 9.4	34.4 \pm 3.2	14.2 \pm 1.0	89.2 \pm 13.9	291.4 \pm 18.9	184.4 \pm 19.1
Northern England	16.4 \pm 1.6	20.6 \pm 1.6	18.5 \pm 3.5	140.7 \pm 27.7	254.9 \pm 33.6	140.1 \pm 33.7
North East England	30.6 \pm 3.6	46.3 \pm 7.4	15.5 \pm 2.1	110.4 \pm 14.2	168.3 \pm 13.5	242.8 \pm 28.5
North West England	70.3 \pm 11.6	55.9 \pm 4.8	11.2 \pm 2.3	89.4 \pm 7.1	150.7 \pm 5.0	128.4 \pm 10.0
Wales	10.9 \pm 2.9	9.3 \pm 1.0	4.5 \pm 1.1	41.8 \pm 5.9	159.9 \pm 8.7	108.4 \pm 21.1
Central West England	48.6 \pm 9.4	24.1 \pm 1.6	14.8 \pm 1.3	90.7 \pm 2.2	206.5 \pm 12.4	195.2 \pm 8.0
South West England	29.0 \pm 3.9	27.9 \pm 2.5	9.8 \pm 1.4	96.5 \pm 5.6	218.2 \pm 10.0	163.9 \pm 14.4
Central East England	30.9 \pm 5.8	32.8 \pm 4.7	15.4 \pm 2.6	102.5 \pm 16.7	254.9 \pm 13.6	245.9 \pm 33.9
East Anglia	44.6 \pm 11.1	20.2 \pm 2.9	11.1 \pm 1.5	105.8 \pm 8.2	255.1 \pm 18.9	104.1 \pm 22.6
South East England	48.4 \pm 5.2	47.5 \pm 3.2	18.3 \pm 1.91	103.7 \pm 5.2	245.0 \pm 5.1	276.1 \pm 3.2

Table 2.4.2.1 Results of tests for linear declines in Starling numbers on CBC plots with respect to different habitat and spatial divisions. Significance of trends was tested using Likelihood Ratio Tests (LRTs) and the parameter estimates (± 1 standard error) for the appropriate terms, on the log scale, are given, together with a brief interpretation of the results.

Habitat/spatial split	LRT: χ^2 , d.f., <i>P</i>	Parameter	Estimate	Interpretation
None (n = 246)	1192, 1, <0.001	Year	-0.037 (0.001)	Significant linear decline over time
Farm type (n = 51, 96, 185)	7.2, 2, <0.028	Arable Mixed Grazing	-0.011 (0.006) -0.029 (0.002) -0.026 (0.002)	Steeper decline on pastoral and mixed farms
Region (n=40, 57, 79, 24, 34)	59.0, 4, <0.001	South East East South West West North	-0.050 (0.002) -0.025 (0.003) -0.034 (0.004) -0.040 (0.003) -0.042 (0.003)	Significant declines in all regions, steepest in South East followed by North and West.
Geographic Location (n = 684)	43.5, 2, <0.001	Year \times latitude Year \times longitude	0.049 (0.008) 0.045 (0.012)	Declines tend to be steeper in the North and in the West
Buildings (n = 284, 47)	0.29, 1, N.S.			No difference in trends
Altitude (n = 702)	25.6, 1, <0.001	Year \times altitude	0.0001 (0.0001)	Declines tend to be steeper at lower altitudes
Proximity to coast, South/East only (n = 265, 63)	62.0, 1, <0.001	Inland Coastal	-0.037 (0.002) -0.070 (0.004)	Steeper declines on plots in coastal 10km squares
Proximity to salt marsh, South/East only (n = 288, 40)	109.2, 1, <0.001	Non salt marsh: Salt marsh:	-0.037 (0.002) -0.088 (0.005)	Steeper declines on plots in 10km squares containing salt marsh

Starling population trends

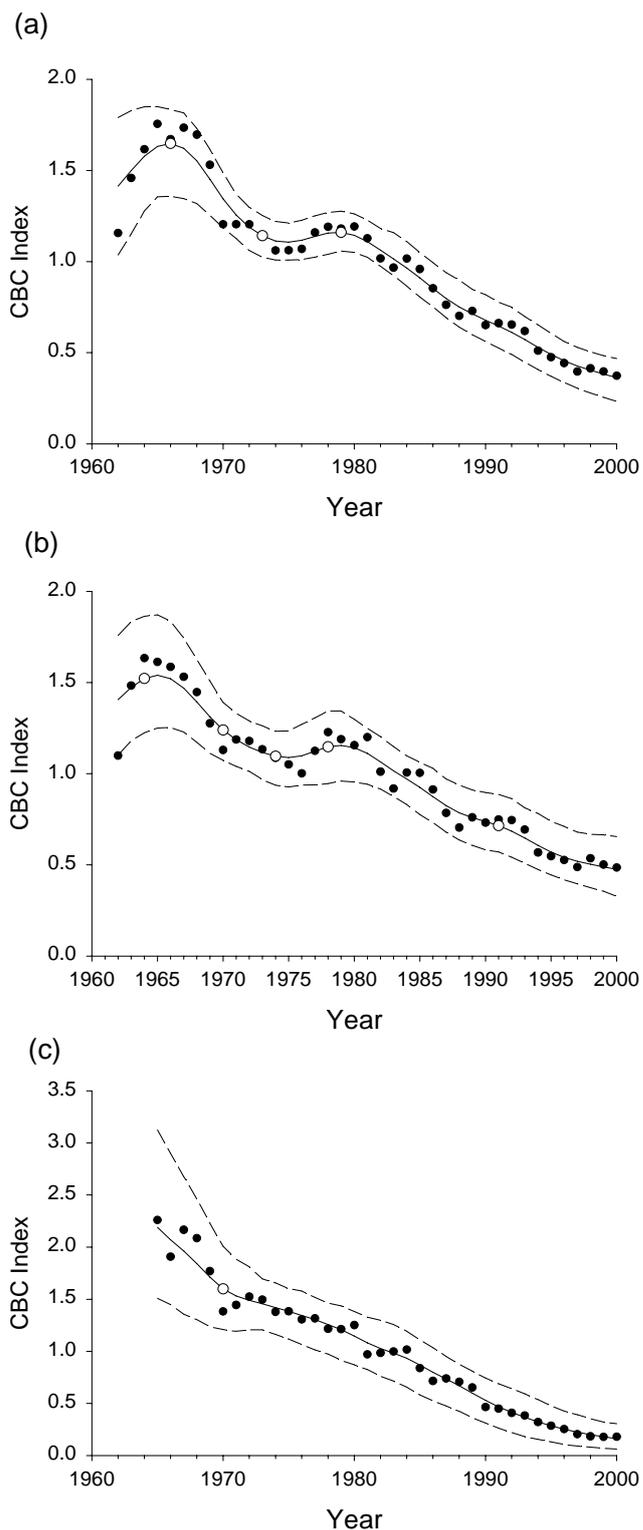


Figure 2.4.2.1 Population index of Starling in Britain. Data from CBC for (a) all plots, (b) farmland plots and (c) woodland plots only. Solid line represents a smoothed GAM trend and the dashed line 95% confidence limits (see text for details). Filled circles represent annual indices (i.e. no smoothing) and open circles significant ($P < 0.05$) turning points in the GAM trend.

Starling population trends

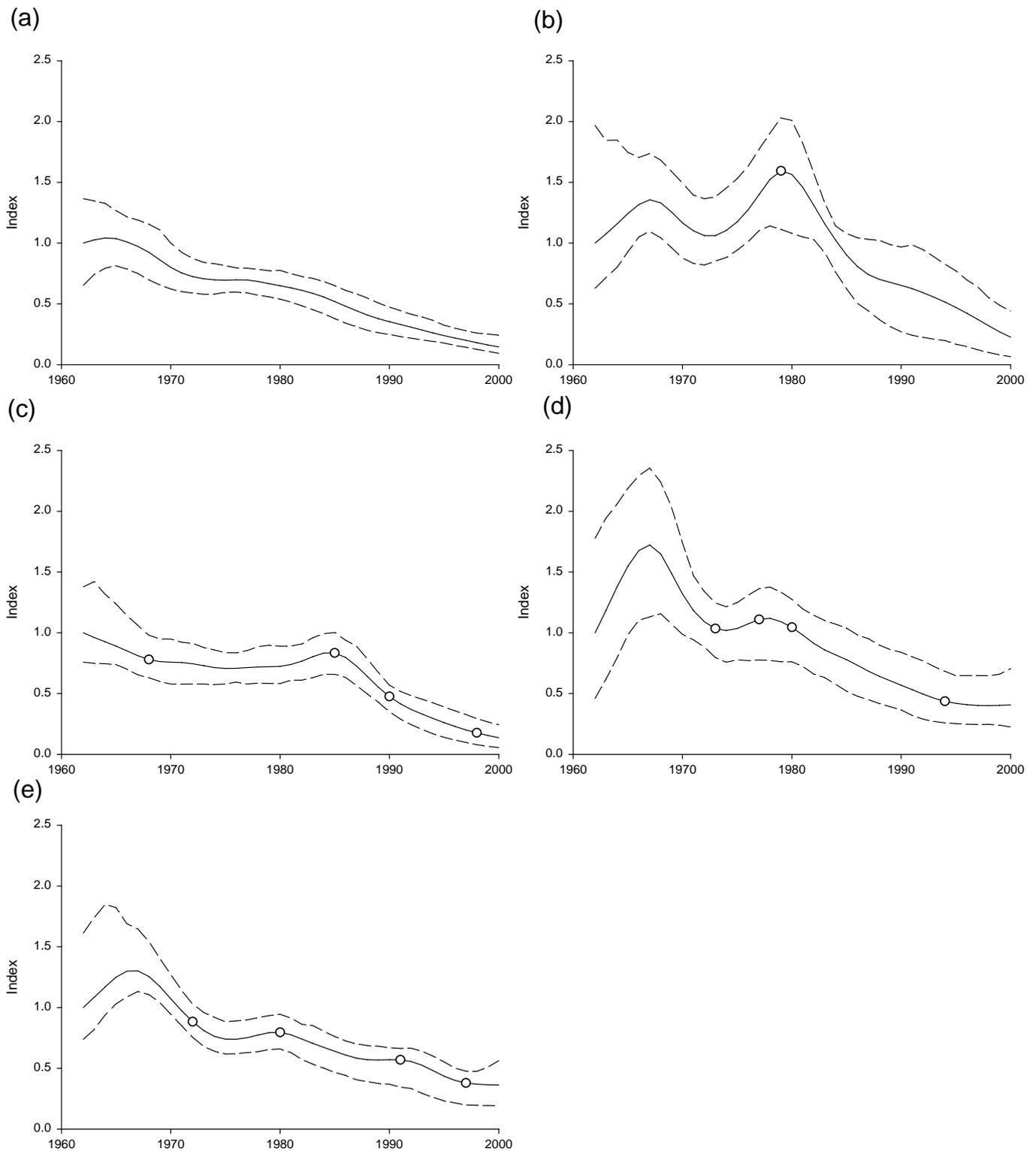


Figure 2.4.2.2 Regional population indices for Starling as measured from CBC. Details as Figure 2.4.2.1. (a) South East England, (b) South West England, (c) Eastern England (d) Wales and Western England (e) Northern Britain (see text for details).

Starling population trends

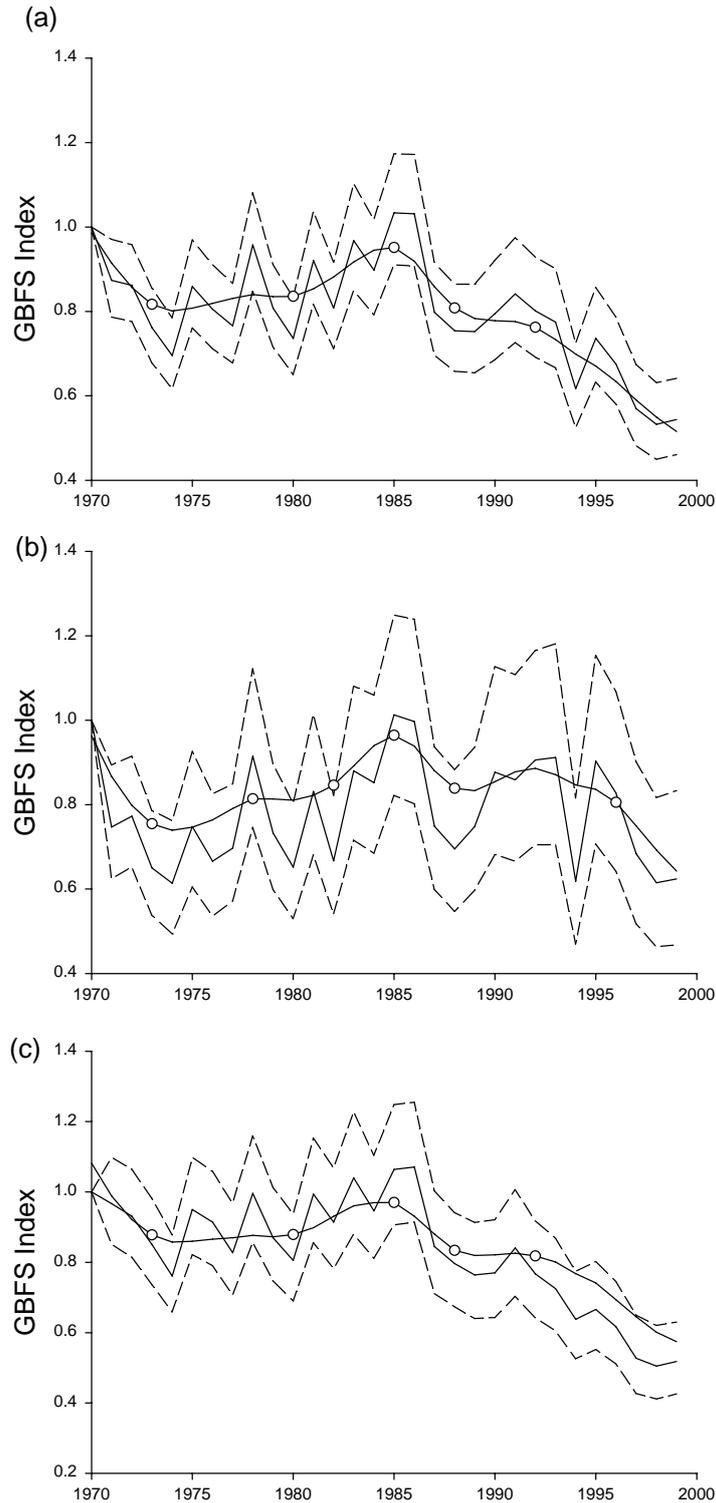


Figure 2.4.2.3 Temporal trends in use of gardens by Starlings from the GBFS. (a) All plots, (b) Rural plots only, (c) Suburban/Urban plots only. The annual index of abundance for each year (October to March) is given (dashed lines represent 95% confidence limits) as is the smoothed (10df GAM, see text) trend. Circles on the GAM trend indicate significant turning points in the smoothed trend ($P < 0.05$).

The number of birds using gardens during the winter varied markedly from year to year (Figure 2.4.2.3). In general, numbers peaked in the mid 1980s, however, there has been a long-term decline in the number of Starlings using garden feeding stations, beginning in 1985, though with a brief respite in 1988-92. The decline has not been equal in all gardens. While urban and suburban gardens are now used much less than they were in the mid 1980s (41% decline since 1985), the decline in usage of rural gardens has been much less marked. Although there has been a 33% decline in numbers in these rural gardens since 1985, this is within the large degree of annual variation in numbers present. The relatively poor precision of the (annual) estimates, means that little confidence can be placed in the magnitude of this apparent decline. This becomes clear when considering population changes over a longer time frame. Numbers in urban gardens are now much lower than they were in 1974 (33% decline), whereas numbers in rural gardens have declined much less (13% decline).

2.4.3 Correlates of population decline

Although there has been an overall decline in numbers recorded on all farmland CBC plots, this decline has not been equal across farm types (Figure 2.4.3.1). Overall, the decline has been steepest on farms containing livestock (either alone, or in combination with arable crops), with declines on arable farms being less, though still significant (Table 2.4.2.1). The timing of the declines has also differed between farm types. Numbers on mixed farms appear to have declined continuously since the mid 1960s, whereas numbers on grassland plots remained more or less stable until the late 1970s, only subsequently declining. Numbers in arable plots, however, show a big transient peak in the late 1970s and early 1980s; although numbers have declined on these plots since 1980 (as elsewhere) numbers are only slightly lower than they were in the early 1970s, particularly in the light of the wide confidence limits about the GAM trends.

Abundance on farmland CBC plots (controlling for temporal variation) tended to be higher in arable areas (LRT: $\chi^2 = 12.1$, d.f. = 1, $P < 0.001$) and lower where these crops were for stockfeed (LRT: $\chi^2 = 29.3$, d.f. = 1, $P < 0.001$). Abundance is also lower in areas with more extensive rough grazing (LRT: $\chi^2 = 17.0$, d.f. = 1, $P < 0.001$), which tend to be towards the North and West of Britain and at higher altitudes.

Contrary to our hypothesis, numbers of birds on CBC plots close to salt marsh habitat did not show a significantly smaller decline than numbers on more inland plots in Southern and Eastern England (Table 2.4.2.1; Figure 2.4.3.2). (Very similar results were obtained when plots from all regions were used, $\chi^2 = 104.5$, d.f. = 1, $P < 0.001$). More generally, the declines tended to be steepest in the North and West of the country, and at lower altitudes (Table 2.4.2.1).

The decline in numbers breeding in the wider countryside has been significantly steeper than the decline in numbers of birds using gardens in winter. This is the case both when the indices are used and when just the indices from farmland plots and rural gardens are compared; these latter indices are likely to represent quite similar habitats (Table 2.4.3.1). Overall, the quadratic trends indicate a period of relatively high use of gardens in the winter in the 1980s and lower use in the 1970s and 1990s (Figure 2.4.3.3). In comparison, numbers breeding in the wider countryside were largely stable until the late 1970s, with a subsequent decline. In suburban gardens in winter, the current rate of decline (since 1985) is similar to that in the wider countryside, but the decline measured by the CBC has been going on for longer, so the overall decline is greater (Table 2.4.3.1). Farmland CBC plots containing buildings, however, did not show a different rate of decline than those without (Table 2.4.2.1).

Starling population trends

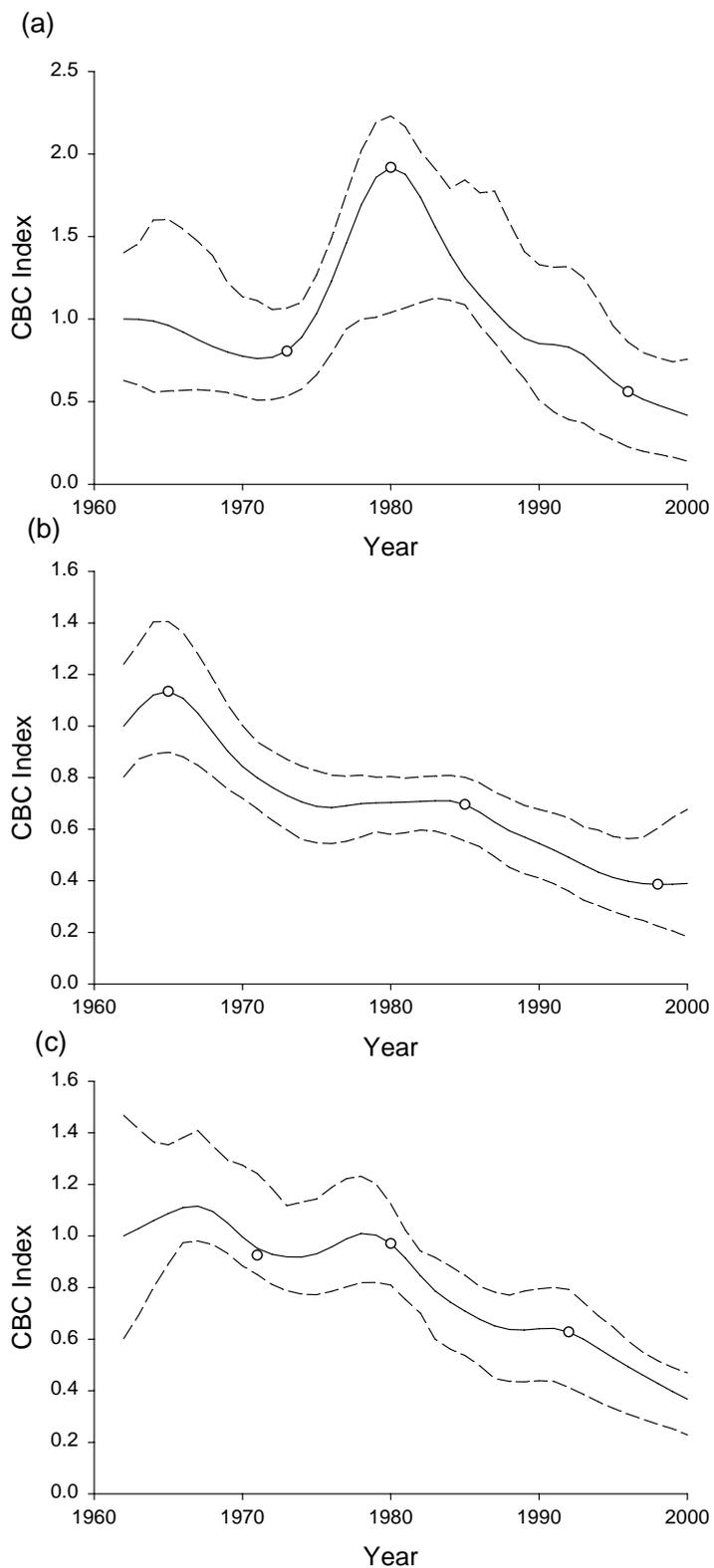


Figure 2.4.3.1 Temporal trends in starling population on different types of farmland as measured from CBC. Details as in Figure 2.4.2.1 (a) arable, (b) mixed and (c) grass farms. (see text for details).

Table 2.4.3.1 Comparison of CBC and GBFS data sets for temporal trends in starling numbers 1970-1999. Year was specified either by an annual term (class variable with 30 levels) or by quadratic (two parameter continuous) or linear (one parameter continuous) trends. Significance was tested using log-likelihood ratios (see text).

CBC plots	GBFS gardens	Model	χ^2	d.f.	P
All Plots	All gardens	Annual	448.7	29	<0.001
		Quadratic	228.3	2	<0.001
		Linear	208.5	1	<0.001
Farmland	Rural	Annual	89.2	29	<0.001
		Quadratic	145.7	2	<0.001
		Linear	134.8	1	<0.001
All Plots	Suburban	Annual	180.2	29	<0.001
		Quadratic	124.2	2	<0.001
		Linear	114.2	1	<0.001

(a)

(b)

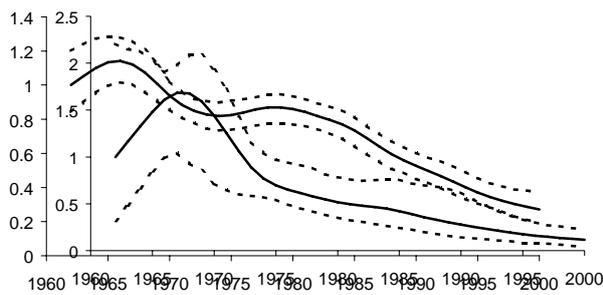


Figure 2.4.3.2 Temporal trends in Starling numbers on CBC plots (a) close to saltmarsh and (b) on inland plots. Trends are GAMs with 10 d.f. and dashed lines represent 95% confidence limits.

Starling population trends

(a)

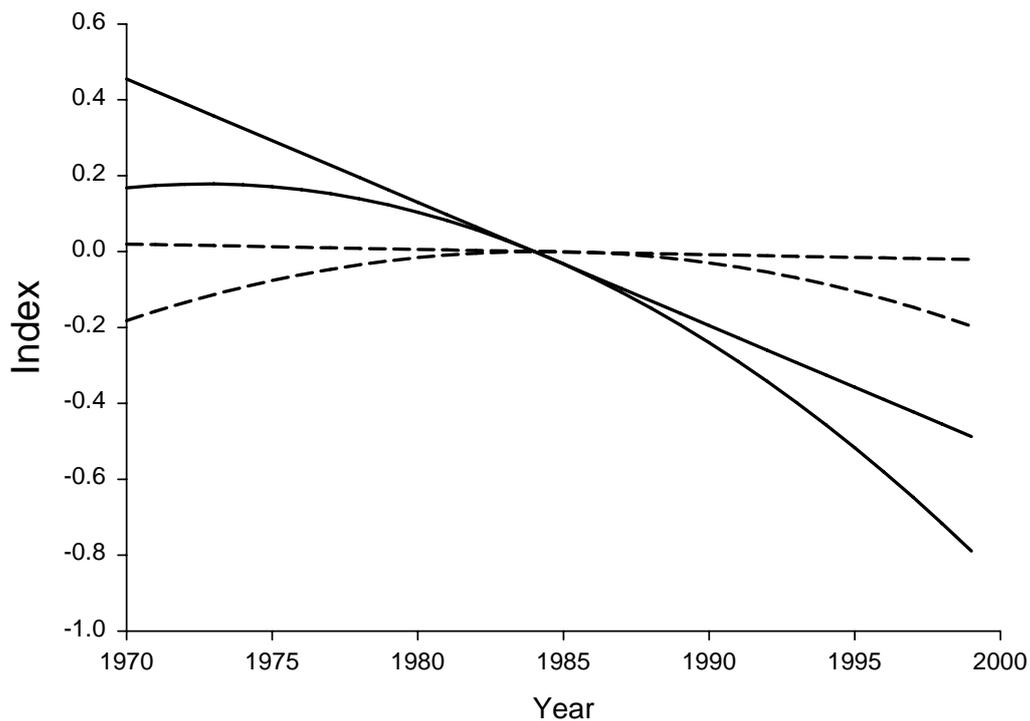
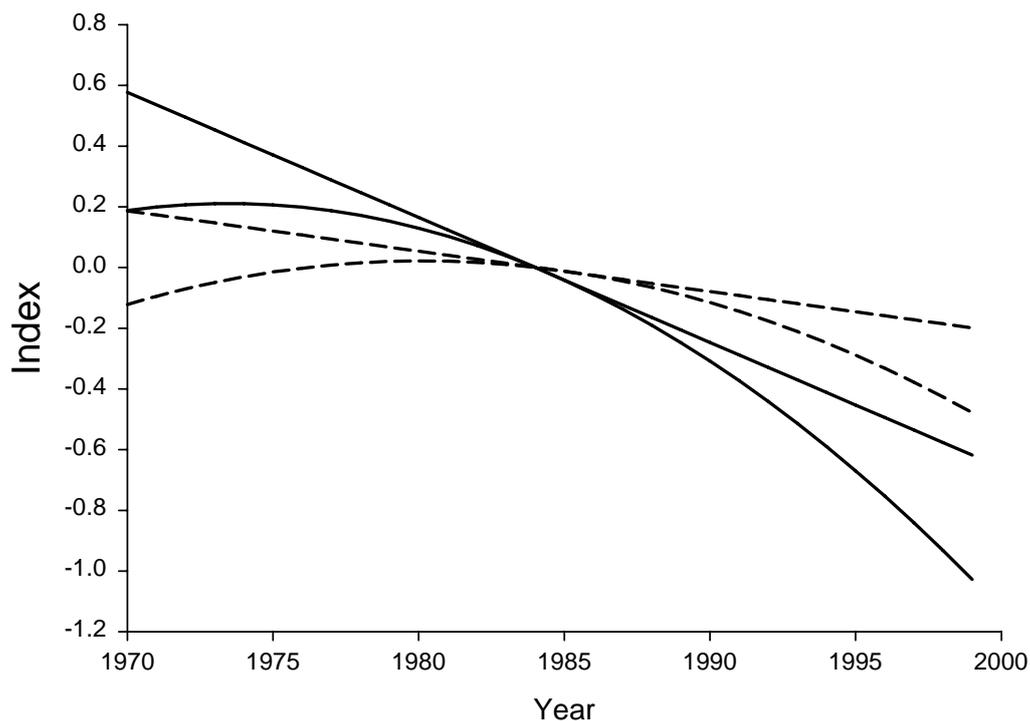


Figure 2.4.3.3 Comparison of linear and quadratic trends in time for CBC (solid lines) and GBFS (broken line) for the period 1976-1999. Comparison for (a) all CBC plots and all GBFS gardens and (b) farmland CBC plots and rural GBFS gardens only.

Even over the relatively short period covered by the BBS, some significant trends in numbers can be observed (Table 2.4.1.1). Although numbers are declining in most habitats, numbers appear to be generally increasing in areas of improved grassland; it is in this habitat and in arable habitats where Starlings are *currently* doing best. However these trends are not equal across regions. For example, numbers in town gardens in the West Midlands (Central to West England) and South West England seem to be declining particularly strongly, whereas numbers in this habitat are increasing in Wales. Numbers on improved pasture are declining in the South East of Britain, but generally increasing in Scotland and (though not significantly) in the North and West of England and Wales.

2.5 DISCUSSION

2.5.1 Population Estimates

This chapter presents the first quantitative assessment of the number of Starlings breeding in Britain. Although often considered a bird of pastoral farming, about half of the British breeding population is found in towns and villages. The BBS recorded a population estimate of some 8.5 million birds breeding in Britain in the late 1990s. It is difficult (and of uncertain value) to convert the number of birds given here into number of pairs because Starlings are, to some extent, polygynous, and many birds do not breed in their first year (Feare 1984; Chapter 5). Gates *et al.* (1993) estimated the number of Starling territories in Britain in 1990 at around 1.1 million, based largely on densities on 79 CBC plots. This is clearly an underestimate, since urban habitats, in particular, were poorly monitored. Assuming CBC plots monitor farmland and woodland only, they would census about one third of the total population (Table 2.4.1.1). Accounting for this would give a population estimate of around 3.3 million territories. The BBS counts all adult birds present in the square at the time of the survey and does not explicitly record the number of breeding territories as the CBC does. In a species in which polygyny is common each 'territory' will, on average, contain more than two adult birds. The 3.3 million territories estimated by Gates *et al.* (1993) thus, implies a total well in excess of 6.6 million birds, in line with the BBS estimate of 8.5 million birds which will also include any non-breeding birds present during the summer.

2.5.2 The Starling population decline

Populations of Starlings have declined in all three habitats for which monitoring data are available. The decline has been greatest in woodland, with the decline in garden habitats being similar to that on farmland, though in gardens it apparently started later.

The woodland CBC index has declined by over 90%. Starlings are obligate hole nesters, consequently woodland will be a prime nesting habitat but, although birds do forage in woodland, densities of soil invertebrates, their preferred prey, will be relatively low and most woodland nesting Starlings probably forage on adjacent farmland (Feare 1984). Hence, woodland habitat probably represents a sub-optimal habitat and the BBS indicates that densities in woodland average 7.9 birds km⁻², much lower than in farmland or garden habitats. Thus, as the breeding population as a whole has declined, woodland habitat has been vacated preferentially. Consistent with this, the decline in woodland habitat appears to have preceded that in farmland habitats. Although changes in woodland structure, or perhaps increased nest predation cannot be ruled out as contributory to the decline, it seems likely that the major cause of the decline in this habitat operates actually in farmland habitats.

It is possible that the later decline in urban gardens, compared to the wider countryside CBC index, could be a methodological artefact. Participants in the winter GBFS survey record the maximum number of birds seen at one time in their garden each week during the winter. As individual Starlings can range over a wide area in winter, local declines may be obscured by a temporary influx of birds from neighbouring areas, since this larger count will be recorded. However, this seems unlikely to account for all the discrepancy. The GBFS records birds visiting gardens in winter and thus censuses breeding birds, their offspring of the year and winter immigrants, which originate from North Eastern Europe (Feare in press). In response to global climatic trends, and possibly the decline in population

Starling population trends

size, productivity of Starlings has generally increased over time, through a combination of larger broods and higher nest survival rates, at both the chick and egg stages (Baillie *et al.* 2001; see Chapter 6 for a detailed discussion of productivity trends). Although it is not known how, or if, the number of nesting attempts has changed, it is possible that the delayed decline in GBFS index compared to the CBC index could be caused, at least in part, by increased productivity offsetting a decline in breeding numbers.

A local study, in rural Oxfordshire, which represents a mixed farming landscape, shows the number of Starlings present during the winter has declined by more than 50% (Easterbrook 1999), which is similar to that documented by the GBFS. However, given the degree of mobility amongst individual birds (Feare *et al.* 1992; Feare in press) and the large, but unquantified, influx of birds from continental breeding populations during the winter months, it is likely that the GBFS indices, though long-term, provide relatively poor indicators of trends in British breeding populations.

The British wintering population of Starlings probably originates from countries abutting the Southern Baltic, arriving in Britain from the Low Countries during November (Feare, in press). Trends in breeding population are relatively poorly documented in these areas, but there is some evidence of declines since the early 1980s (Appendix 2.1), and these may exceed that seen in the British breeding population (Feare in press). It is unlikely that all individuals from these areas winter in Britain, a proportion will winter in the Low Countries and France and in recent years, global temperatures have increased, particularly since the mid 1980s (Hulme *et al.* 2002) and it is likely that the number of birds wintering in Britain has decreased, since conditions are likely to be more clement closer to their Northern breeding grounds. It is thus unclear how trends in the continental breeding populations will relate to those of wintering birds in Britain. Nevertheless, any marked reduction in numbers in breeding areas from which our winter migrants originate is likely to be reflected in a reduction in the numbers that winter in Britain (Feare 1994).

Some large starling winter roost sites were destroyed with the felling of trees and certain human structures, such as piers, in the storm that swept Southern England in October 1987, and there were some anecdotal reports of large numbers of individual birds killed. However, no real quantification of the number of birds involved was attempted, and many natural roost sites, such as reedbeds, would have been little affected. As many of these birds were winter immigrants, the effect on the British breeding population seems to have been slight and there was no sudden decrease in the CBC index for the following year.

The difference in population trends of Starlings between rural and urban gardens could suggest the existence of two discrete populations, though this seems unlikely given that the median distance moved by Starlings between winters is 23km (with a range of 0-600km, from 2,361 ringing recoveries (Feare in press)). It could also suggest that village habitats represent better wintering habitat, so birds use these preferentially. For example, villages may provide opportunities for small roosts close to daily foraging areas, birds will thus save commuting costs compared to those in larger, but more distant roosts (Clergau 1981). The number of birds using rural gardens tended to be greater during the 1980s, when winters as a whole tended to be colder (see Chapter 4), indicating the prevalence and importance of winter feeding of birds in gardens. At least some of the subsequent decline in numbers since 1985 will reflect the tendency towards less severe winters in the 1990s (Hulme *et al.* 2002).

There is a clear decline in Starling numbers on livestock farms, whether these are entirely pasture based, or mixed with arable components (Table 2.4.2.1). Starlings frequently associate with livestock, particularly around stock feeding areas, where they will feed on cereal grain (Feare 1984). Birds utilising these areas tend to remain faithful to a particular foraging site through the winter, whereas birds in arable areas tend to forage more widely (Feare in press). Whilst the number of cattle has declined, numbers of sheep and pigs have increased (DEFRA statistics). However, patterns of stock rearing are likely to have changed, with more raised indoors (particularly cattle), partly to reduce disease transmission by birds, and less use of fodder crops. This may have reduced the foraging

opportunities available to Starlings and it is interesting to note that a recent increase in on-farm growing of maize silage as cattle feed in South Western England has, reportedly, increased the numbers of Starlings wintering in these areas, though impacts on breeding numbers are unknown (C.J. Feare pers. comm.).

The main prey of Starlings are soil and ground-dwelling invertebrates, particularly leatherjackets (tipulid larvae) and earthworms, though they take a wide range of other taxa and some plant material, particularly in autumn (Kluyver 1933; Tinbergen 1981). There is little information published on population trends in tipulids and numbers are quite variable from year to year, making trends difficult to discern (Wilson *et al.* 1999). Biomass of soil invertebrates generally, and tipulids in particular, are highest in areas of permanent pasture, where soil disturbance is minimal (Paoletti 1999). Foraging birds are strongly associated with areas of pasture, particularly those with high densities of invertebrates (Whitehead *et al.* 1995; Feare 1994; Bruun 2002). The area of permanent pasture in Britain has decreased by two million hectares (5%) since 1965, which would have reduced the area of available foraging habitat. Also the use of insecticides on grassland, though low, is targeted partly at tipulids, which may have reduced foraging opportunities further (Vickery *et al.* 2001). However, the total area decline tells us relatively little; some knowledge of the spatial patterning of this change would be required to fully ascertain how important this loss of habitat is in driving the decline in the Starling population.

In summary, Starlings have decreased in both woodland and farmland habitats in the wider countryside. This is likely to reflect changes in the farming landscape, probably mediated through factors affecting survival, rather than productivity and may reflect changes in food resources. There is also some evidence for a decline in urban environments, though this must be interpreted cautiously as it is based on counts made during the winter period. At least some of the declines since 1985 are likely to be because of decreased usage of British gardens, because of less severe winter weather conditions, both in Britain and abroad. The BBS suggests that populations in urban/suburban habitats are currently declining less than those in the wider countryside. Research into the relative number and quality of nesting and foraging opportunities in urban/suburban habitats and the wider countryside and movements between them is required.

Appendix 2.1 Summary of population trends of Starlings breeding and wintering in different populations in Europe.

<i>Country</i>	Breeding Numbers	Winter Numbers	Source
Netherlands	Declining in woodland, increasing/stable in farmland, stable in natural habitats: declining overall (1984-1999).	Broadly stable (1980-1999).	1
Germany	Stable in all habitats (1989-1999), perhaps levelled off after a marked earlier decline (c. 1970 onwards) across N, NW & C Europe.		2
Belgium	Probably little change since early 1970s, general increase through the 20 th Century.		3
Finland	19 th Century to 1950s continuous increase and northward spread (4, 7). Slow, steady decline since 1981 (5). Decline started in late 60s/early 70s, slowed in 1980s, with some large local populations going extinct (4). Much regional variation in timing and rate of decline (4).	Decline since mid-1970s (perhaps mid-1960s). Winter counts fluctuate more than breeding ones.	4, 5, 7
Belgium	Decrease in 1983-93.		12
France	Southward spread of southern birds suggests population increase (6,7). Increase 1965-75, but apparent decline since 1980s (12).	Substantial falls in north west; millions of birds killed at roosts with "starlicide" since 1980. (3).	3, 6, 7
Italy	Southward expansion of range suggests population increase, but now stable.		7, 12
Spain	Southward expansion of species into Spain suggests population increase, but competition with Spotless Starling possible.	Substantial reductions in the east and south.	7, 8
Ireland	Small (2.3%) range contraction 1970 vs. 1990.		9
Russia	Finnish decline reflected here.		7
Estonia	Slight decline in 1960s, crashed 1997-81.		12
Poland	Marked increase from mid 19 th Century (12), Finnish decline reflected here (7).		7, 12
Iceland	Increasing slowly.		12
Sweden	Marked decrease since 1950 (10) similar decline to that in Finland.		7, 10, 11
Norway	Anecdotal reports suggest similar trend to that in Finland (11) Slight decrease in north (12).		11, 12
Britain (Range)	3.6% range contraction 1970 vs. 1990.		9

Starling population trends

References

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- 2 Schwarz & Flade 2000
- 3 Devillers *et al.* 1988
- 4 Solonen *et al.* 1991
- 5 Väisänen & Solonen 1996; Väisänen 1999a; Tiainen & Pakkala 2000
- 6 Feare *et al.* 1992
- 7 Hagemeyer & Blair 1997
- 8 Peris *et al.* 1992
- 9 Gibbons *et al.* 1993
- 10 Robertson & Berg 1992
- 11 Orell & Ojanen 1980
- 12 Snow & Perrins 1998

3 STATUS AND POPULATION TRENDS OF THE HOUSE SPARROW *Passer domesticus* IN GREAT BRITAIN

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3.1 CHAPTER SUMMARY

1. Populations of House Sparrow have declined throughout Europe over the last two to three decades, with particular concern being focused in urban areas.
2. In this chapter, we analyse data from extensive census schemes organised by the BTO to determine the population size of the House Sparrow in Britain, and the numbers occurring in different regions and habitats. We also assess long-term patterns of change, using generalised additive models, both in the wider countryside and in urban environments.
3. The national breeding population of House Sparrows was estimated at approximately 13 million individuals (95% confidence interval, 11.9-14.8 million), or about six million pairs. Most of these occur in South East England and densities are greatest in suburban and rural garden habitats.
4. Overall, populations in both suburban areas (in winter) and the wider countryside (in summer) have declined by over 50% since the mid 1970s. The population declined first in the wider countryside, where it has been declining since 1983, while the decline in garden habitats has mostly occurred since the mid 1980s. Declines have been steepest in the South and East of England and in arable habitats.
5. Changes in farming practices are likely to account for at least some of the decline in the wider countryside, probably related to changes in food resources, with a loss of grain in fields and better storage of harvested grain, though these changes are unquantified.
6. In urban areas, an early decline in the first half of the 20th century due to the loss of horse-drawn transport and generally cleaner streets, is likely to be continuing. There are differences in trends between different urban areas and other evidence suggests that population processes in the House Sparrow may be relatively fine-grained, occurring at a smaller scale than can be detected by national analyses.
7. Correlations between the number of breeding House Sparrows and social deprivation and the presence of roof insulation reported in Bristol should be further examined, by conducting similar censuses in other urban areas.

3.2 INTRODUCTION

The House Sparrow (*Passer domesticus*) is, to many people, amongst the most familiar of bird species. Frequently commensal with man and common in our villages, towns and cities, it has been viewed both as a pest (of agriculture and in the fouling of buildings) and as a desirable enhancement of the human environment, leading to its introduction in many parts of the world (Summers-Smith 1988).

More recently, there have been reports of House Sparrow declines throughout Europe (Summers-Smith 1999; Appendix 3.1), though anecdotal reports from different European cities suggest these have not been equally severe everywhere (McCarthy 2001). In Britain, particularly high profile declines have occurred in London (Sanderson 1996), though these seem to be mirrored in other parts of the country. Public concern is such that one national newspaper has even promised a prize of £5000 to anyone who can explain the decline in British House Sparrow population (McCarthy 2000).

In Britain, the control of wild bird numbers for economic, health or other reasons must be specifically licensed. However, the control of certain common “opportunistic” species is permitted under a general licence, for which specific approval for individual measures is not required. This licence is permitted under a derogation from the EC Wild Birds Directive (EC/1979/409), which requires that monitoring be undertaken to ensure that the conservation status of the species concerned is not affected. Of the nine species covered by the general licence and monitored by the BTO’s survey schemes, populations of only two, House Sparrow and Starling (*Sturnus vulgaris*) have undergone appreciable population declines over the last few decades (Wilson *et al.* 1998). National, historical census information on breeding populations are lacking for House Sparrow in urban habitats, limiting the certainty with which declines can be confirmed and measured. However, urban population changes can be viewed in the context of the changes across the wider countryside and several long-term and/or large-scale survey schemes run by the BTO provide information on the latter. These schemes provide opportunities to measure population changes and to describe them quantitatively, as well as to compare the fates of birds in different habitats or regions.

A number of hypotheses have been put forward to explain the decline of the House Sparrow. These include lack of food, particularly aphids, which adults feed to nestlings, possibly as a result of the increased use of unleaded fuel; increased predation from cats or Sparrowhawks; cleaner streets providing reduced foraging opportunities; and a reduced availability of nest sites, particularly under the eaves and in the roofs of houses. Many of these hypotheses cannot be tested using national census data sets. However, such data sets highlight regional and habitat differences which can provide some information on the likely relative importance of these different factors.

In this chapter, we present a comprehensive analysis of the changes in House Sparrow abundance since 1976, using historical data from the BTO’s Common Birds Census (CBC) and Garden Bird Feeding Survey (GBFS), together with the BTO/JNCC/RSPB Breeding Bird Survey (BBS). The CBC monitors populations in the wider countryside, being particularly representative of farmland in South East England (Fuller *et al.* 1985); its coverage of gardens, and human habitats in general, is poor. The CBC monitored numbers of House Sparrows between 1976 and 2000 and has since been replaced by the BBS, which commenced in 1994 and has a wider and more representative geographic and habitat coverage of Britain. The GBFS has, since 1970, monitored the number of birds feeding in gardens during the winter.

We use these data sources to examine the long-term population trends across the regions and habitats of Britain and to investigate the use of gardens over time. This is the first time that extensive data on abundance in gardens at a national scale have been analysed. These data also allow us to distinguish between suburban gardens and their rural counterparts. Whilst population trends in rural gardens might be expected to mirror those in the wider countryside, trends in suburban areas have been poorly documented, being only peripherally covered by the standard monitoring schemes (with the exception of the relatively recent BBS). In Britain, and elsewhere, the House Sparrow is extremely sedentary with most birds moving less than a few kilometres during their lifetime (Summers-Smith & Thomas *in press*). Thus, there is the potential for population trends to differ between rural and suburban situations. We also analyse the data regionally and with respect to particular habitat types and aim to address the following hypotheses:

- Do population trends differ between the gardens and the wider countryside?
- Have changes been greater in pastoral or arable farming areas?

- Have changes been greater in urban and suburban gardens compared to rural gardens, as might be expected if urban streets are cleaner or increased use of unleaded petrol was a determining factor?

Finally, we produce an estimate of the number of House Sparrows breeding in Britain, and quantify the number and density of birds breeding in each region and habitat. This will enable us to determine which populations are the greatest contributor to the national population trend and yield information on the relative quality of different areas as House Sparrow breeding habitat.

3.3 METHODS

3.3.1 Data Sources

3.3.1.1 Common Birds Census

Until the inception of the Breeding Bird Survey (below), the CBC was the mainstay of terrestrial bird monitoring in Britain, although House Sparrows were only counted from 1976 (Marchant *et al.* 1990). Between 1962 and 2000, between 200 and 300 plots were visited eight to 12 times each year and territories of all breeding species were mapped by volunteer observers. CBC plots were characterized as farmland, woodland or “special” (the latter consisting of areas dominated by nature reserves, lakes, coastal habitat, etc.), though very few House Sparrows were recorded on woodland and special plots. On average, House Sparrows were recorded on 76 plots each year. Some more detailed habitat information was also recorded for each CBC plot, along with location and altitude data. Cropping patterns on farmland CBC plots have been shown to be representative of those across Southern and Eastern Britain (Fuller *et al.* 1985). We use both the complete CBC plot sample and farmland plots alone to investigate long-term trends in breeding abundance.

3.3.1.2 Garden Bird Feeding Survey

Since 1970, the GBFS has provided annual information on the numbers of birds using artificial food and water sources during winter in a sample of rural and suburban gardens in Britain. Rural gardens are defined as being situated in an area consisting of more than 50% open country, while suburban gardens are surrounded mostly by other houses and gardens (this includes both suburban and urban gardens, which are often not clearly differentiated). Suburban gardens constitute around 60% of the sample. Volunteer observers record the maximum number (the “peak count”) of each species using garden bird feeding stations in their gardens in each week of the winter (26 weeks from October to March, inclusive). The sample of gardens has changed over time more than that of the CBC as observers have entered and left the scheme, but an average total annual coverage of around 190 sites with House Sparrows has been maintained over the course of the survey. Throughout the life of the GBFS, efforts have been made to ensure that gardens are broadly representative of a range of garden types (large, small, rural, suburban, etc.) with a consistent, national spatial distribution. If an observer leaves the scheme, another observer with a similar garden and feeding regime is sought as a replacement. The amount of food provided for garden birds has generally increased across Britain during the life of the scheme and this is likely to apply to the food provisioning in GBFS gardens too.

Annual indices of abundance in rural and suburban gardens and reports on long-term trends are produced regularly (e.g. Glue 2001), but GBFS data have generally been under-utilised in the monitoring of Britain’s birds. Changes in numbers on GBFS plots will reflect both changes in numbers of birds resident on the plots, but also winter movements, for example, in response to severe weather conditions. However, House Sparrows are extremely sedentary, particularly after initial natal dispersal, and rarely move more than one or two kilometres from their nesting colony (Summers-Smith 1988; Summers-Smith & Thomas in press). Thus, even though the GBFS is a winter survey, it is likely to provide a reasonable index of breeding numbers in a given locality.

3.3.1.3 Breeding Bird Survey

The BBS was introduced in 1994 as a long-term replacement for the CBC. It was designed to improve on the CBC by providing wider, randomised spatial coverage that is representative of bird populations and habitats across the country. The BBS is based on 1×1km square survey units across which two 1km transects are walked by volunteer observers twice between the beginning of April and the end of June each year; any birds seen or heard are recorded in distance bands on either side of the transects (Noble *et al.* 2001). Habitat is also recorded, the 2km length of recording transect is divided into ten 200m sections in each of which habitat is characterised in terms of habitat descriptions drawn from the standard BTO habitat coding system (Crick 1992), which identifies broad habitat type. The BBS protocol allows the estimation of densities in specific habitats through distance-sampling analysis (Bibby *et al.* 1992; Buckland *et al.* 1993; Thomas *et al.* 1998).

3.3.2 Statistical Models

The basic statistical framework employed is that of generalised linear and generalised additive modelling, each employing a log link function and a Poisson error distribution, as is appropriate for count data (ter Braak *et al.* 1994; Thomas 1996; Fewster *et al.* 2000). Generalised linear models (GLMs) allow the modelling of annual variation and simple linear and quadratic (etc.) trends, as well as analyses of the strength of relationships between abundance and various predictor variables, such as habitat characteristics. Generalised additive models (GAMs) allow the estimation of non-parametric smoothed trends, with a pre-defined level of smoothing defined by the degrees of freedom, providing the best description of a long-term trend without imposing constraints on its shape (unlike a linear, quadratic or other parametric function; Fewster *et al.* 2000).

3.3.2.1 CBC and GBFS

We fitted GLMs using the GENMOD procedure of SAS and compared models using likelihood-ratio tests (SAS Institute, Inc. 1996). Confidence intervals were derived from the analytically estimated standard errors produced by SAS. GAMs were fitted using the program GAIM (Hastie & Tibshirani 1990), models being fitted using ten degrees of freedom (recommended by Fewster *et al.* 2000) to produce smoothed trends and $T-1$ degrees of freedom, where T is the number of years in the analysis, to produce unsmoothed trends (Fewster *et al.* 2000), and confidence intervals were calculated by bootstrapping from a matrix of 199 replicates generated from re-runs of each model on new samples generated by re-sampling survey sites with replacement.

Both the GLM and GAM analyses of CBC data modelled number of birds counted as a function of a categorical plot effect and year, the latter being parameterised as either a categorical variable or as a continuous (parametric or non-parametric) predictor. Further predictor variables or interactions between these were introduced to make specific comparisons or to test hypotheses. GLM analyses of GBFS data used basic models of peak weekly count as a function of a categorical garden effect, a year effect and two continuous variables describing the cyclical pattern of counts through the winter. This cyclical pattern was modelled using a combination of sine and cosine functions (Fisher 1993). The latter were calculated as the sine and cosine of the week of the year (week number divided by 52: week sine effect = $\sin(2 \times \pi \times (\text{week}/52))$, cosine effect = $\cos(2 \times \pi \times (\text{week}/52))$). In order to account for the much repeated counts made on for GBFS plots (each year had up to 26 weekly counts), we included an auto-correlated covariance matrix within the GLM specification. In this, within each site and each year, weekly counts (Y_i) were correlated in an autoregressive manner, such that $\text{corr}(Y_i, Y_{i+1}) = \alpha^1$, where α is constant across site-year combinations. This was necessary to take into account the fact that counts from adjacent weeks were likely to be more similar than those separated by greater time intervals.

The software available to fit GAMs did not allow the fitting of complex models to be combined with bootstrapping to estimate confidence intervals, so we simplified the GBFS data before producing smoothed trends. Analyses of the weekly patterns of variation in abundance over the entire GBFS survey period showed that peak abundance occurred between weeks 7 (mid November) and 17 (late

January) inclusive, where week one is the first week in October each year. Consequently, we averaged the weekly peak counts over this period to produce a single estimate of numbers in each garden in each year. These averaged counts were then entered into GAMs with a categorical garden effect and a year effect as predictors (Fewster *et al.* 2000).

To identify significant turning points in the smoothed CBC and GBFS trends, we employed the methods of Siriwardena *et al.* (1998a) and Fewster *et al.* (2000), slightly adapted to consider changes in population growth rate rather than in abundance. Thus, we estimated the second derivatives (rates-of-change of the rate-of-change) of the population trends in each year (on the log scale), together with their 95% confidence intervals, using the smoothed GAM trends and the matrix of 199 bootstrapped replicates of these trends. Years where the 95% confidence interval of the second derivative did not overlap zero could be considered to be years in which there was significant curvature in the original trend being analysed (Siriwardena *et al.* 1998a; Fewster *et al.* 2000). These turning points then provided both an intrinsically useful tool for describing trends and an objective means of dividing the population index time series into units with homogenous trends (e.g. Siriwardena *et al.* 1998b; 2000c).

Smoothed CBC trends were produced for five regions of Britain and for each of arable-dominated, grass-dominated and mixed CBC plots. The five regions were based on those used by Chamberlain *et al.* (1999) to compare intensive arable farming (in Eastern England) with other agricultural types and were defined as follows:

East -	Hertfordshire, Bedfordshire, Northamptonshire, Nottinghamshire, Humberside and eastwards,
North -	Merseyside, Manchester, South Yorkshire and areas to the North,
West -	Gloucestershire, Warwickshire, Leicestershire, Derbyshire, Cheshire and areas to the west,
South West -	Avon, Wiltshire, Dorset and areas to the west,
South East -	London, Buckinghamshire, Oxfordshire, Berkshire, Hampshire and areas to the South and East.

Other tests took the form, as appropriate, either of comparisons between linear year effect terms for different plot classifications or with respect to a continuous modifier of trend slope. We compared CBC and GBFS trends using annual plot and garden specific counts (i.e. the simplified garden data also used to fit GAMs), testing whether simplified, underlying long-term trends (either linear or quadratic) differed between the two schemes, by using log-likelihood ratio tests as before, to test whether a year \times scheme interaction term significantly reduced the residual deviance.

3.3.2.2 BBS

BBS data were used to assess densities of House Sparrows with respect to habitat and region, using a distance-sampling approach (Bibby & Buckland 1987; Buckland *et al.* 1993; Thomas *et al.* 1998). This method incorporates modelling of how the probability of detection of a bird falls as distance from the transect line increases and allows these detection functions to be calculated on a habitat-specific basis (detectability is likely to vary between habitats due to differences in visibility and the efficiency of sound transmission). We calculated habitat-specific densities using the methods of Gregory & Baillie (1998), with the refinement that abundance-habitat relationships were assumed to be uniform only within each of the ten regions in Britain rather than across the whole country. In addition, that the random geographical coverage of the BBS (stratified by observer density: Gregory & Baillie 1997) allowed us to use BBS habitat records to estimate the area covered by each habitat category in each region and thus to produce estimates of regional and national population sizes by combining the area of each habitat in a region with region- and habitat-specific densities.

Following Gregory & Baillie (1998), we estimated House Sparrow densities from BBS data for each of 15 habitat categories: deciduous woodland, coniferous woodland, mixed woodland, scrub, semi-

natural grassland, heath, improved grassland, unimproved grassland, mixed farming, arable farming, urban human sites, suburban human sites, rural human sites, areas adjacent to water bodies and miscellaneous areas. In a separate analysis, we also divided the data into the ten British geographical regions used by the European Community for statistical purposes. We conducted these analyses for each year for which BBS data were available, i.e. 1994-2000, calculating 95% confidence intervals for the region- and habitat-specific densities using a bootstrapping procedure in which survey squares were re-sampled, with replacement, 400 times (after Gregory & Baillie 1998). This enabled us to examine the variation in population trends among the regions and habitats occupied by House Sparrows to identify any population strongholds and problem areas for conservation. Finally we undertook a brief analysis to investigate how densities varied in different habitats along a gradient from South East to North West using Spearman's Rank Correlation. The regions were ranked as follows: Scotland, 1, Northern England, 2, North East, North West England and Wales, 3, Central East, Central West and South West England, 4, and East Anglia and South East England, 5.

3.4 RESULTS

3.4.1 How many House Sparrows are there?

BBS data suggest that there are approximately 13,220,000 House Sparrows present during the breeding season (averaged over the period 1994-2000, with 95% confidence limits of 11,950,000 and 14,850,000), however, these were not distributed evenly throughout the country (Table 3.4.1.1). Most of these occur in just two broad habitats, farmland and human associated habitats. Nearly two-thirds of the population is associated with human habitats; consequently the South and East of England holds over half of the population.

Bird density is greatest in suburban and rural habitats (Table 3.4.1.2), being an order of magnitude lower in farmland habitats. The importance of farmland habitat in terms of population numbers arises from the large area (75% total land area) covered by this habitat. The density of birds in pastoral habitats (both improved and unimproved pasture) varied geographically, being lower in the North and West of the country than in the South and East ($r_s = 0.87$, $n=10$, $P = 0.001$). Densities in arable farmland ($r_s = 0.26$) and garden habitats ($r_s = 0.03$) did not show consistent regional variation.

Table 3.4.1.1 Population estimates by region and habitat for House Sparrow as measured from BBS. For each habitat and region combination, the first column gives the percentage of the British population supported and the second column gives the mean annual percentage change during the period 1994-2000, changes in bold are significant at $P < 0.05$. Population change was not calculated for 'other' habitats, which represented a heterogeneous range of wood, scrub, heath and coastal habitats. For the final line, habitats were ranked within each region according to the severity of decline (one being most severe) and these rankings averaged across the regions.

	Unimp. Grass ¹		Imp. Grass ²		Arable		Rural Human		Suburban		Urban		Other		All Habitats	
Scotland	1.91	+18.2	0.38	+15.4	1.71	+10.6	1.73	+17.0	4.56	+1.5	0.86	-12.8	1.93	-	13.08	+27
Northern England	1.60	-35.4	0.13	+1.1	0.42	-24.6	0.28	0.0	2.32	-34.5	0.94	+39.9	0.44	-	6.14	-4.4
North East England	0.68	-4.3	0.35	-0.6	0.72	-1.1	1.36	+9.5	2.79	+6.6	1.02	-8.8	0.45	-	7.38	-22.5
North West England	0.98	-6.9	0.23	-2.2	0.13	+22.3	0.78	+2.1	2.53	-3.9	0.52	-6.6	0.40	-	5.56	-14.6
Wales	2.34	+3.8	0.72	+7.3	0.09	-4.8	0.49	+12.7	1.83	+24.8	0.96	+37.5	0.60	-	7.04	+64
Central West England	1.63	-19.1	0.42	+3.0	0.67	-2.1	0.99	+0.6	3.00	-7.6	1.84	-20.1	0.75	-	9.30	+1.76
South West England	2.57	+13.2	0.61	-1.9	0.67	-4.8	2.01	-0.1	2.73	-7.5	2.48	+4.5	1.05	-	12.12	-6.5
Central East England	0.58	-3.0	0.37	+3.9	1.52	-4.2	1.49	0.5	3.70	0.0	1.34	-5.3	0.88	-	9.89	+37
East Anglia	0.23	-12.7	0.20	-8.0	1.43	-4.1	0.15	-4.6	0.68	-10.2	1.97	-0.1	0.68	-	5.34	-14.1
South East England	1.60	-4.1	0.58	-1.6	2.19	-6.0	4.51	+1.3	10.50	-8.8	2.73	-11.6	2.05	-	24.15	-31.2
All Regions	14.13	-4.1	3.99	+3.1	9.55	-2.6	13.80	+2.8	34.65	-3.3	14.66	-5.6	9.23	-	100	-5.5
Mean Rank of Decline		2.8		4.3		3.1		4.8		3.0		3.0				

¹ Unimproved Grassland; ² Improved Grassland

Table 3.4.1.2 Density estimates by region and habitat for House Sparrow as measured from BBS. For each habitat and region estimates of density (km^{-2}) ± 1 standard error are given, for the years 1994-2000.

	Unimproved Grass	Improved Grass	Arable	Rural Human	Suburban	Urban
Scotland	22.5 \pm 3.1	11.8 \pm 11.1	24.5 \pm 2.2	232.4 \pm 228.9	364.6 \pm 31.0	91.8 \pm 27.2
Northern England	45.0 \pm 3.1	7.6 \pm 6.3	27.1 \pm 1.9	478.0 \pm 17.8	522.3 \pm 12.9	358.8 \pm 11.2
North East England	36.8 \pm 7.3	25.9 \pm 14.4	25.6 \pm 1.3	298.8 \pm 22.3	349.1 \pm 24.3	237.3 \pm 11.5
North West England	53.7 \pm 2.2	45.1 \pm 2.9	20.0 \pm 1.2	194.8 \pm 28.0	264.4 \pm 14.0	163.1 \pm 25.3
Wales	35.0 \pm 2.6	40.9 \pm 1.3	19.7 \pm 3.5	148.6 \pm 10.4	304.5 \pm 39.1	188.5 \pm 23.7
Central West England	59.6 \pm 2.8	48.2 \pm 3.6	31.0 \pm 2.9	416.7 \pm 10.9	310.0 \pm 11.2	290.8 \pm 16.8
South West England	41.5 \pm 1.6	38.6 \pm 2.5	18.6 \pm 1.8	313.1 \pm 24.1	327.0 \pm 26.4	233.4 \pm 10.1
Central East England	32.1 \pm 1.7	71.4 \pm 2.6	28.7 \pm 1.9	348.9 \pm 38.8	444.0 \pm 19.8	238.4 \pm 4.6
East Anglia	58.9 \pm 1.4	90.6 \pm 4.4	23.0 \pm 1.5	256.3 \pm 19.4	309.2 \pm 16.4	278.4 \pm 8.7
South East England	53.7 \pm 2.9	46.3 \pm 5.5	34.1 \pm 3.1	378.6 \pm 35.1	338.7 \pm 17.5	180.2 \pm 18.0

3.4.2 Long-term Trends

Over the last thirty years, the House Sparrow population has declined markedly. In garden habitats in winter, the sparrow population in Britain has declined by some 58% since 1970 (Figure 3.4.2.1, all figures of population change from GAM trends). The population was largely stable until 1983, with a more or less continuous decline since then; the turning point in 1995 is only marginally significant. This overall pattern of a period of population stability in the 1970s and early 1980s with a subsequent continuous decline (since 1983 in both cases) is evident in both rural and urban gardens. However, populations in rural gardens have declined to a lesser extent (48%) than those in suburban gardens (60%).

Populations in the wider countryside, which are indexed by the CBC, have also declined, by 53% since 1976 (Figure 3.4.2.2). The main period of decline (38% in the period 1979-83), however, is prior to that observed in gardens and the population now appears to be stable (albeit at a lower level), having shown little change since 1994. The decline on farmland plots (46%) was slightly less than that on all plots, though the decline appeared to have begun at an earlier stage (1976 or earlier) in farmland areas, so the total extent of this decline may have been underestimated.

The general pattern of a decline followed by a period of stability since the mid 1990s has not been reflected regionally across the country, with different regions varying in the extent of the decline observed (Figure 3.4.2.3). The steepest declines were observed in the East and South East of England. Populations in Wales and the Midlands also declined significantly, but those in Northern Britain and South Western England showed no overall change. In each of the three regions that showed significant population declines, the general pattern of most of the decline occurring the late 1970s and/or early 1980s held (Table 3.4.2.1). The wide confidence limits on the increase in Eastern England from 1975-79 suggest that it may be more apparent than real and should be interpreted with caution.

Table 3.4.2.1 Results of tests for linear declines in House Sparrow numbers on CBC plots with respect to different habitat and spatial divisions. Significance of trends was tested using Likelihood ratio tests (LRTs) and the parameter estimates (± 1 standard error) for the appropriate terms, on the log scale, are given, together with a brief interpretation of the results.

Habitat/spatial split	LRT: χ^2 , d.f., <i>P</i>	Parameter	Estimate	Interpretation
None (n = 246)	283.9, 1, <0.001	Year	-0.048 (0.003)	Significant linear decline over time
Farm type (n = 28, 69, 48)	56.5, 2, <0.001	Arable	-0.122 (0.012)	Decline steepest in arable areas, least in pastoral
		Mixed	-0.036 (0.005)	
		Grazing	-0.018 (0.006)	
Region (n=79, 40, 24, 34, 57)	192.3, 4, <0.001	South East	-0.054 (0.004)	Steepest declines in the East, and South East and West. Declines in South west and North not significant
		East	-0.128 (0.008)	
		South West	-0.004 (0.010)	
		West	-0.027 (0.009)	
		North	0.007 (0.008)	
Buildings (n = 129, 16)	62.2, 1, <0.001	Buildings	-0.034 (0.004)	Steeper declines on farmland plots without buildings
		No buildings	-0.275 (0.035)	
Geographic Location (n = 238)	123.4, 2, <0.001	Year \times latitude	0.002 (0.021)	Declines steepest in East, but no difference between North and South
		Year \times longitude	-0.275 (0.027)	
Altitude (n = 246)	51.8, 1, <0.001	Year \times altitude	0.0003 (0.0001)	Declines tend to be steeper at lower altitudes

House Sparrow population trends

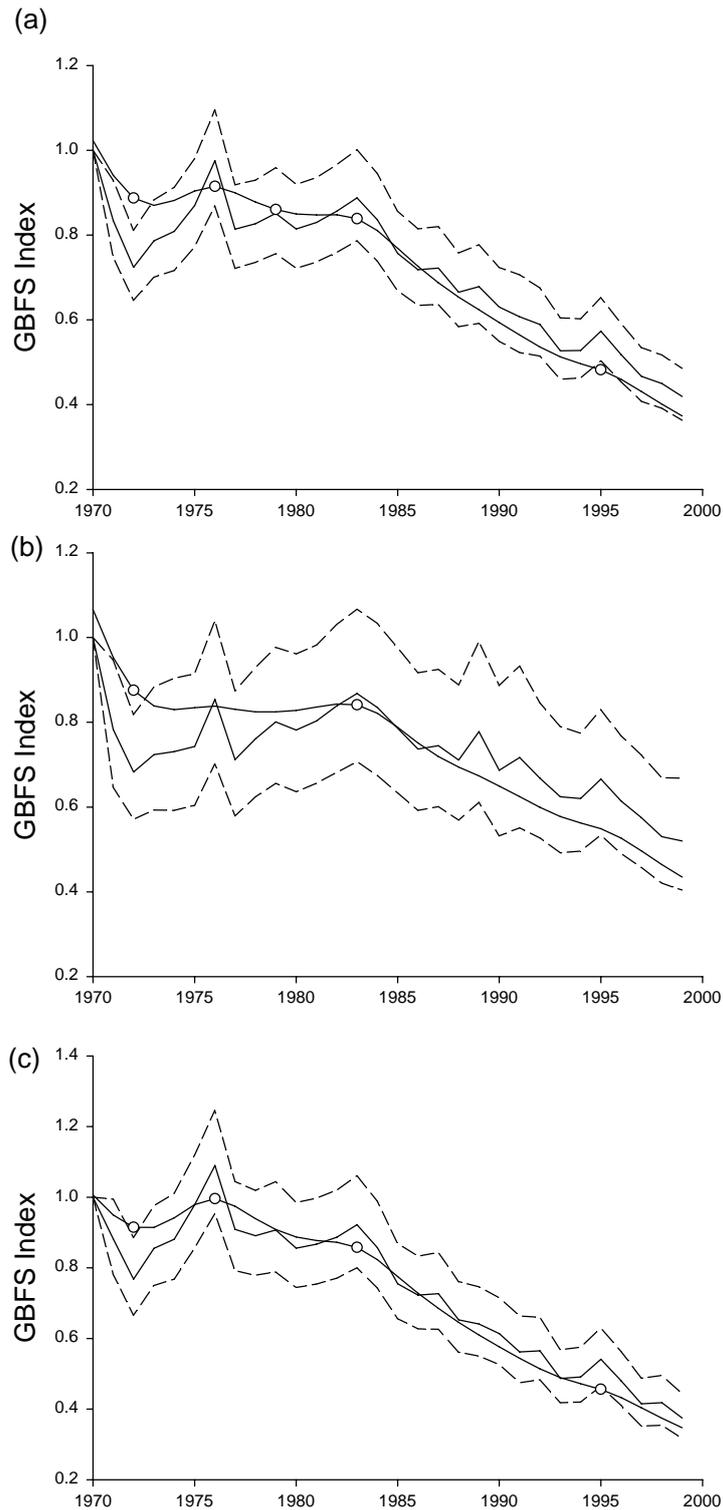


Figure 3.4.2.1 Temporal trends in use of gardens by House Sparrows from the GBFS. (a) All plots, (b) Rural plots only, (c) Suburban/Urban plots only. The annual index of abundance for each year (October to March) is given (dashed lines represent 95% confidence limits) as is the smoothed (10df GAM, see text) trend. Circles on the GAM trend indicate significant turning points in the smoothed trend ($P < 0.05$).

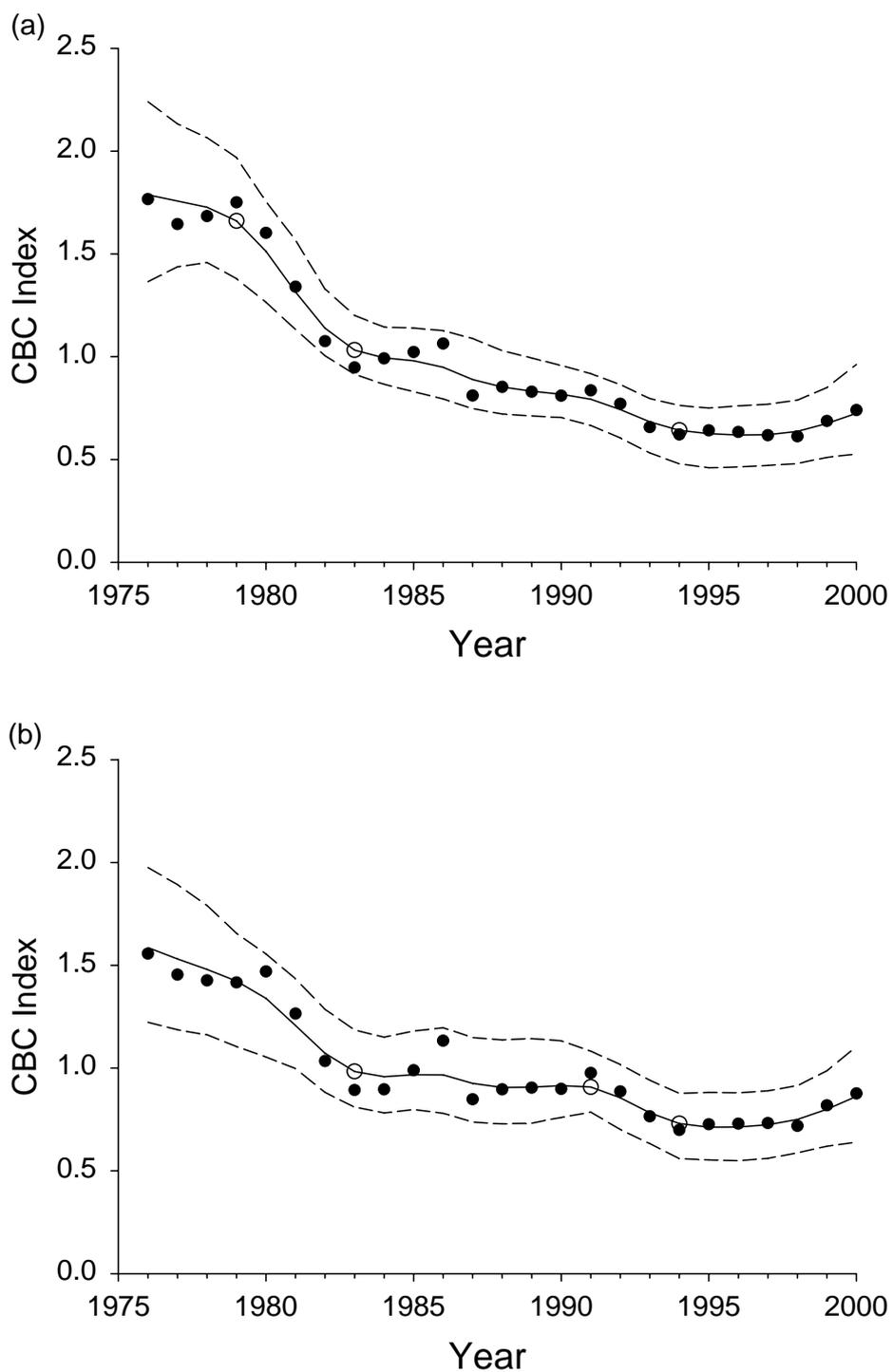


Figure 3.4.2.2 Population index of House Sparrow in Britain. Data from CBC for (a) all plots, (b) farmland plots only. Solid line represents a smoothed GAM trend and the dashed line 95% confidence limits (see text for details). Filled circles represent annual indices (i.e. no smoothing) and open circles significant ($P < 0.05$) turning points in the GAM trend.

House Sparrow population trends

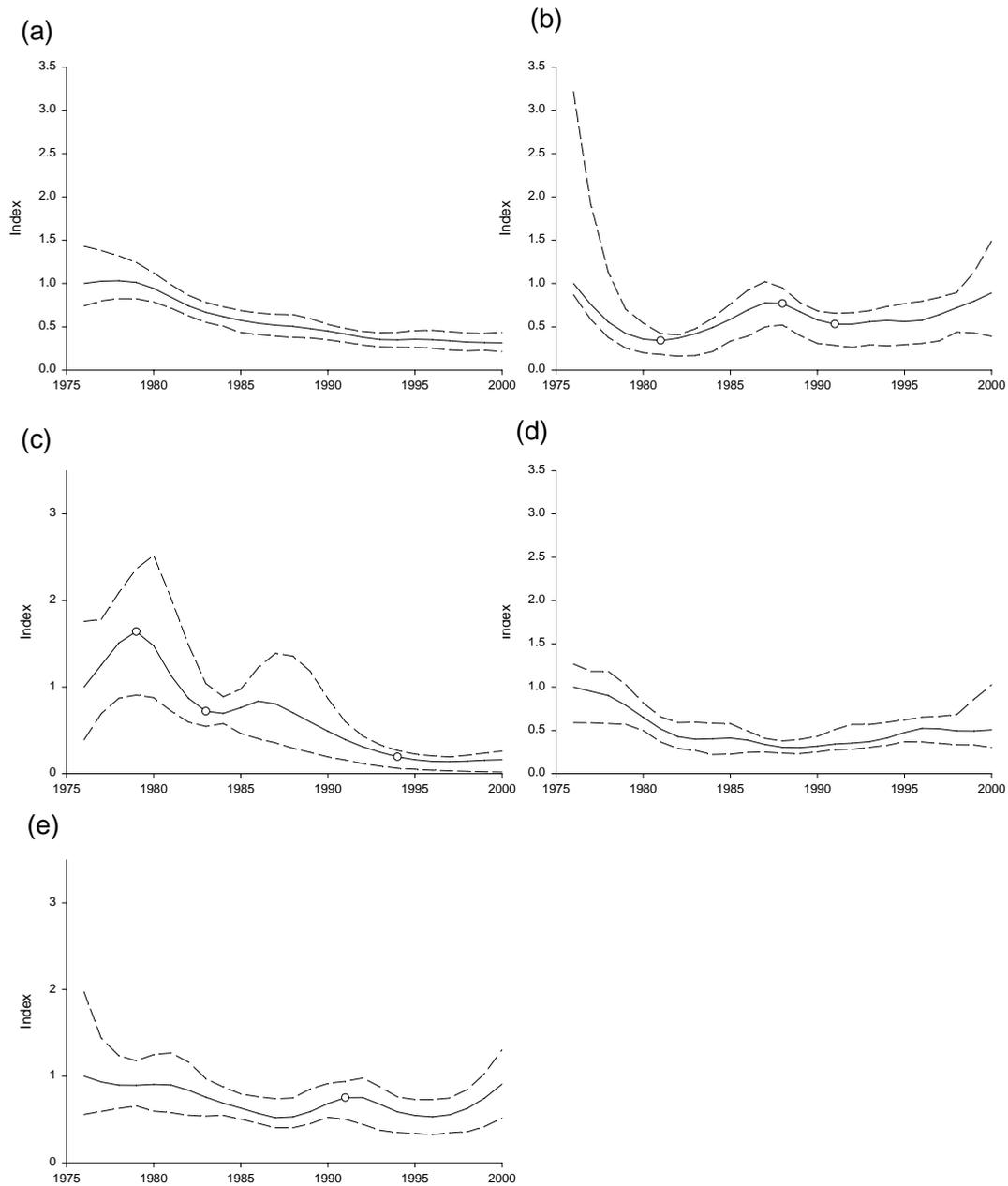


Figure 3.4.2.3 Regional population indices for House Sparrow as measured from CBC. Details as Figure 3.4.2.2. (a) South East England, (b) South West England, (c) Eastern England, (d) Wales and Western England (e) Northern Britain (see text for details).

3.4.3 Correlates of population change

The magnitude of the decline in House Sparrow numbers varied between different types of farm. The mean annual rate of decline was far steeper on arable farms than either mixed or livestock farms (Table 3.4.2.1). Declines were also steeper on CBC plots with no buildings, i.e. those that are relatively remote from human habitation. The steeper declines observed in Eastern areas and at lower latitudes are likely to be confounded with farming type, and reflect the fact that farms in these areas are more likely to be arable.

Overall, House Sparrow breeding populations in the wider countryside, as indexed by CBC, and winter gardens, indexed by GBFS, have declined at a similar rate (comparing linear trends), irrespective of whether the all-plots indices or just those from farmland and rural plots, which are likely to represent similar areas, are considered (Table 3.4.3.1). However, a comparison of quadratic trends shows that the timing of the declines in the two indices differ significantly; essentially, farmland populations declined but have recently been more stable, whereas the garden index was initially stable, but has since declined (Figure 3.4.3.1).

The current status of populations in different habitats can be assessed by looking at the trends in numbers on BBS plots over the period of the survey (Table 3.4.1.1). Although non-significant over the short period of the BBS, the decline in arable areas appears to be continuing, with declining numbers in all but two regions. Populations in urban/suburban habitats are also declining, particularly in South Eastern England, where the population is largest. In contrast, populations appear to be increasing in Scotland, particularly in more intensively farmed areas (improved grass and arable), and Wales, where urban and suburban populations are increasing. Populations in rural areas (i.e. with a mix of countryside, mostly farmland, and human habitation) seem to be declining least, with small (and non-significant) declines in only two regions, whereas numbers in urban and suburban areas are declining relatively rapidly).

Table 3.4.3.1 Comparison of CBC and GBFS data sets for temporal trends in the House Sparrow numbers 1976-1999. Year was specified either by an annual term (class variable with 23 levels) or by quadratic (2 parameter continuous) or linear (1 parameter continuous) trends. Significance was tested using log-likelihood ratios (see text).

CBC plots	GBFS gardens	Model	χ^2	d.f.	P
All Plots	All gardens	Annual	134.6	23	<0.001
		Quadratic	54.2	2	<0.001
		Linear	3.09	1	0.079
Farmland	Rural	Annual	290.9	23	<0.001
		Quadratic	28.3	2	<0.001
		Linear	0.00	1	N.S.

House Sparrow population trends

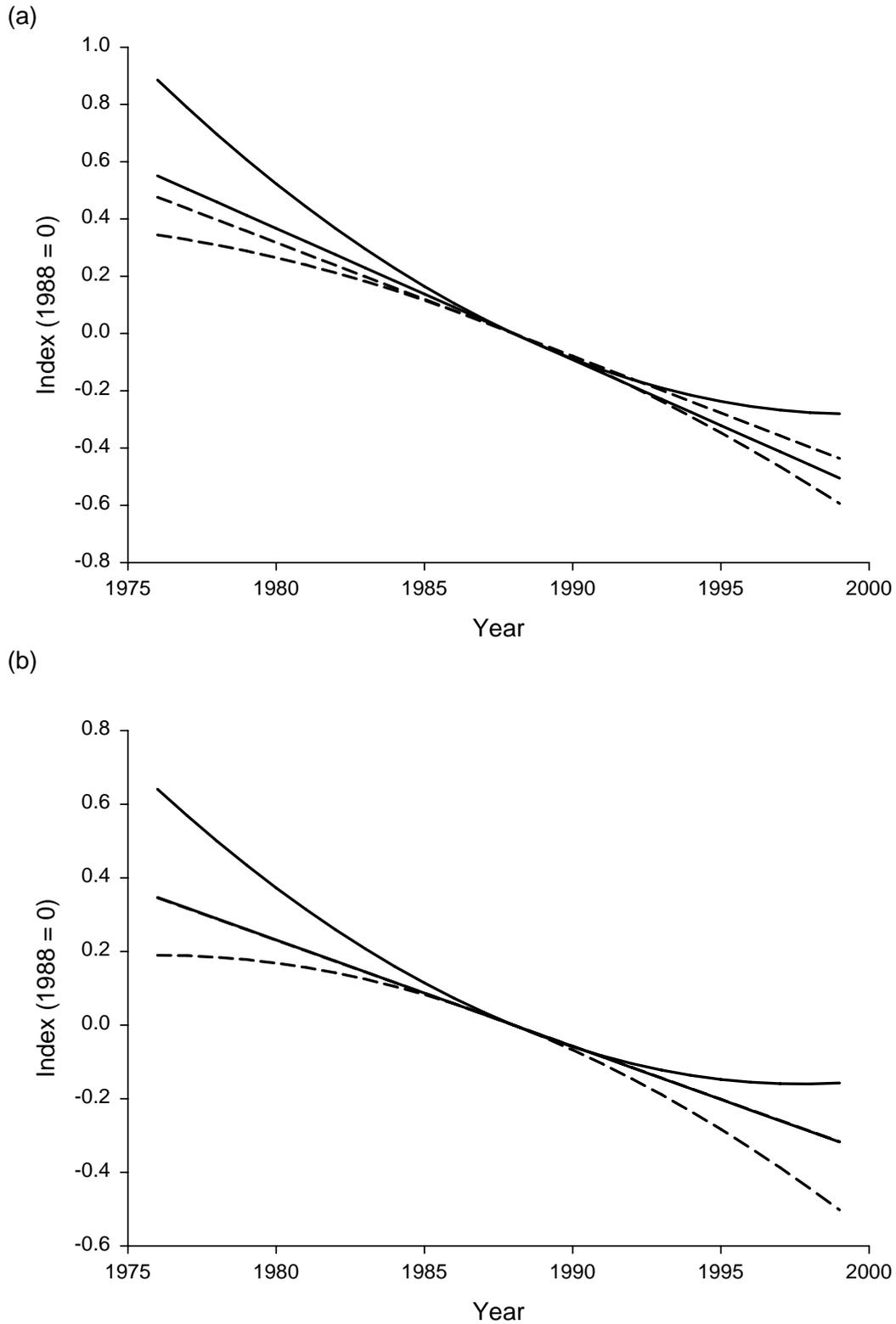


Figure 3.4.3.1 Comparison of linear and quadratic trends in time for CBC (solid lines) and GBFS (broken lines) for the period 1976-1999. Comparison for (a) all CBC plots and all GBFS gardens and, (b) farmland CBC plots and rural gardens only.

3.5 DISCUSSION

The data presented here quantify, for the first time, the number of House Sparrows breeding in Britain. Around two-thirds of the population is associated with human habitats, with densities in the wider countryside being an order of magnitude lower. Populations have, however, declined by almost 60% since the early 1970s. These declines occurred initially in the wider countryside, but have since been followed by declines in gardens.

3.5.1 Population Estimates

Sparrows form relatively stable pair bonds, though extra-pair copulations are frequent and there may be a small surplus of non-breeding birds (Summers-Smith 1988). Consequently, given our estimate of approximately 13 million birds, this suggests that there are currently in the region of six million pairs of House Sparrows breeding in Britain. This is somewhat higher than previous estimates. Gates *et al.* (1993) estimated the population in the early 1990s, based on densities on 41 CBC plots, to be around 720,000 pairs. This is clearly an under-estimate, as it will not accurately reflect the much greater density in urban areas and Table 3.4.1.3 suggests that densities measured on CBC plots (which are concentrated in South East and Central England) are not representative of Britain as a whole. BBS data suggest that the wider countryside accounts for only about one-third of the total population (Table 3.4.1.1), although taking this into account yields a population estimate of only 2.2 million pairs. Summers-Smith (1999), based largely on a presumed decline from previous local surveys (Summers-Smith 1959), estimated the population in the late 1990s to be in the order of 3.6 million pairs. House Sparrows, being a colonial breeding species with a highly aggregated distribution, are difficult to census accurately. However, because of its rigorous methodology, the BBS estimate of 13 million birds must be considered the most statistically robust estimate of sparrow population size and it suggests there were previously in excess of 25 million House Sparrows living in Britain.

As House Sparrows breed colonially, calculating population size by extrapolating from estimates of density in particular locations may not be straightforward. Thus, the habitat specific densities calculated from BBS data are somewhat lower than those reported previously. For example, Summers-Smith (1988) quotes densities in suburban areas of 611km^{-2} (averaged over 19 studies) and in rural areas of 724km^{-2} (21 studies), while densities in excess of 3000km^{-2} have been reported (e.g. Heij & Moeliker 1990). Part of this difference may stem from the large population decline. Extrapolating from the declines observed on GBFS plots, population densities in suburban/urban and rural gardens in the early 1970s may have been approximately 1000km^{-2} and 400km^{-2} respectively. However, comparisons with local studies should be made with caution, as the survey effort is likely to be concentrated in areas where House Sparrows are breeding, resulting in potentially inflated estimates of density over larger scales (Summers-Smith 1999), whereas BBS transect sections will often include a broader range of habitats, some of which will be less suitable for House Sparrows.

3.5.2 Decline of the House Sparrow

In the 19th century, House Sparrows spread into Northern and Western Britain as these areas became more urbanized (Holloway 1996). However, there seems to have been a long-term decline since the end of the First World War, as evidenced by the long-term decline in numbers in London's Kensington Park (Sanderson 1996; Moss 2001). This exceptionally long-term study, initiated by Max Nicholson, found that numbers steadily decreased from a peak of 2,603 birds in 1925 to 885 in 1948, 544 in 1975 and just eight in 2000. The early phase of the decline is likely to be linked to the gradual replacement of horse-drawn transport by automobiles (e.g. Bergtold 1921). This reduction in the number of animals would have reduced the amount of food resource (spilt grain, as both feed and dung) available to House Sparrows. More recently, Easterbrook (1999) also recorded a more or less continuous decline in winter abundance during the period 1975-1999 in the largely mixed farming landscape of Oxfordshire. Declines in House Sparrow numbers have also been reported in other

studies, both in Britain and elsewhere in Europe, particularly in the late 1980s and early 1990s (Appendix 3.1; Summers-Smith 1994).

Our analyses show that declines in farmland populations were already occurring in the mid 1970s, when CBC monitoring of House Sparrows began, and that populations in other habitats, such as woodland or scrub, declined markedly in the late 1970s and early 1980s. In contrast, populations in towns (and to a lesser extent rural habitations) started to decline only in the mid-1980s. This suggests that one of two mechanisms might be responsible for the declines. Firstly, the two populations are largely discrete and different factors may have caused population declines at different times in each population index. Alternatively, populations indexed by the GBFS form a source population, the excess dispersing into farmland and other habitats, possibly, but not necessarily, in some form of metapopulation structure (Hanski & Gilpin 1991; Altwegg *et al.* 2000).

Consistent with the idea that farmland and garden populations are linked, Heij & Moeliker (1990) found that, in the Netherlands, the density of sparrows in suburban areas was almost twice that in rural areas. Birds in rural areas (particularly juveniles) foraged over a much larger area than their suburban counterparts and consequently had a higher mortality (road traffic mortality formed a significant component). They argued that rural populations were supported by immigration from suburban areas. From this, we might predict that the BBS should show populations in suburban areas to be declining less than those in farmland or rural gardens; in fact, this is only true for three of the ten regions for farmland and only Wales for rural gardens suggesting populations in Britain are not linked, at least at this scale (Table 3.4.1.1).

In Britain, House Sparrows are extremely sedentary and generally do not move from the colony in which they make their first breeding attempt (Summers-Smith & Thomas in press). Juveniles, however, do disperse from their natal colony and most long-distance recoveries of birds ringed in Britain & Ireland (about 3% are over 20km) are likely to involve such birds. As Humphries & Ruxton (2002) show, relatively small individual movements can maintain populations over much larger ranges, because of this, and introduced populations of House Sparrows can expand their range at rates of 15-80km yr⁻¹. Garden populations could, in theory, maintain at least some farmland ones, but it is unclear to what extent this actually happens.

Populations of many farmland birds in Britain and, indeed, North West Europe, have declined over approximately the same period as the House Sparrow, with the greatest changes occurring between 1977 and 1982 (Fuller *et al.* 1995; Siriwardena *et al.* 1998a; Chamberlain *et al.* 2000). These changes are related to the increasing intensification of agriculture over the same period and, at least partly, can be attributed to a decrease in resource availability, primarily weed seeds and cereal grain (Chamberlain *et al.* 2000; Robinson & Sutherland 2002). This has occurred through a loss of seed-rich habitat and also a decline in the number of seeds available, both because there are fewer weeds and because harvesting is much more efficient than previously. Cereal, and other crop, seeds are increasingly sown with seed-dressings, which is likely to decrease the palatability of the seed to birds (Green 1980). Improvements in grain storage post-harvest in response to stricter hygiene laws represents another lost foraging opportunity. With the decrease in spring sowing of cereals, the availability of sown cereal has become concentrated in the autumn, reducing food resources throughout the winter.

Reductions in the amount of grain in fields may account for the greater declines on CBC plots with no buildings, which will be relatively remote from human habitation. Spilt grain may be relatively concentrated around farm buildings mitigating the effects of declines of grain in harvested fields. However, given the relative magnitude of the populations and the timing of their declines, it is extremely unlikely that changes in the farmed landscape have contributed significantly to the declines in urban areas.

A number of hypotheses have been put forward to explain the declines in suburban and urban House Sparrow populations (Summers-Smith 1999; Moss 2001). Much has been made of declines in some

inner cities, such as London (Sanderson 1996) and Edinburgh (Dott & Brown 2000). It is notable that urban/suburban populations in Wales are increasing significantly, whereas those in the South East and West Midlands are decreasing significantly (Table 3.4.1.1). Prowse (2000) notes that there is apparently no trend in numbers in urban Manchester, but that there are declines in London, Edinburgh and Dublin. As indicated by the Kensington Park survey (Sanderson 1996), populations in London seem to have declined more (59%) than those in the rest of South East England (21%), mirroring the difference in winter population between urban and rural garden populations found in the GBFS data.

Urban streets may be cleaner than previously, extending a trend begun in the pre-war period (see above) and brown field sites are likely to be fewer as city development plans infill, rather than expanding out into the greenbelt. Although birds in 'natural' habitats forage largely on seeds, those in urban populations have a catholic diet taking a wide range of household scraps (Snow & Perrins 1998). Dröscher (1992) reported that the House Sparrow had become a rarity in West Berlin, but remained relatively common in East Berlin, which might reflect a general lack of development under the former communist regime. East Berlin has since undergone massive redevelopment so it would be interesting to discover if these differences still exist. A survey of House Sparrow numbers in Bristol (as part of Bristol City Council's Local Agenda 21 biodiversity initiative, J. Tully & R. Bland *in litt.*) in the winter of 2000/01 showed a strong correlation between House Sparrows and the degree of social deprivation between city electoral wards ($r = 0.61$, $n = 35$, $P < 0.001$). House Sparrows were largely absent from the wealthy suburbs and most abundant in the post-war overspill housing estates. Similarly, a survey of Norwich in the autumn/winter of 2000 (Paston 2001) found the greatest number of House Sparrows in estates of council provided housing.

Over the lifetime of the GBFS there has been a marked increase in both the prevalence of garden bird feeding and in the quantity and range of foodstuffs provided (Cannon 2000). However, numbers of House Sparrows using gardens did not increase in response to this, even in the pre-decline period. It is possible that a greater decline would have been seen had these extra resources not been available. It is unlikely that disease transmission between House Sparrows has increased, since the incidence of large flocks foraging in gardens has decreased (see Chapter 4). The incidence of cross-species disease transmission, however, may have become more frequent as the total number of birds of all species concentrated on garden bird feeders has increased (Hartup 2001). Thus, it seems likely that over-winter survival may be the limiting factor on population numbers, at least in urban areas.

In response to the impact of leaded petrol on air quality in built-up areas, there has been a significant increase the use of lead-free petrol (Barnaby 1983; Achten *et al.* 2001). However, this fuel contains volatile organic compounds as lead substitutes, particularly benzene and methyl, tert-butyl ether (MTBE). It has been hypothesized that MTBE, or one of its by-products, might affect the number of aphids which House Sparrows feed to their chicks in the first few days after hatching (Mitschke *et al.* 2000; Moss 2001). The increased use of unleaded petrol is thought to have coincided with the major period of decline in House Sparrow populations. While urban populations of House Sparrow in South East England (primarily London) do seem to be declining more rapidly than suburban or rural populations (Table 3.4.1.1), this is not true of other species, such as tits, which also feed on aphids (Noble *et al.* 2001; Prowse 2002). It is also unclear why Welsh urban populations should be apparently unaffected and why sparrows should be absent from suburban areas of Bristol (J. Tully & R. Bland *in litt.*), where pollution from vehicle emissions might be expected to be lower than more urban areas. Indeed, in the Bristol study there was no correlation between wards with high levels of aerial benzene and low House Sparrow numbers ($r = -0.24$, $n = 35$, N.S.).

Two other hypotheses, that would also suggest impacts on invertebrate food supplies in suburban and urban gardens are the suggestions (1) that garden use of insecticides might have decreased food availability for House Sparrows and (2) that the cultivation of non-indigenous plants, unsuitable as hosts for House Sparrow prey, has increased. However, there are no available data sources on trends in these factors, but they could be investigated by carefully designed survey or experimental work in a national sample of gardens. But, as for the issue of pollution, the lack of consistent response of House

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Sparrows in different regions suggests that these hypotheses are unlikely to apply to all House Sparrow populations.

House Sparrows nest in a variety of holes and crevices in buildings, trees, earth-banks and even in the foundations of larger nests, such as those of the Corvidae (Snow & Perrins 1998). It has been suggested that modern buildings may contain fewer nest sites for birds, and those in old buildings may be being destroyed (Moss 2001). In support of this, the Bristol survey (J. Tully & R. Bland *in litt.*) found a negative correlation with the extent to which loft insulation had been installed in houses ($r = -0.56$, $n = 35$, $P < 0.001$). This may result in fewer nesting opportunities and there may also be a possibility of adverse respiratory effects from airborne fibreglass on breeding birds or their chicks. However, the prevalence of insulation is likely to be confounded with the measure of deprivation used earlier and the two effects cannot be separated on the basis of the present analysis. On the other hand, although they present no quantitative data, both Dott & Brown (2000) and Prowse (2000) thought that the number of nesting opportunities in cities had not changed significantly, although there had been large declines in House Sparrow numbers.

Populations associated with rural dwellings appear to have declined recently to a lesser extent than other habitats, with only arable dominated East Anglia showing a marked, but non-significant, decline in rural habitats (Table 3.4.1.1). This probably reflects the mix of habitats present, with buildings present for nesting, gardens for foraging on insects and fields to provide a source of grain. Although there is no published data, it is likely that declines in the amount of cereal grain available to sparrows have been greatest in arable areas, where farmers are most likely to invest in the latest, most efficient machinery and storage, which may account for the greater decline in East Anglia. In pastoral areas, House Sparrows will still also be able to forage on food put out for livestock which often contains some grain.

In summary, it seems likely that different factors are responsible for the declines in House Sparrow numbers in farmland and garden habitats, based largely on the differences in densities and the timing of the declines. On farmland, loss of seed resources and other factors associated with the increased intensity of farming are likely to be primary causes, hence the decline has been most widespread in arable areas (Table 3.4.2.1), though the effects of reduced immigration from garden populations cannot be ruled out. The decline in more urban areas is harder to explain, though, on balance, changes in demography occurring during the breeding season perhaps seem more plausible as an explanation.

Given the discrepancy of the estimates of population size derived from BBS counts and previous estimates, a population survey, specifically targeted to account for the difficulties in assessing numbers of a colonial species, such as the House Sparrow, is clearly warranted. A simultaneous assessment of foraging and nesting opportunities would also be invaluable. Particular attention should be paid to assessing differences in abundance between cities and within different areas of the same city. Exploiting the differences in abundance and trends outlined here may go some way to explaining why, for example, Welsh urban populations are apparently doing so well while those in London are faring so badly.

Appendix 3.1 Summary of population trends of House Sparrows breeding and wintering in different populations in Europe.

Country	Breeding Numbers	Winter Numbers	Source
Netherlands	Stable 1984-1990, subsequent steady decline; supported anecdotally	Steady decline since 1984	1, 2
Germany	Decline 1989-1998, especially 1991-1995; supported anecdotally; disappearance from an urban park (Dortmund) between early 1960s and late 1990s		2, 3
Spain	Recent decrease in north with abandonment of cereal farming and loss of nest sites		8
Belgium	Possible decline since early 1970s, but early/late data not strictly comparable	Populations hit by severe winters in 1980s, but some signs of recovery	4, 8
Finland	Decline since c. 1988, stable/increasing 1984-1987	Strong increase to mid-1970s, subsequent strong decline, maybe more stable in 1990s, decline stronger further south	2,5
Faeroe Islands	Increase to c. 1975, then decrease, but increases in early 1990s		8
Sweden	Slight decrease since 1950		6
Ireland	6.8% range contraction 1970 vs. 1990		7
Eastern Europe	[Absence of decline implied by omission]		2
Britain (Range)	5.3% range contraction 1970 vs. 1990		7

References

- 1 SOVON/ Statistics Netherlands (A.J. van Strien pers. comm.).
- 2 Hagemeyer & Blair (1997).
- 3 Schwarz & Flade (2000); Abs & Bergen (1999).
- 4 Devillers *et al.* (1988).
- 5 Väisänen & Solonen (1996); Väisänen (1999a,b); Solonen *et al.* (1991); Tiainen & Pakkala (2000).
- 6 Robertson & Berg (1992).
- 7 Gibbons *et al.* (1993).

4 SEASONAL AND TEMPORAL CHANGES IN USE OF GARDENS BY STARLINGS *Sturnus vulgaris* AND HOUSE SPARROWS *Passer domesticus*

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Robinson, R.A., Siriwardena, G.M & Hewson, C.M. (2002) Seasonal and temporal changes in the use of gardens by Starlings *Sturnus vulgaris* and House Sparrows *Passer domesticus*. In H.Q.P. Crick, R.A. Robinson, G.F. Appleton, N.A. Clark & A.D. Rickard (eds) *Investigation into the causes of the decline of Starlings and House Sparrows in Great Britain*. BTO Research Report No 290, pp 53-72. DEFRA, Bristol.

4.1 CHAPTER SUMMARY

1. The number of birds using gardens has been monitored since 1970 by the Garden Bird Feeding Survey, and since 1995 by the Garden BirdWatch. In this chapter, we use these data to assess the use of gardens by Starlings and House Sparrows during the winter.
2. Numbers of both Starlings and House Sparrows increase towards a mid-winter peak, then decrease again through to the spring. We described this seasonal change in numbers using a mix of sine and cosine functions and looked for changes in timing in relation to garden type and region. We also assessed the effect of winter severity on the numbers of birds using gardens.
3. Numbers of House Sparrows and Starlings using gardens varied between regions, being highest for both species in Eastern England, where the highest population densities are also seen. The timing of the House Sparrow mid-winter peak varied between regions, being earliest in pastoral regions and latest in arable regions. There were few regional differences in the seasonal pattern of Starlings through the year.
4. Both House Sparrows and Starlings are coming into gardens earlier in the winter. Peak numbers were lower and occurred later in the winter in rural than suburban gardens. However, the timing of the rural peak for House Sparrows, but not Starlings, had advanced relative to the timing of the peak in suburban gardens.
5. The number of House Sparrows using gardens in winter did not vary in relation to the severity of winter, but Starling numbers did. The number of Starlings in gardens was higher during cold winters and this relationship was more marked in the years of the population decline.
6. These results suggest that gardens are an important supplemental food source in winter. The increase in relative garden use indicates that habitat quality in the wider countryside is probably declining.

4.2 INTRODUCTION

The House Sparrow *Passer domesticus* and the Starling *Sturnus vulgaris* are amongst the most familiar of bird species in Britain, as both are frequently commensal with man in our cities, towns and villages. However, they have both undergone serious population declines in Britain over the past few decades (Baillie *et al.* 2001). Both species breed in large numbers within towns and villages (Chapters 2 & 3) but they also forage there, using food that people provide for them in garden feeders (Cannon 2000).

The number of birds occurring in any habitat will reflect both demographic processes (the number of births and deaths) and movements between habitats, both at local and larger scales. Movements

between habitats are usually related to differences in resource availability, often food availability (Wiens 1989; Sutherland 1996) and may represent small-scale movements in response to local conditions or large-scale migrations (e.g. Prŷs-Jones 1984; Berthold 1993).

Weather is likely to be a major determinant of garden use during the winter (Elkins 1988; Cannon 2000). Cold temperatures will increase energetic requirements as individuals increase their thermoregulatory activity during the day and store extra fat reserves for the night-time roost (Evans 1969; Kendeigh *et al.* 1977). Snow or frost cover will decrease the availability of both seeds and invertebrates to ground foragers, reducing food intake rates. Thus, during cold periods with extensive snow cover, ground foragers such as House Sparrows and Starlings are likely to suffer reduced intake rates, and consequently higher mortality, particularly when these periods are prolonged and hence the stress is sustained (Prŷs-Jones 1984; Pinowski & Pinowska 1985).

Although both House Sparrows and Starlings use gardens extensively, the degree of between-habitat dispersal varies markedly between the two species (Wernham *et al.* in press). In Britain, House Sparrows are remarkably sedentary. Although there is some (limited) juvenile dispersal during the autumn following hatching, individuals rarely move more than a few kilometres in their lifetime (Summers-Smith & Thomas in press). Starlings, on the other hand, may move large distances, although their migratory status differs between populations (Feare *et al.* 1992; Feare in press). Starlings which breed in Britain are largely sedentary, although adults can move a few tens of kilometres and juveniles may disperse much further in their first year of life. European Starlings are much more migratory and Britain receives a significant influx of continental immigrants, which are present between October and March (Fliege 1984; Feare in press). Thus, Starlings are likely to have a far greater capacity to respond to short-term spatial variation in resource availability than House Sparrows.

The number of birds using gardens in Britain has been monitored by a combination of two schemes, the Garden Bird Feeding Survey and Garden BirdWatch. The GBFS is a long term study initiated in 1970 which aims to collect information about how birds use food provided in gardens during the winter months, whilst the GBW started in 1995 and aims to collate information about all birds using gardens throughout the year. In this chapter, we analysed the counts from both schemes to see whether the widespread declines have been reflected in the occurrence of these species in gardens in winter and whether occurrence patterns in gardens can provide an insight into the causes of the declines. We also investigated the possible influences of severe winter weather on abundance through post-hoc analyses of the observed variation in the CBC index values presented in Chapters 2 and 3.

4.3 METHODS

4.3.1 Data Sources

4.3.1.1 Garden Bird Feeding Survey

Since 1970, the GBFS has provided annual information on the numbers of birds using artificial food and water sources during the winter, in a sample of rural and suburban gardens in Britain. Rural gardens are defined as those situated in an area consisting of more than 50% open country, while suburban gardens are surrounded mostly by other houses and gardens (the latter sample includes some gardens that most people would describe as “urban”, but these are a minority and are included with suburban gardens to avoid problems of definition). Suburban gardens constitute around 60% of the sample. Volunteer observers record the maximum number (the “peak count”) of each species using feeding stations in their gardens in each week of the winter (26 weeks from October to March, inclusive) and an index of the amount of food and water provided. The sample of gardens has changed over time as observers have entered and left the scheme but an average total annual coverage of 191 sites with Starlings and House Sparrows has been maintained in the long term. Throughout the life of the GBFS, efforts have been made to ensure that gardens are broadly representative of a range of garden types (large, small, rural, suburban, etc.) with a consistent, national spatial distribution. If

an observer leaves the scheme, another observer with a similar garden and feeding regime is sought as a replacement. The amount of food provided for garden birds has generally increased across Britain during the life of the scheme and this is likely to apply to the food provisioning in GBFS gardens too.

4.3.1.2 Garden BirdWatch

The BTO/CJ Wildbird Foods Garden BirdWatch scheme was launched in 1995 to monitor and to provide other information about garden birds throughout Britain and all year round. Since then, the scheme has grown to include more than 13,500 participants who are distributed throughout the country. In GBW, recording is focused on ten key common species (including Starling and House Sparrow), for which all birds are counted, in simple numerical categories, throughout the year. Observers record the category containing the maximum number of birds (the “peak count”) of each species that they see each week.

Our analyses of GBW data followed a similar approach to that used for the GBFS, adapted for use with the numerical category arrangement of the data. The maximum number of each species of several each week was assigned to one of these five abundance categories: X = no birds; A = 1-5 birds; B = 6-10 birds; C = 11-20 birds; D = 21+ birds. In order to convert these categorical scores to numerical values we calculated the mean size of flocks of each species that would have fallen within each abundance category using the counts recorded by GBFS. This gave us the following flock sizes for each abundance category; for both species A = 3, B = 8, C = 15. For category D, House Sparrow = 32, Starling = 33. Data from all gardens from which bird data were received in a given week were included in all analyses (i.e. zero counts were included in models and in the calculation of means).

The extent of the observation area and period was assumed to be constant between weeks for each site (as is stipulated by the survey protocol), but may have varied between sites. The data from all sites were combined during analyses. Systematic variations over time in the characteristics of sites contributing data to the survey could result in spurious temporal associations within the data. However, many sites have been surveyed over the entire 6.5 year duration of the survey and thus there is likely to have been little overall change in site characteristics.

4.3.2 Data Analysis

The basic statistical framework employed is that of generalized linear modelling, employing a logarithmic link function and a Poisson error distribution, as is appropriate for count data (ter Braak *et al.* 1994; Thomas 1996). Generalised linear models (GLMs) allow the modelling of annual variation and simple trends, as well as analyses of the strength of relationships between abundance and various predictor variables, such as habitat characteristics. We fitted GLMs using the GENMOD procedure of SAS and compared models using likelihood-ratio tests (SAS Institute, Inc. 1996). Confidence intervals were derived from the analytically estimated standard errors produced by SAS. In order to model accurately the repeated counts made during the year at each site (counts were made at GBFS sites in up to 26 weeks each year and in up to 52 weeks each year at GBW sites), we included an auto-correlated covariance matrix within the GLM specification. In these models, within each site and each year, weekly counts (Y_i) were correlated in an autoregressive manner, such that $\text{corr}(Y_i, Y_{i+t}) = \alpha^t$, where α is constant across all site-year combinations.

Use of gardens is seasonal within years and cyclical between years, so our basic models included a temporal effect to model the seasonal change in abundance. This was calculated as the sine and cosine of the week of the year (measured in $1/52^{\text{nds}}$ of a year: sine week effect = $\sin(2 \times \pi \times (\text{week}/52))$, cosine effect = $\cos(2 \times \pi \times (\text{week}/52))$).

Changes in the seasonal pattern of occurrence (or, more strictly, changes in the cyclicity of abundance) in gardens were identified by including interaction terms between a linear year effect and each of the cosine and sine function of week, testing the significance of adding the two interactions in tandem. A significant result would reveal that directional changes had occurred in the pattern of

occurrence through the winter, independent of overall changes in abundance. GBW data provide wider spatial coverage to investigate the spatial pattern of garden use by House Sparrows and Starlings since 1995. We conducted analyses of these data to investigate further the changes that have occurred over time in the pattern of occurrence of the two species in gardens through the winter. These analyses were analogous to those for GBFS (i.e. using an interaction between sine and cosine effects and year) and were parameterised in broadly the same way.

To investigate the influence of broad landscape type on garden use, the GBW analyses included a 5 level class term for region in the models. These regions were based on those used by Chamberlain *et al.* (1999) to compare intensive arable farming (in Eastern England) with other agricultural types and were defined as follows:

- East - Hertfordshire, Bedfordshire, Northamptonshire, Nottinghamshire, Humberside and eastwards,
- North - Merseyside, Manchester, South Yorkshire and areas to the north,
- West - Gloucestershire, Warwickshire, Leicestershire, Derbyshire, Cheshire and areas to the west,
- South West - Avon, Wiltshire, Dorset and areas to the west,
- South East - London, Buckinghamshire, Oxfordshire, Berkshire, Hampshire, and areas to the south and east.

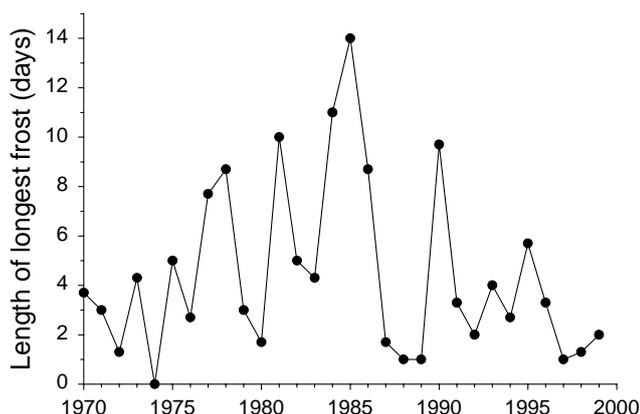
Note these regions are the same as those used in the population trends analyses in Chapters 2 & 3.

4.3.3 Weather variables

Probing ground-feeders, such as the Starling, might be expected to be affected detrimentally by ground frosts in winter, while both Starling and House Sparrow might suffer reduced survival under freezing conditions, affecting populations during winter and in the next breeding season. To investigate this, we extracted daily temperature (available at www.badc.rl.ac.uk) for three weather stations in England selected to give broad regional coverage of lowland areas (to which most of the CBC survey data refer and in which most Starlings and House Sparrows occur, see Chapters 2 and 3): Rothamsted, Hertfordshire (51°48'N 0°21'E, 128m asl); Long Ashton, Somerset (51°26'N 2°40'W, 51m asl) and Cockle Park, Northumberland (55°13'N 1°41'E, 95m asl). For each station, we calculated the length of the longest period of consecutive 'frost' days (mean air temp < 0°C) between October and March (Figure 4.3.3.1).

Because there was an apparent underlying quadratic trend over time in the length of the longest winter frost (Figure 4.3.3.1, $R^2 = 0.28$), we used GLMs which included year and year-squared terms as control terms and looked at the reduction in deviance achieved by adding the winter weather term (using log-likelihood ratios). As regressions were performed on the annual index data, effectively the mean across all sites, normal error distributions and an identity link function were used. This method is statistically much more robust than using de-trended residuals (e.g. Freckleton 2002).

Figure 4.3.3.1 Length of the longest frost period in each of the years, 1970-1999 (the year is



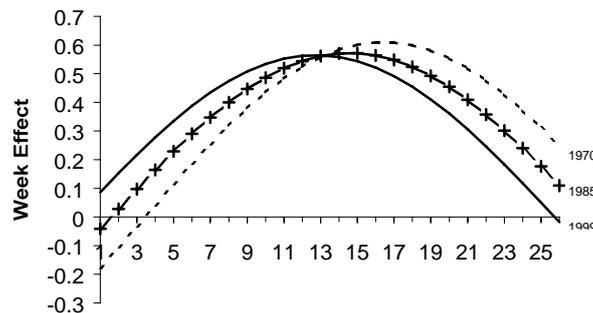
taken to be the one which includes December). Points represent mean values across the three weather stations considered.

4.4 RESULTS

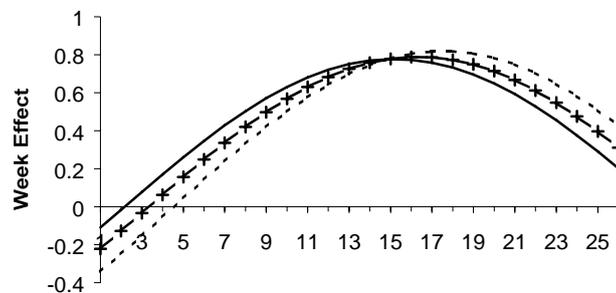
4.4.1 Seasonal patterns of garden use: GBFS

The GBFS indicates that the abundance of both Starling and House Sparrow in gardens in winter has declined markedly. These trends are discussed in Chapters 2 and 3 respectively. Both Starling and House Sparrows are appearing in gardens earlier in the winter than previously. The annual peak in Starling abundance in gardens occurred in late January (week 17) in 1970/71, but in mid-December (week 12) in 1999/2000 (Figure 4.4.1.1). This shift has occurred in both suburban and rural gardens, but the peak tended to be later in any given year in rural gardens (late January), the peak shifting from week 18 to week 15 (early January) in rural gardens and from week 16 (mid January) to week 12 (mid December) in suburban ones (Figure 4.4.1.1). There has also been a tendency for the annual peak in House Sparrow abundance to occur earlier, but the effect was much stronger, the peak moving from mid January (week 16) in 1970/71 to mid-October (week 3) in 1999/2001 (Figure 4.4.1.2). As for Starling, peak abundance of House Sparrows during the winter tended to occur later in the winter in rural gardens than in suburban ones and, although the peak had become earlier in both garden types, there was a much larger change in suburban gardens, from week 15 (early January) to week 4 (late October), than in rural ones, from week 17 (late January) to week 11 (early December) (Figure 4.4.1.2). All these changes were highly significant (Table 4.4.1.1).

(a)



(b)



(c)

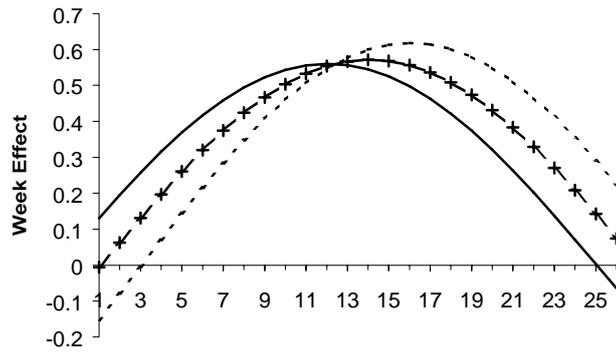
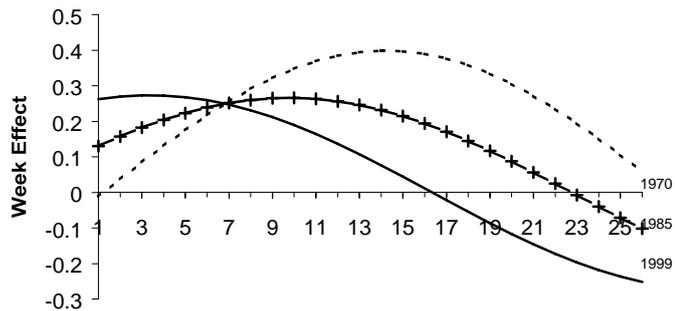
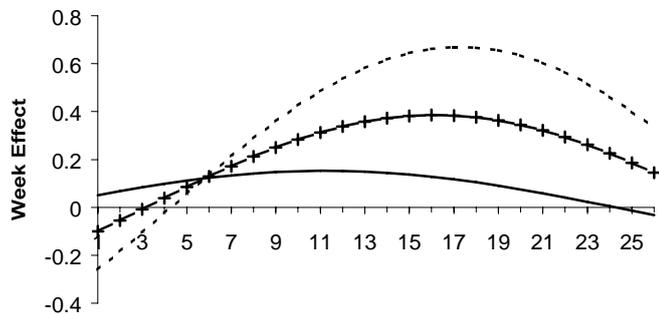


Figure 4.4.1.1 Changes in the seasonality of occurrence of Starlings in gardens in winter from 1970 to 1999 using GBFS data for (a) all gardens, (b) rural gardens and (c) suburban gardens. Weeks are numbered from the beginning of October (week 1) to the end of March (week 26). Short-dash lines 1970, crossed-dash lines 1985 and solid lines 1999.

(a)



(b)



(c)
Figure 4.4.1.2 Changes in the seasonality of occurrence of House Sparrows in gardens in winter from 1970 to 1999 using GBFS data for (a) all gardens, (b) rural gardens and (c) suburban gardens. Weeks are numbered from the beginning of October (week 1) to the end of March (week 26). Short-dash lines 1970, crossed-dash lines 1985 and solid lines 1999.

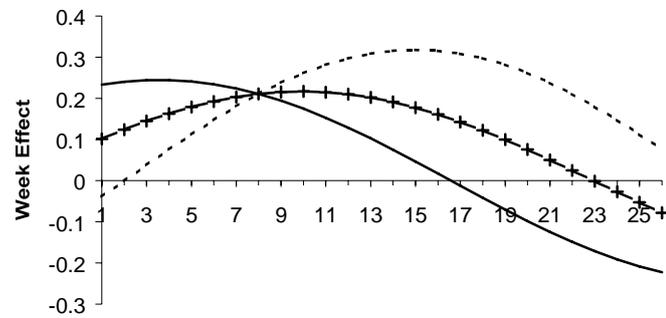


Table 4.4.1.1 Results of likelihood-ratio tests of the significance of change in seasonal abundance (sine and cosine effects tested in tandem) of GBFS peak count.

	Likelihood-ratio test			
	Garden subset	χ^2	d.f.	<i>P</i>
House Sparrow	All gardens	6249.8	2	<0.001
	Rural	3689.8	2	<0.001
	Suburban	3654.9	2	<0.001
Starling	All gardens	3826.0	2	<0.001
	Rural	1119.8	2	<0.001
	Suburban	2817.5	2	<0.001

4.4.2 Seasonal patterns of garden use: GBW

4.4.2.1 Within and between year variation in numbers

Consistent with the patterns demonstrated using the GBFS, the numbers of both House Sparrow and Starling occurring in GBW gardens varied cyclically through the year. However, the nature of this cyclical variation differed between the species. House Sparrow numbers showed a single seasonal peak, numbers being highest in the autumn months (Figure 4.4.2.1.1). Overall, the number of House Sparrows occurring in GBW gardens has decreased significantly, by about 40% over the seven year time period analysed (mean annual change: -7.9%, 95% confidence interval -6.5% to -9.2%).

Starlings, on the other hand, showed two seasonal peaks in numbers present (Figure 4.4.2.1.1). Numbers increased to a mid-winter peak and subsequently decreased through the spring. There is then a second, smaller, peak of numbers which are present through the summer months. The number of birds occurring during the summer months remained similar across the seven years considered. The number of birds present in winter, however, decreased significantly, by about 30% over the same period (mean annual change: -5.0%, 95% confidence interval -3.2% to -6.8%). Consequently, in the final year (2000/01) the number of birds occurring in summer and winter was similar, though the bimodal pattern of occurrence remained.

The two lowest points in the seasonal pattern of Starling abundance occurred consistently in the same weeks each year (in late April and early October). Consequently, as we are primarily interested in the winter period in this analysis, we excised the summer period (between weeks 17 and 40, where week 1 is the first in January) from the time series and considered just the winter counts. Perhaps because we considered only half of the year, the cyclic nature of variation in Starling numbers was simpler than for House Sparrow, with only the cosine terms for each parameter being significant (Table 4.4.2.1.1).

(a)



(b)

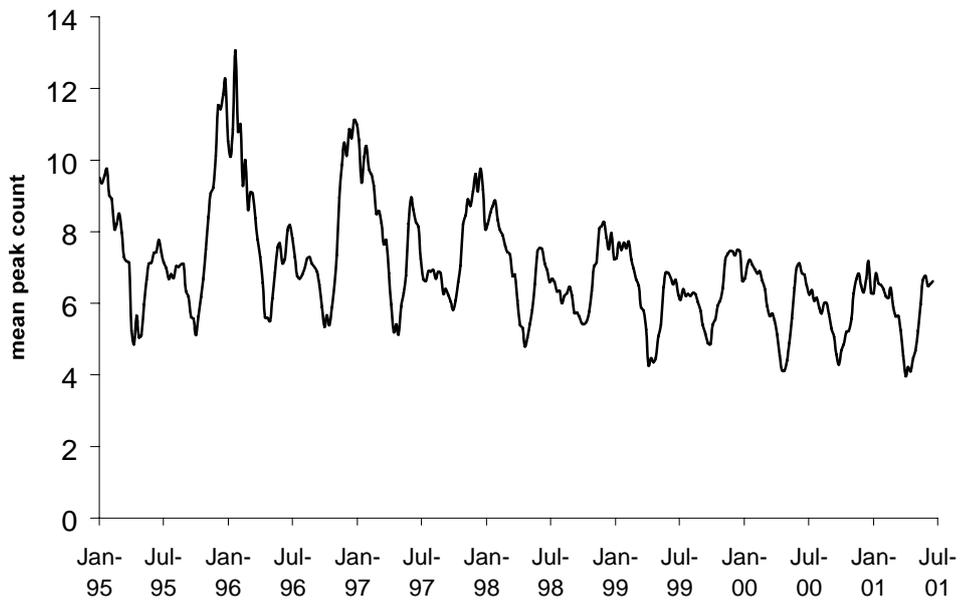


Figure 4.4.2.1.1 Seasonal pattern of occurrence of (a) House Sparrows and (b) Starlings in GBW gardens.

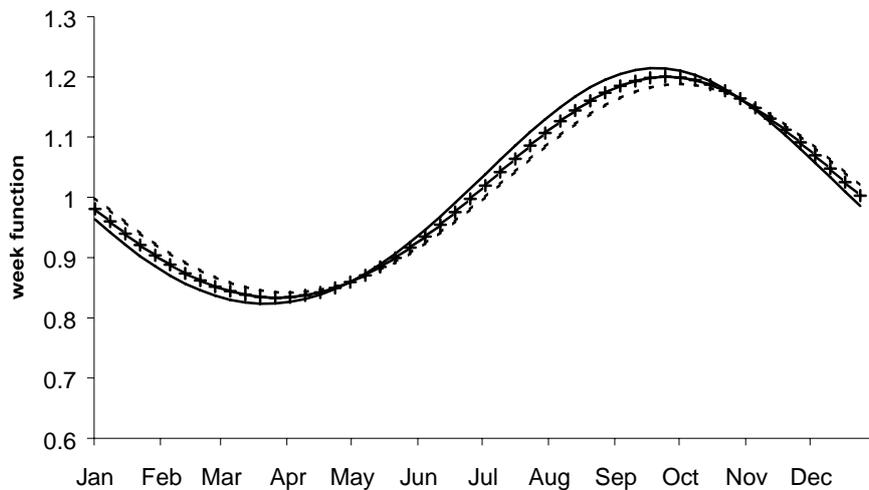
Table 4.4.2.1.1 Factors affecting spatial patterning in seasonality of garden use as measured from GBW. The significance of each term is tested by comparing the reduction in overall deviance when the term is included in the model. Results not significant at $P < 0.05$ are indicated by N.S.

Parameter		d.f.	House Sparrow		Starling	
			χ^2	<i>P</i>	χ^2	<i>P</i>
Week	cos	1	177.76	< 0.0001	932.71	< 0.0001
	sin	1	89.89	< 0.0001	72.66	< 0.0001
Time (year)		1	246.00	< 0.0001	150.54	< 0.0001
Region		4	55.84	< 0.0001	74.60	< 0.0001
Garden Type		1	43.77	< 0.0001	41.21	< 0.0001
Time x Week	cos	1	83.39	< 0.0001	128.03	< 0.0001
	sin	1	63.12	< 0.0001	1.04	N.S.
Region x Week	cos	4	53.02	< 0.0001	27.67	< 0.0001
	sin	4	11.36	0.0228	4.50	N.S.
Garden Type x Week	cos	1	24.59	< 0.0001	9.10	0.0026
	sin	1	47.83	< 0.0001	2.51	N.S.
Region x Time		4	26.30	< 0.0001	28.62	< 0.0001
Garden Type x Time		1	34.65	< 0.0001	0.18	N.S.
Region x Time x Week	cos	4	8.27	N.S.	26.62	< 0.0001
	sin	4	1.85	N.S.	0.86	N.S.
Garden Type x Time x Week	cos	1	10.23	0.0014	5.10	0.0240
	sin	1	15.22	< 0.0001	4.16	0.0413

Differences in the size and timing of the seasonal peak in number of House Sparrows recorded during the seven year survey period were small after the decline in numbers had been taken into account (Figure 4.4.2.1.2). Overall, numbers decreased over time (Figure 4.4.2.1.1) and the seasonality of numbers, i.e. the contrast between numbers recorded in summer and winter, increased slightly, while the mid winter peak tended to occur marginally earlier in the year. As found by the GBFS, this 'mid-winter' peak now occurs in October.

As might be expected from the overall decrease in Starling numbers recorded in winter (Figure 4.4.2.1.1), the amplitude of the winter peak in numbers decreased markedly (Figure 4.4.1.2). It should be noted, though, that this effect is independent of the long-term decline in numbers occurring in winter and reflects the reduced contrast between numbers present in summer and winter. There was no evidence of any marked change in the timing of the peak over the six years of Garden BirdWatch, in line with the relatively small changes noted by the GBFS.

(a)



(b)

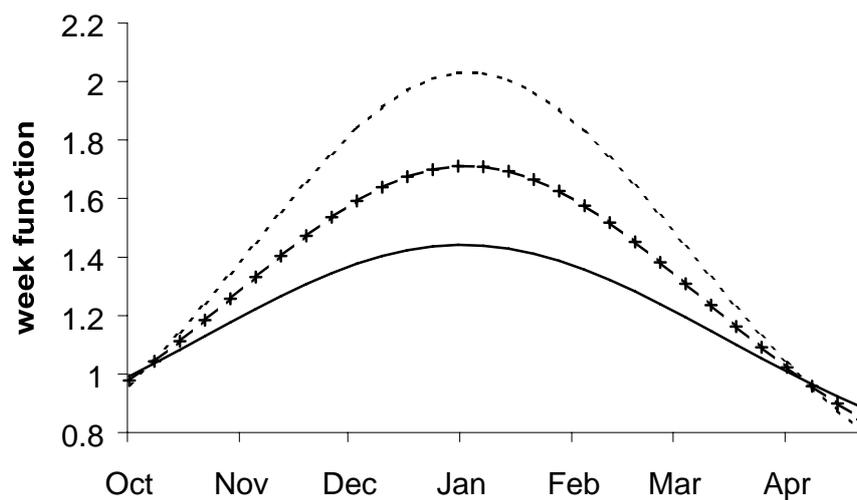


Figure 4.4.2.1.2 Week functions for 1995 (short-dash line), 1998 (crossed-dash line) and 2001 (solid line) using GBW data, showing the change in seasonality between years in (a) House Sparrow numbers and (b) Starling numbers.

4.4.2.2 Regional variation in numbers

The number of House Sparrows present in gardens in each region varied significantly (Table 4.4.2.2.1). Numbers were lowest in the South West (significantly lower than in any other region) and highest in Eastern England though there was no statistically significant difference in numbers between this region and either the West, North or South East regions. The number of birds recorded declined between years in all regions but the decline was slightly steeper in the South East and less severe in the South West. The differences were small, however.

Table 4.4.2.2.1 Mean peak count of House Sparrows measured from GBW (and their 95% confidence intervals in parentheses) occurring in each Region and pattern of temporal change (indicated by the Region × Year interaction of Table 4.4.2.1.1). The parameter estimates are expressed relative to the decline in West and positive numbers indicate a less severe decline.

	Mean peak count		Region × Year
East	12.6 (11.6 – 13.8)	East	1.00 (0.99 – 1.02)
West	11.8 (10.9 – 13.0)	West	1
South East	11.3 (10.5 – 12.4)	South East	0.98 (0.96 – 0.99)
North	11.1 (10.2 – 12.1)	North	1.01 (0.99 – 1.03)
South West	8.45 (7.46 – 9.39)	South West	1.03 (1.01 -1.06)

The seasonality of occurrence in House Sparrow numbers also varied regionally (Figure 4.4.2.2.1). The mid-winter peak occurred much earlier (October) in the largely pastoral West and South West of Britain (with little difference between these two regions) and much later (November) in the largely arable East of England. The amplitude of the curves for these three regions was also slightly greater than for the remaining two regions (North and South-East) indicating a greater contrast between numbers occurring in gardens in winter and summer.

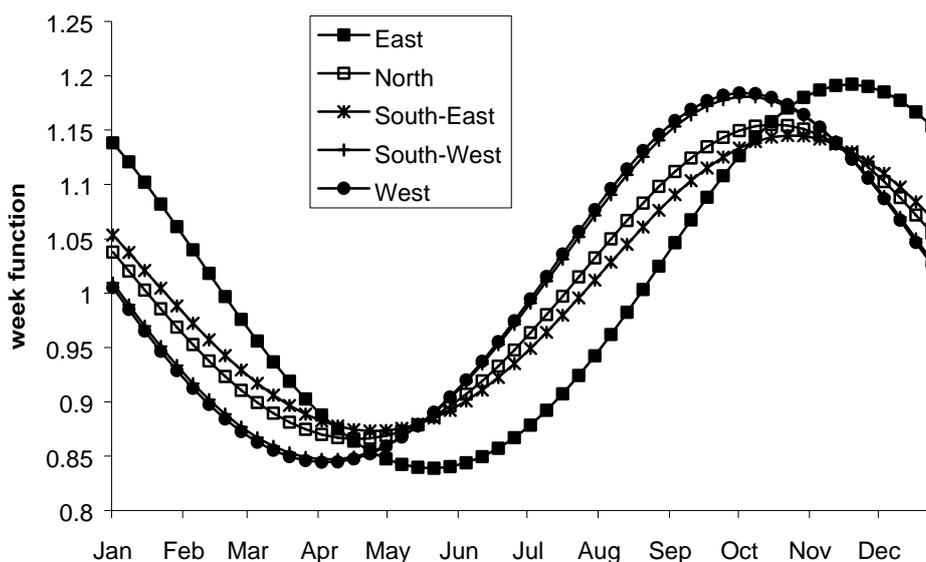


Figure 4.4.2.2.1 Regional variation in the seasonality of House Sparrow peak counts as measured from GBW.

Starling abundance in GBW gardens differed markedly between regions, with numbers being highest in South Eastern and Eastern England (Table 4.4.2.2.2). As with House Sparrow, numbers declined in all regions and, although there was a statistically significant interaction in the decline between regions (Table 4.4.2.1.1), the differences in parameter estimates were small (Table 4.4.2.2.2).

Table 4.4.2.2.2 Mean peak count of Starlings (and their 95% confidence intervals in parentheses) occurring in each Region and pattern of temporal change (indicated by the Region ×

Year interaction of Table 4.4.2.1.1). The parameter estimates are expressed relative to the decline in West and positive numbers indicate a less severe decline.

	Mean peak count		Region × Year
East	8.90 (8.00 – 9.87)	East	0.99 (0.97 – 1.01)
South East	7.76 (7.00 – 8.65)	South East	0.98 (0.96 – 1.00)
West	7.09 (6.36 – 7.99)	West	1
North	6.12 (5.49 – 6.89)	North	1.03 (1.01 – 1.05)
South West	6.07 (5.24 – 6.97)	South West	0.98 (0.95 – 1.01)

Nationally, the seasonality in occurrence in Starlings in gardens decreased, with a smaller contrast between numbers in summer and winter but not for all regions (Figure 4.4.2.3.1). While the amplitude of the winter peak decreased in the West of Britain, it increased in the two southern regions (South East and South West). In contrast, there was little change in either Northern or Eastern Britain. In none of the regions was there an obvious change in the timing of peak occurrence.

4.4.2.3 Differences between garden types

The number of House Sparrows recorded depended quite heavily on garden type. Numbers recorded in rural gardens (mean peak count = 9.4) were significantly lower than in suburban and urban gardens (mean peak count = 11.5). However, the decline in numbers was significantly less steep in rural gardens compared to their suburban counterparts. The seasonality of occurrence differed between rural and suburban gardens, with a smaller contrast between summer and winter numbers in rural gardens compared to suburban gardens (Figure 4.4.2.3.2). The mid-winter peak in numbers also differed, being about two months later in rural gardens. There was little change in the pattern of seasonality in suburban gardens, but the seasonality of rural gardens increased significantly over the seven-year period considered, i.e. there was a greater contrast between summer and winter numbers (Figure 4.4.2.3.3). The mid-winter peak also showed a tendency to become earlier in rural gardens, advancing by about three weeks, but showed little change in suburban gardens.

Seasonal use of gardens

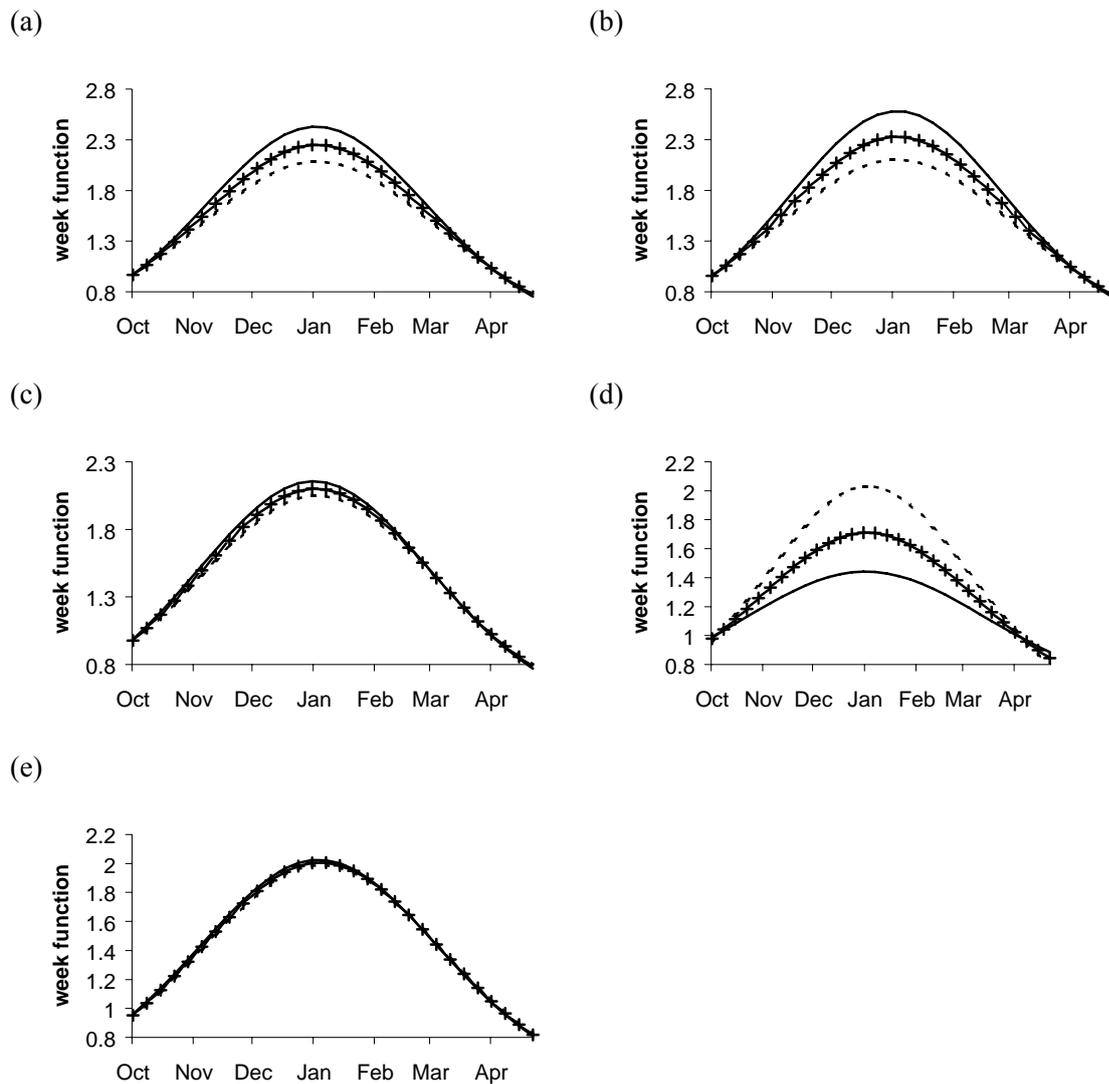


Figure 4.4.2.3.1 Regional differences in the change in seasonality of Starling numbers for GBW. (a) South East, (b) South West, (c) East, (d) West and (e) North. Short-dash lines 1995, Crossed lines 1998 and solid lines 2000.

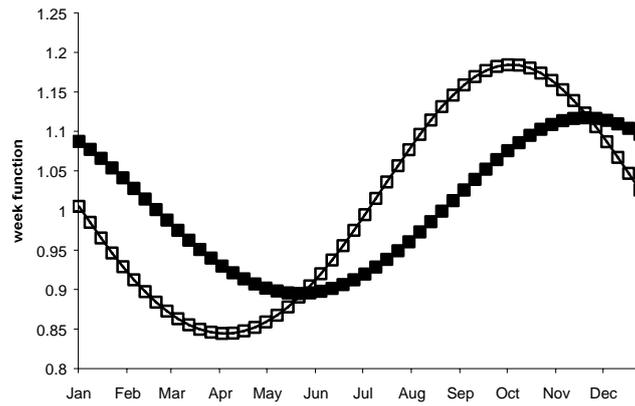


Figure 4.4.2.3.2 Seasonality in House Sparrow numbers in rural (closed symbols) and suburban (open symbols) gardens throughout the year from GBW.

(a)

(b)

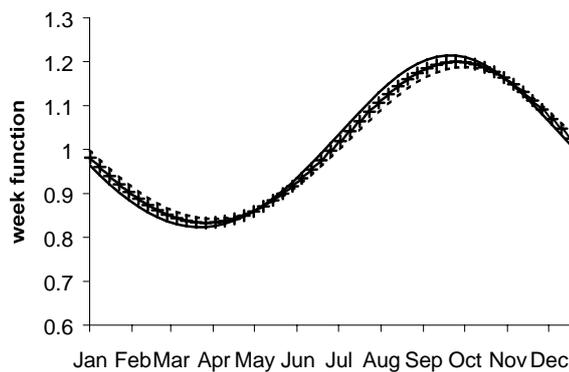
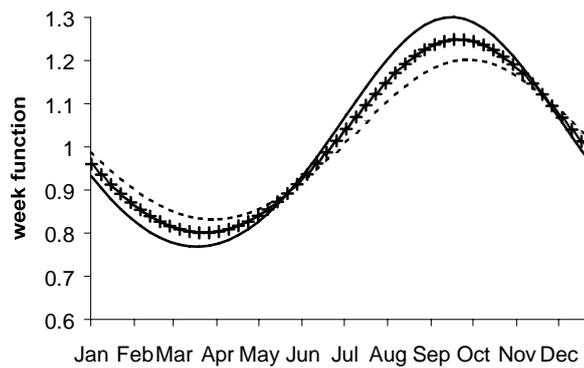
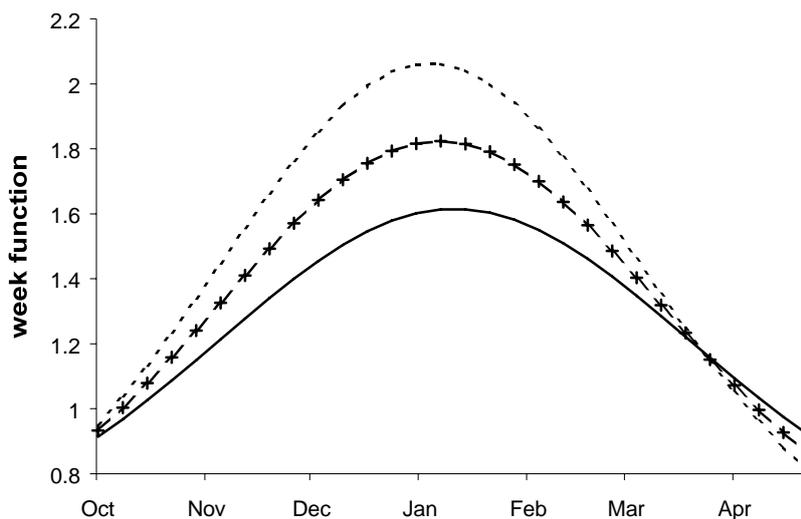


Figure 4.4.2.3.3 Change in seasonality of House Sparrow numbers through time in (a) rural and (b) suburban gardens from GBW. Short-dash line 1995, crossed-dash line 1998, solid line 2001.

Seasonal use of gardens

Significantly fewer Starlings were recorded in rural gardens (mean peak count = 9.6) than suburban ones (mean peak count = 11.2), but for Starlings there was a significant difference in the rate of decline in numbers between the garden types (Table 4.4.2.1.1). Although there was a marginally significant difference in the change in seasonality over the course of a winter between the two garden types (parameter Garden Type \times Time \times Week, Table 4.4.2.1.1) the actual differences were small. In both cases seasonality decreased through time (Figure 4.4.2.3.4).

a)



b)

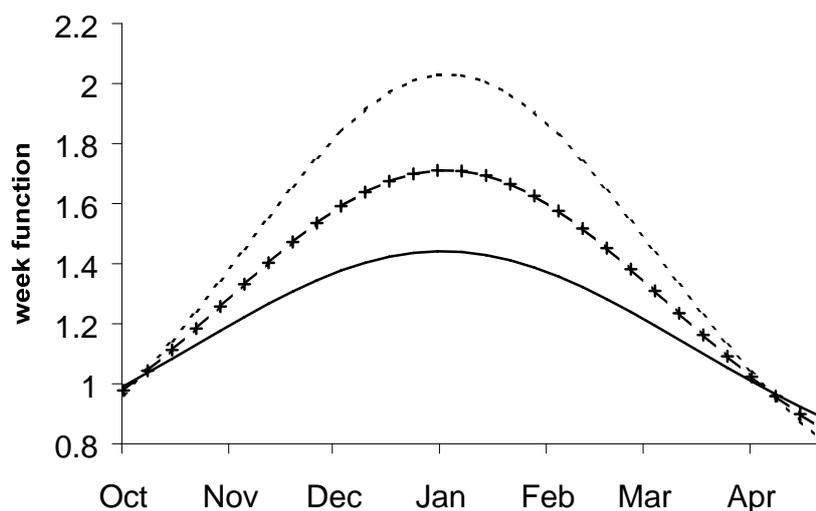


Figure 4.4.2.3.4 Differences between a) rural and b) suburban gardens in the change in seasonality of the number of Starlings in gardens in winter from 1995 to 2001. Short-dash line 1995, crossed-dash line 1998, solid line 2001.

4.4.3 Effect of weather on winter garden use

Over the period of the GBFS, the distribution of House Sparrows at garden feeders in winter did not appear to be affected by the severity of the winter, but usage of gardens by Starling was strongly affected (Table 4.4.3.1). The slope of this relationship was greater for rural gardens, thus birds moved preferentially into rural gardens compared to suburban gardens, perhaps reflecting the fact that rural gardens will be closer to the farmland areas in which they would otherwise forage.

In order to investigate whether the effects for Starlings were similar in periods of approximate stability and periods of decline, we extended the analyses above, splitting the dataset in half at 1985 (Table 4.4.3.2). These results show that, for Starlings, the effect of colder winters was much stronger in the last 15 years (1985-99), compared to the previous 15 years (1970-84). The slopes of the relationships (Figure 4.4.3.1) were similar in the two periods, but variation was much less during the period of decline, suggesting that the influence of other environmental variables on bird numbers was weaker at this time.

At this scale of analysis, winter weather (or at least the measure of it used here) did not appear to affect the population size of House Sparrows in the immediately following breeding season, i.e. cold winters did not result in a reduced breeding population size (Table 4.4.3.1). There was weak evidence for an effect on Starling population size, at least on farmland (where changes in population size are likely to be most accurately monitored). If foraging opportunities are limited in winter, weather conditions might be expected to affect the between-year population change (independently of the absolute population size). We assessed this by relating the length of frost period to the population multiplication rate (PMR) – this is the proportional change in index value between adjacent years. There was no significant relationship for either species.

Table 4.4.3.1 Results of regression tests investigating the relationship between abundance or population multiplication rate (PMR) and lengths of the longest frost each year. “Slope” figures show the parameter estimates for the effect of the frost days variable on the dependent variable and its standard error (in parentheses).

		Slope	χ^2	P
Starling				
CBC	All	0.005 (0.003)	2.86	0.09
	Farm	0.008 (0.004)	5.03	0.025
CBC	PMR	-0.004 (0.003)	1.61	N.S.
GBFS				
	All	0.017 (0.004)	12.10	0.0005
	Rural	0.022 (0.006)	11.61	0.0007
	Suburban	0.014 (0.004)	10.60	0.0011
House Sparrow				
CBC	All	-0.001 (0.004)	0.14	N.S.
	Farm	-0.002 (0.004)	0.26	N.S.
CBC	PMR	0.021 (0.022)	0.86	N.S.
GBFS	All	0.002 (0.003)	0.52	N.S.

Table 4.4.3.2 Results of regression tests investigating the relationship between abundance in GBFS gardens and lengths of the longest frost each year for Starlings during broadly defined periods of stability and decline. “Slope” figures show the parameter estimates for the effect of the frost days variable on the dependent variable and its standard error (in parentheses).

Starling		Slope	<i>F</i>	<i>P</i>
1970-1984 (stable)				
GBFS	All	0.018 (0.008)	4.89	0.046
	Rural	0.023 (0.010)	5.15	0.041
	Suburban	0.016 (0.008)	3.96	0.068
1985-1999 (declining)				
GBFS	All	0.016 (0.005)	10.66	0.006
	Rural	0.021 (0.008)	8.15	0.014
	Suburban	0.013 (0.004)	9.40	0.009

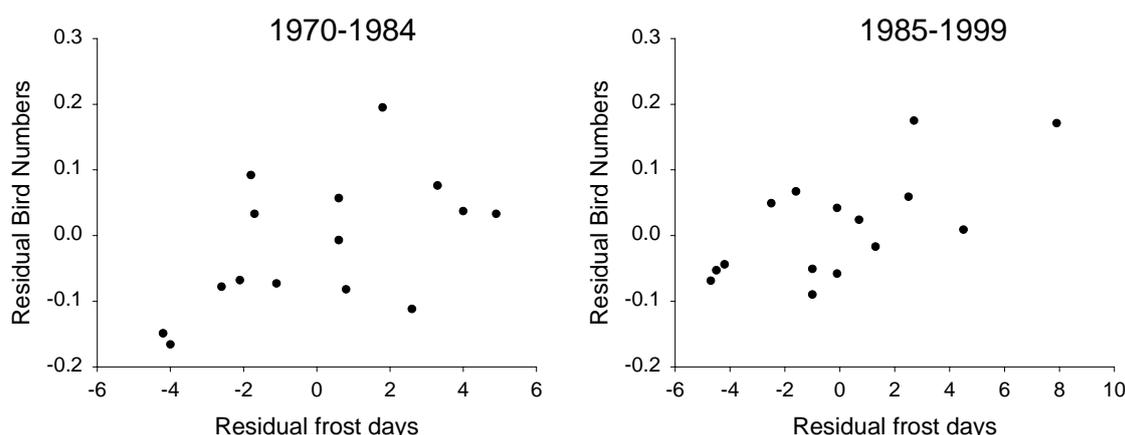


Figure 4.4.3.1 Illustrations of the regression results for the relationships between Starling numbers measured from the GBFS and frost days each winter, divided into data for periods of approximate stability (1970-84) and decline (1985-99).

4.5 DISCUSSION

The analyses presented in this chapter are the first quantitative analyses of long-term changes and spatial patterning of seasonal habitat use. Indeed, this is the first analysis of garden use by birds, at a national scale. As has been demonstrated in Chapters 2 and 3, the number of birds using gardens has declined in the last thirty years; these results show that the way in which gardens are used has also changed. The use of peak counts potentially confounds changes in population numbers, with changes in social behaviour, particularly flocking behaviour. The decrease in numbers reported here could suggest that concentrated food sources have disappeared and birds have to forage in a more dispersed fashion independently of a decline in the population size. Although this is extremely unlikely to be the sole cause of the observed change in numbers, the flocking behaviour, and individual movements more generally, require further study.

The numbers of Starlings and House Sparrows occurring in gardens were highest in the East of England (numbers of Starlings in South Eastern gardens were almost as high). These regional differences are broadly consistent with the regional differences in breeding numbers outlined in Chapters 2 and 3. Both species occurred with lower abundance in rural gardens, compared to suburban gardens, and peak numbers in mid-winter were also lower compared to numbers present in summer in rural gardens. The mid-winter peak in House Sparrow numbers occurred earlier in pastoral than arable regions, whilst there appeared to be no difference between regions in the timing of the Starling mid-winter peak.

House Sparrows are relatively sedentary, though flocks may move one or two kilometres in search of food, particularly in the autumn (Summers-Smith 1988). This may explain why no great immigration into gardens during periods of severe weather is seen. The Starling, on the other hand is highly mobile during the winter and, having a catholic diet can exploit a range of food sources (Feare 1984). Thus, during periods of prolonged frost, when the availability of soil invertebrates (and also seeds on the ground) is likely to be low, birds come into gardens to exploit the food sources. Because of this adaptability, Starlings do not seem to suffer from increased mortality during periods of severe weather (Dunnet 1956; Cawthorne & Marchant 1980). As winters have become less severe, the seasonal influx of birds into gardens has declined.

The use of gardens by House Sparrows in winter suggests they are a supplemental, rather than a primary food source. During the winter, House Sparrows forage primarily on cereal grains and, to a certain extent, larger weed seeds, which are likely to be most abundant on farmland. It must be noted, though, that foraging opportunities for House Sparrows, and Starlings, in urban and rural habitats are unquantified. The number of seeds available to birds will diminish through the winter (Robinson & Sutherland 1999) and this is likely to affect the timing with which House Sparrows use gardens. Thus, birds in pastoral areas, where grain and weed seeds will be generally scarce on farmland, gather in gardens much earlier in the winter than do those in arable areas. Similarly, the mid-winter peak in rural gardens, where individuals can feed on farmland and in gardens concurrently, occurs much later than that in suburban gardens, where such alternative foraging opportunities will not be available to a species that does not wander far. The relatively low number of House Sparrows that occur in rural gardens during winter compared to the summer months, may reflect a greater proportion of birds foraging in alternative ('better') habitats, or simply that the density of birds on farmland tends to be lower than that in suburban areas, there thus being a smaller pool of individuals in the catchment area of each garden (Chapter 3).

The number of cereal grains, weed seeds and soil invertebrates available to birds on farmland has decreased markedly in recent decades (Ewald & Aebischer 1999; Robinson & Sutherland 2002). Changes in hygiene legislation have improved grain storage, such that birds should no longer be able to gain access to these stores, in order to reduce the incidence of disease transmission. These will have represented a major foraging opportunity for House Sparrows and, to a lesser extent, Starlings. Their effective removal are likely to have had a significant impact on the over-winter survival of these species. Consequently, gardens are likely to have become a relatively more important source of winter food (Cannon 2000). The changes in seasonality of both House Sparrow and Starling numbers support this hypothesis. Thus, over the last thirty years, the mid-winter peak in numbers of both species has occurred earlier in the winter. For Starlings, the peak has advanced by about six weeks, possibly reflecting a food source that is being depleted earlier in the season. This advance is greater in suburban gardens, where food resources are, presumably, scarcer initially. Starlings are also increasingly relying on gardens during periods of severe weather. Thus in the 1970s, although the number of Starlings visiting gardens was related to the severity of winter weather, there was some degree of scatter in this relationship, suggesting that in some years, although weather was severe, food was sufficiently abundant in their preferred habitats (mainly pastoral farmland) in some years they had no need to utilise gardens. Since the mid 1980s, however, the relationship between severity of winter weather and the numbers of Starlings in gardens has been fairly close, suggesting that alternative food sources on farmland have diminished. This is discussed further in Chapter 12.

Seasonal use of gardens

For House Sparrows, the mid winter peak that occurred in the early 1970s, has disappeared entirely, with peak numbers now occurring in the autumn (around October). In rural gardens, the pattern in the number of birds present through the winter appears to have changed very little over time, whereas in suburban gardens the peak is the same magnitude, but just occurs earlier (Figure 4.4.1.2). Although House Sparrows are largely sedentary, there is clearly increased flocking in gardens in the winter months, which could reflect an influx of birds into gardens from adjacent areas, or simply birds in adjacent gardens banding together. This no longer seems to be happening in rural gardens, suggesting individual colonies have become increasingly isolated, with little movement between (previously adjacent) colonies; the distribution of suburban colonies may be more continuous.

These results show that the pattern of occurrence of both House Sparrows and Starlings in gardens has changed over the last thirty years and that this change is consistent with a decrease in food resources in the wider countryside. Two major unknowns, however, are the availability and quality of foraging resources in urban and suburban areas and the amount of movement of individual birds between habitats. Understanding how birds use different habitats in winter and how this relates to breeding distribution will be critical in understanding why the population has declined and hence in determining remedial action.

5 THE DYNAMICS OF A SUBURBAN NESTBOX BREEDING COLONY OF STARLINGS *Sturnus vulgaris*

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5.1 CHAPTER SUMMARY

1. The breeding numbers and success of Starlings were monitored from 1975 to 1997 in a nestbox colony in suburban Surrey. The number of pairs that bred annually remained more or less constant until 1991, when numbers fell to about one third of their former population.
2. Throughout the study, significant between-year differences were recorded in date of initiation of laying, clutch size, proportion of clutches that produced young, brood size at 16 days old (taken to represent the brood size at fledging), and body mass at 16 days old (taken to represent mass at fledging). However, there were no trends over the time of the study and no discontinuities in these parameters at or just before the population decline.
3. Most birds that had been reared in the colony and subsequently returned to breed were first recorded doing so in their first and second years. This applied to both males and females although males showed a significant tendency to first breed at a greater age than females. Some females were not recorded to have their first breeding attempt until five years old, and some males until seven years old.
4. Birds that returned to breed in the colony were recorded doing so in up to five years but, as they were not always recorded breeding in consecutive years and some were not recorded first breeding until later in life, Starlings were recorded nesting up to their ninth year of life.
5. Up to 1987, individuals of both sexes were regularly recorded breeding at up to six years of age, but after 1987 females were recorded breeding in their first or second years and males in only their first, second and third years.
6. Few birds that had been raised in the colony were subsequently recorded breeding there: 5% of birds from first brood chicks, 2% from intermediate broods and 1% from second broods. The number of chicks that returned from each year's production was highly variable, with a few years producing several recruits, but most years producing few. After 1987, variation in the recruitment from annual cohorts continued but the peaks of earlier years were not attained.
7. Most recruits to the breeding colony had not been reared there and must have immigrated from nests in the local area or from further afield. After 1989, the number of immigrants to the colony, the number of birds that had bred there previously and the number of recruits that had been reared in the colony all declined, leading to the observed reduction in the number of pairs that nested in the colony.

8. There was no evidence that changes during the breeding season, that affected the output of young, contributed to the decline in the size of the population. Declines after 1987 in the number of adults that returned to breed, the number of years in which they bred and the number of young that returned to breed suggest that survival of adults, juveniles or both, had declined or that birds were emigrating from the area. The openness of the nestbox colony precluded the estimation of post-fledging and adult survival but, as the number of immigrants declined as well as the number of local birds, a decrease in survival seems the more likely candidate underlying the colony's decline.
9. There did not appear to have been any major changes in habitats suitable for Starlings during the course of this study. It is likely that factors operating outside the colony were most influential because the colony appeared to depend on immigration and was not self-sustaining.

5.2 INTRODUCTION

The Starling *Sturnus vulgaris* is one of Britain's most numerous and familiar birds, living in close association with man on farmland and in towns and gardens. Starlings in the British Isles are of two origins, a resident population that breeds and winters within the islands, and a wintering population that migrates here for the winter from breeding areas mainly in Scandinavia, Russia and the Baltic states (Feare in press).

In the mid-eighteenth century Starlings were less numerous and more restricted in range than a century later (Parslow 1973; Feare 1984; Holloway 1996), their stronghold being the Western Isles of Scotland. Numbers increased subsequently and their range expanded to occupy all of Britain apart from the uplands. A similar trend appears to have occurred in northern Europe, leading to vast numbers of immigrant Starlings wintering in Britain. The factors underlying this increase in numbers are not known but probably involved various changes in agricultural practice and suburban development that promoted habitats favourable to Starlings. Numbers reached a peak around the 1950s - 1970s, when they were regarded as serious agricultural pests through their consumption of soft fruit, germinating cereals and, especially, cereals in cattle food rations. In addition, huge numbers roosted at night in city centres, leading to considerable fouling and public health and safety concerns. Many large roosts in rural areas damaged woodlands and, when near airfields, presented air safety hazards (Feare 1984). At this time, Sharrock (1972) estimated that Britain hosted up to seven million pairs of resident birds, and Potts (1967) considered that there might be an additional 35 million birds entering the country for the winter. These estimates were, however, based on census techniques that are much less reliable than those used today.

Since the 1970s, The BTO's Common Birds Census (CBC) has recorded a decline in the number of Starlings that breed in Britain (Marchant *et al.* 1990). This has continued (Baillie *et al.* 2001) and the recently inaugurated BTO/JNCC/RSPB Breeding Bird Survey has indicated further declines in numbers in 1994-2000 (Noble *et al.* 2001). In the early 1960s, Finnish ornithologists reported falls in numbers and local extinctions in the north of that country, and since then declines have been reported more widely from Scandinavia, and also from countries further south (Feare 1989). This has led to reductions in the number of Starlings that winter in Western and South Western Europe (Feare *et al.* 1992), including Britain (Feare 1994). Further agricultural intensification is thought to have contributed to these declines, which have now exceeded 50% for British breeding birds (Gregory *et al.* 2001, Chapter 2), leading to the admission of the Starling to the amber list of Birds of Conservation Concern (Gibbons *et al.* 1996), with consideration now being given to red-listing the species (Gregory *et al.* 2001).

This study reports the population trend in a suburban colony of Starlings that nested in specially provided nest boxes within the 2 ha grounds of the former Ministry of Agriculture research laboratory at Tangley Place, Worplesdon, Surrey. This population was monitored from 1975 to 1997 and the study included a period of rapid decline in the early 1990s. The aims of this analysis are to examine,

as far as possible, parameters associated with breeding output, return of young to breed in the colony, and return of breeding adults, to look for changes just before, or coinciding with, the decline in breeding numbers.

5.3 STUDY AREA AND METHODS

Each year, *c.* 40 nestboxes were available to Starlings. They were sited mainly on trees (a few on buildings) in open woodland within the grounds of the laboratory, which was situated on the fringe of Guildford, Surrey. The surrounding area, where the birds fed, included large suburban gardens, a small area of parkland, and farmland that was grazed by horses and donkeys. During the mid to late 1970s, some of the parkland was developed for further housing, mainly smaller houses with small gardens but this area was 500m or more from the nestbox area. Many large old trees were left during this development and, in addition to lawns within small gardens, larger areas of lawn were created in public areas.

The nestboxes were originally established for the 1974 breeding season but monitoring of parameters associated with breeding did not begin until 1975. Observations of the number of occupied nestboxes continued until 1997 but data on other aspects of breeding ceased in 1995. Observations of the nestboxes began in late March each year and, following the discovery of the first egg each year, nestboxes were visited daily, in the afternoon to minimise disturbance to laying birds (Feare *et al.* 1982), until first clutches were complete. Occupied boxes were visited again after 11 days of incubation to determine the number of eggs that hatched, and when chicks were 16 days old for weighing using a Pesola 100g balance. This was regarded as the chicks' fledging mass as, by this time, their asymptotic mass had been reached, and visits closer to their fledging, at *c.* 22 days, risked stimulating the birds to leave the nest prematurely. The laying of first clutches within a Starling colony is highly synchronous, with clutches initiated within a period that usually did not exceed six days (Feare 1984). First clutches were defined as those that were initiated within ten days of the first egg being discovered each year. All boxes that had not been occupied by birds laying first clutches were visited periodically to look for eggs laid later. These comprised intermediate clutches (defined as clutches that were initiated 11 to 40 days after the initiation of first clutches) and second clutches (laid by females that had already reared a successful first clutch), where laying began a minimum of 41 days after the commencement of the first clutches. In each year (except 1997) nestboxes were visited until young from second broods were expected to have fledged, in order that all clutches laid were recorded. These visits to the nestboxes allowed the following data to be collected: date of clutch initiation, number of eggs laid, number of eggs that hatched, number of chicks that fledged (chicks that survived to 16 days rarely failed to fledge, but checks were made after fledging for any dead chicks remaining in the nests), and chick mass at fledging.

All chicks were ringed with BTO numbered rings. In addition, from 1977 onwards, attempts were made to catch all adults during incubation, using either a spring trap temporarily fixed within the nestbox entrance, or by placing a small net over the entrance during each catching attempt. Those that were caught were ringed, or their existing ring numbers were recorded. In practice, all females were caught each year, but males, which spend less time on the nest than females and are thus more difficult to catch (Feare 1984) were sometimes missed. These ring data permitted estimation of the age at which birds ringed as chicks returned to breed and of the number of breeding attempts made by each individual.

5.4 RESULTS

5.4.1 Number of nestboxes occupied each year

Figure 5.4.1.1 shows the number of boxes occupied by first, intermediate and second broods each year. The number of clutches initiated in first broods remained relatively stable from 1975 to 1991 but this was followed by a rapid decline to a lower occupancy in 1992, and this level was sustained to the end of the study. The numbers of intermediate and second clutches were lower than the number of first clutches in all years and were variable. This was especially true of second clutches and, before the 1991 decline in the population, the three years in which no second clutches were laid were years in which laying of the first clutches began later than in all other years (1978, 1979 and 1986, see below).

The catching of ringed birds showed that intermediate clutches involved three types of bird: (i) females replacing first clutches that had been lost, (ii) females that were apparently laying for the first time in a particular year (they had not laid earlier in the nestboxes but could have lost clutches in nests nearby that were not monitored), and (iii) females that were mated to polygynous males who already had a female incubating their first clutches. The relative proportions of these could not be quantified due to uncertainties over the previous breeding experience of females in each breeding season, and failure to catch all males each year precluded identification of all cases of polygyny.

Second clutches were usually identifiable as true second breeding attempts within the breeding season, the females having already successfully raised a first brood. In the few examples where females had not apparently raised a first clutch that season, these birds might have reared a brood in a nearby nest that was not monitored, since Starlings sometimes change nest sites, and also mates, between first and second clutches (Feare & Burnham 1978).

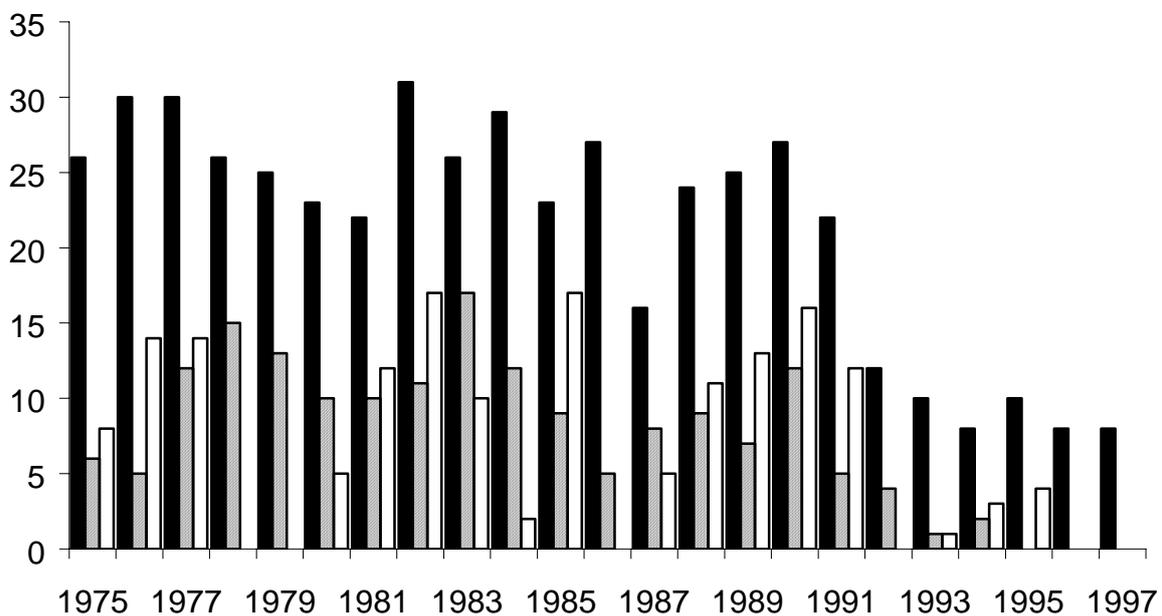


Figure 5.4.1.1 The number of first (black columns), intermediate (hatching) and second (white) clutches laid in the Worplesdon nestboxes 1975-1997 (but note that nestboxes were not examined for intermediate and second clutches in 1997).

5.4.2 Date of initiation of first clutches

The date of initiation of first clutches varied significantly over the period of study, with extremes of 27 March (1990) and 19 April (1986). However, there was no significant trend over time and no significant change at the time of the decline in numbers (Figure 5.4.2.1) between 1991 and 1992. The dates of initiation of intermediate and second clutches are dependent upon the date of initiation of first clutches and they followed similar patterns, despite the smaller samples that were available for analysis.

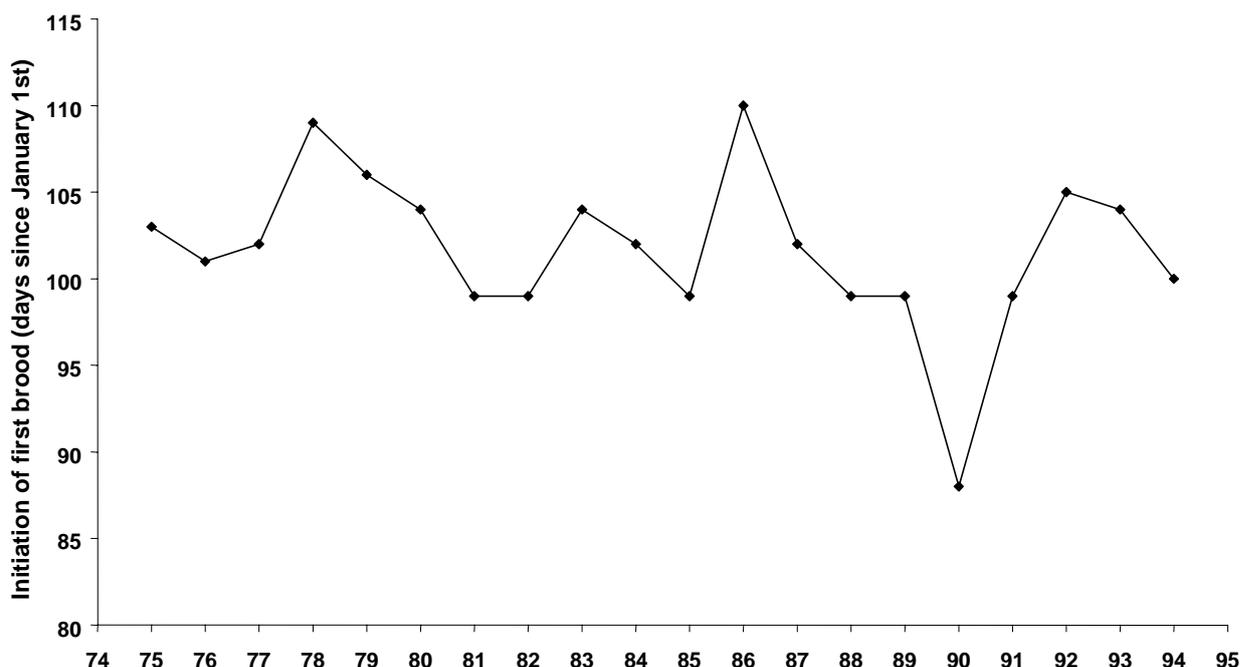


Figure 5.4.2.1 Modal date of initiation of first broods in the Worpleston boxes 1975-1994. Date is numbered from 1 January, such that 90 = 29 March and 110 = 18 April.

5.4.3 Clutch size

Although clutch size varied significantly over years in first and intermediate clutches (first: $F_{19,468}=1.69$, $P=0.035$; intermediate: $F_{19,153}=1.85$, $P=0.022$), there was no significant variation in the size of the small sample of second clutches ($F_{15,144}=0.67$, $P=0.814$). However, there were no trends over time in the size of first clutches (Figure 5.4.3.1). For the three clutch types, mean annual clutch size varied as follows: first 3.75-5.11, intermediate 3.50-5.40, second 3.40-4.40. Second clutches were significantly smaller than first and intermediate clutches (Friedman non-parametric two-way ANOVA on the mean number of eggs from each clutch each year: $\chi^2_2 = 27.3$, $P < 0.001$).

In first clutches, but rarely in intermediate and second clutches, intra-specific nest parasitism (in which a female Starling lays one or more eggs in the nest of another pair) was identified as a factor that could confound true clutch size of nest owners. The incidence of such nest parasitism reflected the amount of human disturbance in the colony (Feare 1991) and in years when this aspect of Starling behaviour was closely studied, Evans (1988) found that up to 37 % of first clutches at Worpleston contained eggs that had not been laid by the female owners of nests. The influence of this on

estimates of clutch size within the colony have not been established. Parasitism is also sometimes under-recorded unless genetic techniques are used to identify parasitic eggs, as some parasitic females remove an egg when laying their own so that the observed clutch size in a nest is unaltered.

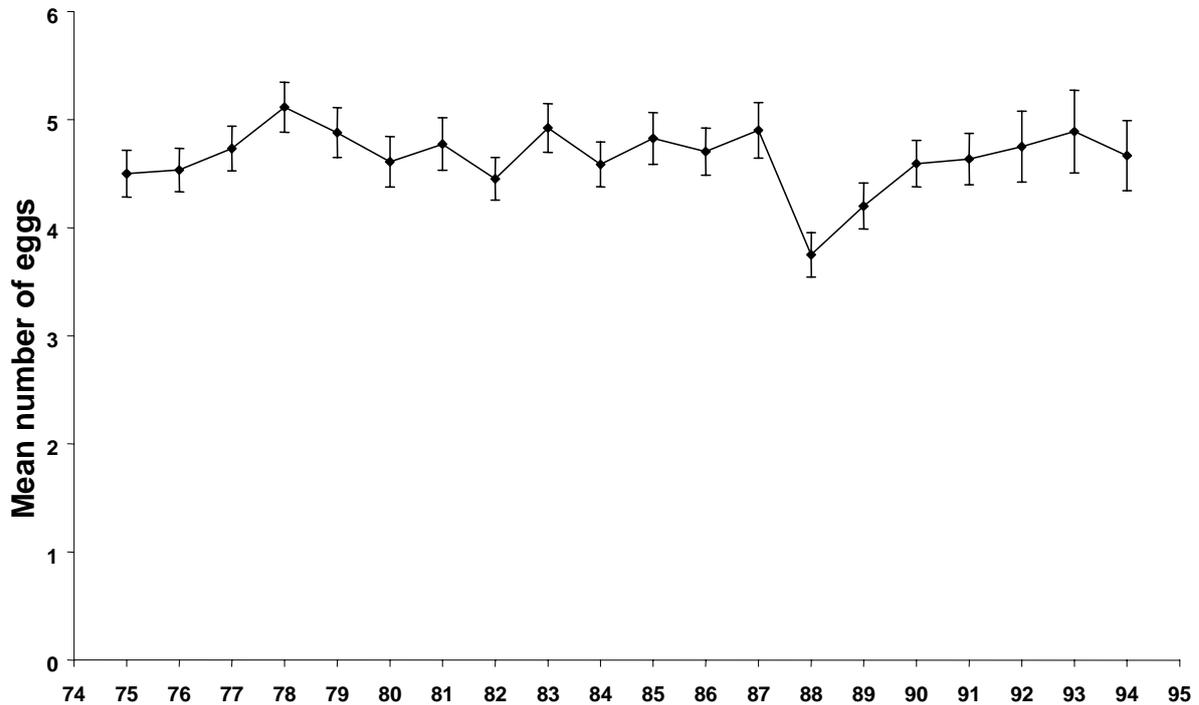


Figure 5.4.3.1 Mean clutch size in first broods in Worpleston boxes, 1975-1994. Vertical error bars represent ± 1 standard error.

5.4.4 Inter-Clutch Intervals

In all years except 1978, 1979, 1986, 1992 and 1996, some females were recorded rearing first clutches to fledging and then returning to lay second clutches (Figure 5.4.1.1). In each year, the number of females involved ranged from one to 14. The mean interval between the laying of the first egg of the first clutch and the first egg of the second clutch, for each year ranged from 39.0 to 54.3 days. No trends over time were apparent in this variation.

5.4.5 Brood size at 16 days

For first and second clutches, brood size at 16 days varied significantly between individual years (first: $F_{19,468}=2.14$, $P=0.004$; second $F_{19,144}=3.50$, $P<0.001$), but did not do so for intermediate clutches ($F_{19,153}=1.08$, $P=0.381$). There were no trends over time (Figure 5.4.5.1), and the depressed numbers of young in 1978 and 1979 were due to high levels of disturbance in the colony in those years. For the three clutch types, mean brood size at 16 days ranged as follows: first 1.12-4.11, intermediate 1.00-5.00, second 0.01-3.00.

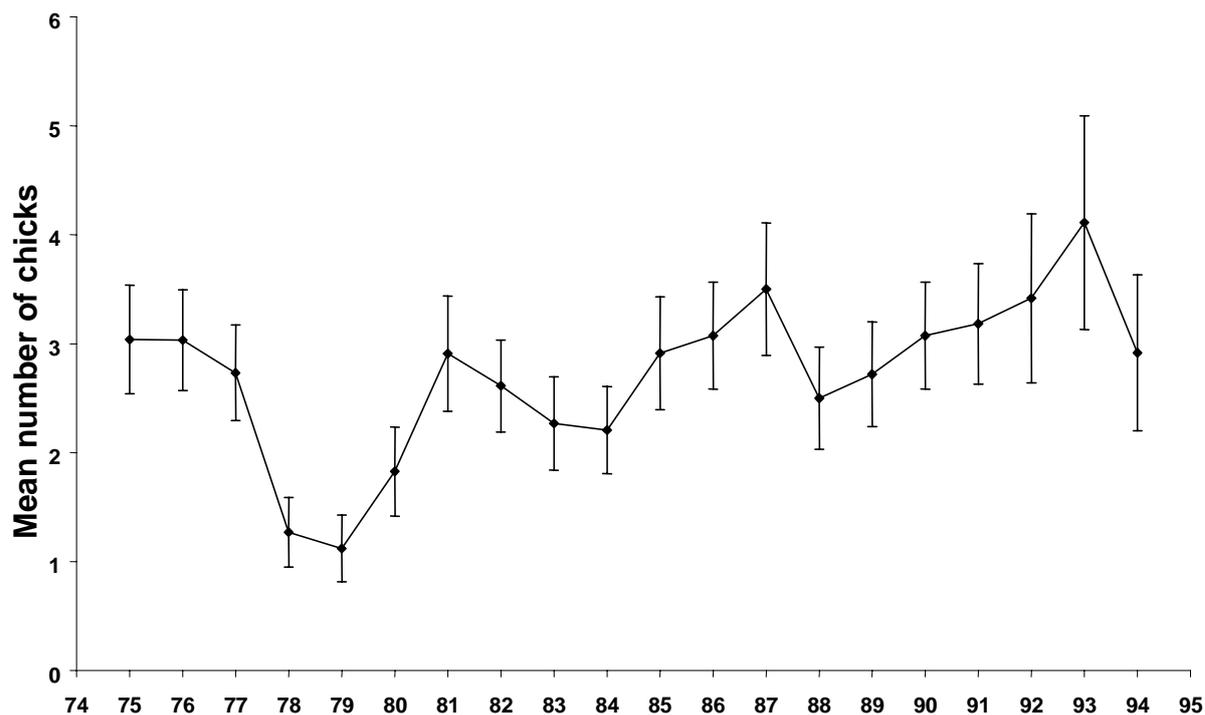


Figure 5.4.5.1 Mean brood size of first broods at 16 days old in the Worplesdon boxes, 1975-1994. Vertical error bars represent ± 1 standard error.

5.4.6 Proportion of clutches that produced young

The proportion of clutches that produced at least one fledged young each year varied significantly for first and second clutches (first: $\chi^2_{19}=64.78$, $P<0.001$; second: $\chi^2_{19}=64.78$, $P<0.001$) but not for intermediate clutches ($\chi^2_{19}=23.39$, $P=0.220$). There were no significant trends over time (Figure 5.4.6.1) and the low success of first clutches in 1978 and 1979 was again due to considerable human disturbance in the colony in those years.

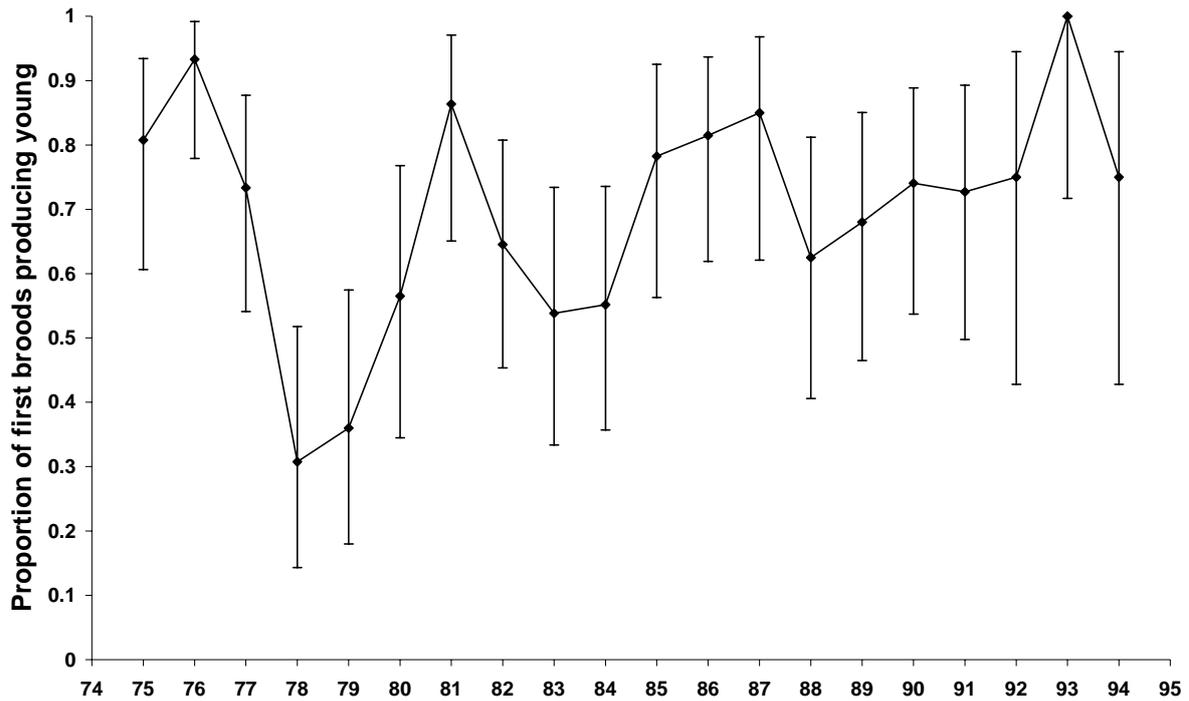


Figure 5.4.6.1 Nesting success (proportion of nests that produced fledged young) for first broods in the Worplesdon boxes, 1975-1994. Vertical lines are 95% confidence limits.

5.4.7 Total number of 16-day-old young produced

The total number of 16-day-old young produced from each clutch each year is shown in Figure 5.4.7.1. Clearly, most young were produced from first clutches and fewest from second clutches. Over the study, the proportions of 16-day-old young produced by first, intermediate and second clutches was 0.690, 0.192 and 0.118 respectively. With first clutches, low production in 1978 and 1979 were again due to considerable human disturbance in those years and, omitting these years, production varied between years, with a decline in production from 1992 onwards, corresponding to the smaller number of pairs that nested after the 1990-1992 decline in nestbox occupancy. Intermediate clutches showed great variability over the period, again with low production from 1992 onwards, and second clutches generally produced very few young, except in 1985 and 1990.

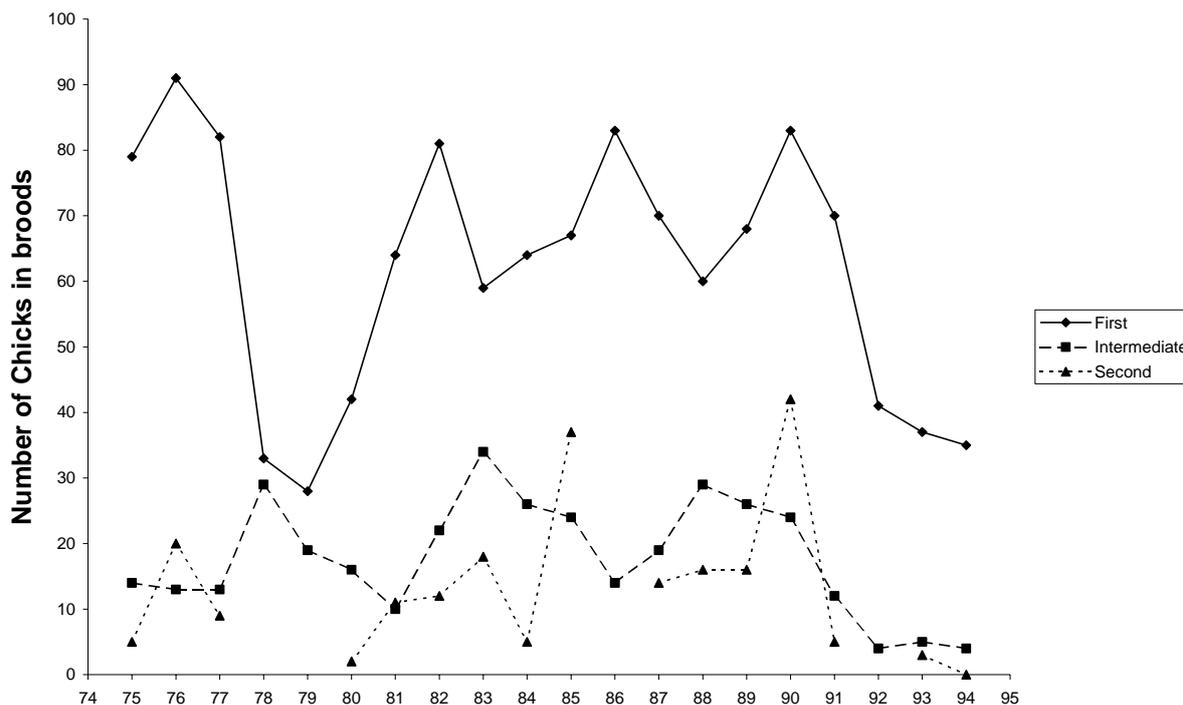


Figure 5.4.7.1 Total number of 16-day-old young produced by first, intermediate and second clutches between 1975 and 1994. The small numbers of chicks produced from first clutches in 1978 and 1979 reflect human disturbance in the colony in those years.

5.4.8 Body mass of 16-day-old chicks

In all clutches, the body mass of chicks at 16 days varied significantly over years (first: $F_{19,1230}=14.55$, $P<0.001$; intermediate: $F_{19,338}=4.59$, $P<0.001$; second: $F_{14,196}=2.67$, $P=0.001$). Mean annual body masses (g) ranged as follows: first 66.8-79.8, intermediate 59.6-77.0, second 57.1-74.7. There were no significant trends over years although mean masses of intermediate chicks in 1975-1979 were lower than in all other years (Figure 5.4.8.1).

Of 67 chicks that returned as adults to the Worplesdon colony to breed, 45 had fledged at a body mass heavier than the mean for each year, whereas only 22 that fledged at a body mass lower than the mean for each year returned. The proportion of heavier chicks that returned was significantly different from the null hypothesis that body mass did not affect rate of return (Binomial test: $Z = 2.69$, $P = 0.007$).

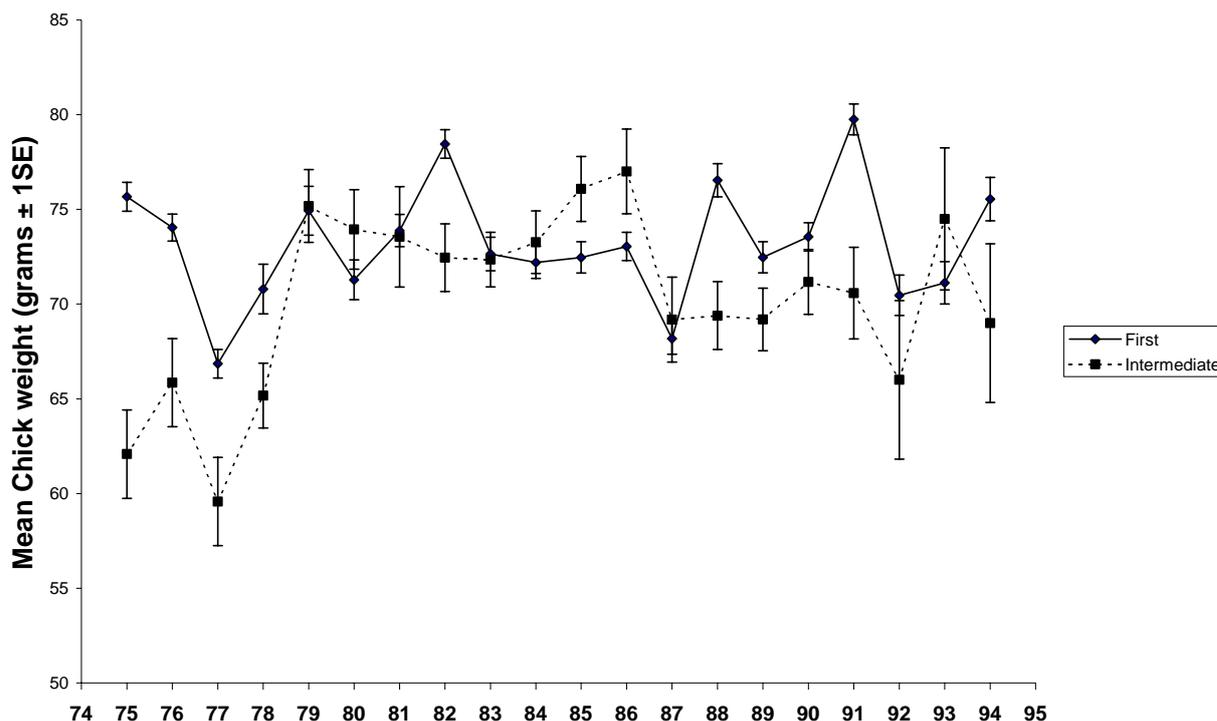


Figure 5.4.8.1 Mean masses of chicks from first and intermediate broods, 1975-1994. Vertical error bars represent ± 1 standard error.

5.4.9 Age at which birds ringed as chicks returned to breed

The sex of chicks could not be determined in this study and thus the sex ratio of chicks that fledged was unknown. When they returned to breed, however, the sex of these birds was recorded and thus the age at which each individual first bred could be recorded (Table 5.4.9.1).

Table 5.4.9.1 The age at which birds ringed as chicks returned to breed for the first time. These data include birds that were reared between 1975 and 1991.

Sex\Years	1	2	3	4	5	6	7
Female	16	9	1	1	1		
Male	12	16	6	0	1	2	1

Males and females were both recorded breeding for the first time at one-year-old, but males showed a greater tendency to be recorded breeding for the first time at two-years and older ($\chi^2_1 = 4.31$, $P = 0.038$).

5.4.10 Number of breeding attempts by birds, ringed as chicks, that returned to breed

Birds that returned to the nestbox colony to breed were recorded breeding in up to five years (Table 5.4.10.1). There was a tendency for females to make more annual breeding attempts than males but this difference was not significant (Table 5.4.10.1; Mann-Whitney $W_{4,4} = 29$, N.S.). Birds that bred in two or more years were not all recorded breeding in consecutive years (i.e. they were not recorded breeding in the study area in each year after they first appeared); of the 16 females that bred in two or more years, two birds did not breed, or bred elsewhere, in one year. Similarly, of 15 males that bred in two or more years, four missed a year (differences between sexes not significant). As a result of

this, and of the delayed start of breeding by some birds (Table 5.4.9.1), the number of years in which they bred did not reflect the birds' ages and some birds bred when seven to nine years old (Table 5.4.10.2).

Table 5.4.10.1 The number of years in which Starlings, ringed as fledglings in the Worplesdon colony, were recorded breeding.

No. of years recorded	1	2	3	4	5
Females	15	5	4	2	4
Males	17	9	4	1	1

Table 5.4.10.2 The ages at which Starlings, ringed as fledglings in the Worplesdon colony, made at least one attempt to breed.

Age	1	2	3	4	5	6	7	8	9
Female	15	17	11	9	7	3			
Male	12	19	15	5	3	3	3	1	1

The data from which Table 5.4.10.2 was derived are presented more fully in Table 5.4.10.3, showing for each year the number of birds of different ages that attempted to breed. This suggests that prior to 1987, birds of a broad spectrum of ages bred in years when reasonable numbers of birds that had been reared in the colony returned. In other words, birds that returned were surviving for up to six years (females) and nine years (males). After 1987 there appeared to be an abrupt change in female returns, with birds breeding in only one year, mainly their first year of life. In males the picture was less distinct since there appeared to have been a more gradual decline in the number of years for which birds bred, but culminating in a restriction to two or three years of breeding per individual after 1987.

Table 5.4.10.3 The number female (F) and male (M) Starlings, ringed as fledglings in the Worplesdon colony, of different ages that attempted to breed each year

Age	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94
F																				
1		3	2			1			1		1	1	2		1	1	1			1
2	1	3			1	2	1		3		3		2	1						
3	1	4			1	1					2		2							
4		3				1			1		2		2							
5		2				1			2				2							
6		1							1				1							
M																				
1		2				1		2		1	2			1	1	1	1			
2		2	1	1		1	1	2	3	1	1	1	1	1	1	1	1			
3		3	2	1		1		3	1	1	1	1		1						
4			1	1				1		1		1								
5			1	1		1														
6		2	1																	
7		2	1																	
8		1																		
9		1																		

5.4.11 Proportion of ringed chicks that returned as breeding birds

As most chicks that returned to breed began doing so within three years, birds that fledged in 1992 or later might not have returned before the end of the study in 1995 and therefore 1991 was the last birth year used in the analysis of the number of birds that returned from each year of the study.

Between 1975 and 1991, 1696 16-day-old nestlings were ringed in the nestboxes. Of these, 67 (3.95%) were later found in the nestboxes as breeding adults. However, there were differences in the proportions of birds from the three clutches that returned: first clutch – 59 returned from 1165 ringed (5.06%); intermediate clutch – six from 335 ringed (1.79%); second clutch – two from 196 (1.02%). The difference in the proportions that returned from the first and later clutches was significant ($\chi^2_1 = 11.02$, $P = 0.001$).

These data show that too few birds fledged from intermediate and second clutches returned to the colony for analysis of annual trends. For birds that fledged from first clutches, however, between 1975 and 1986 there was great variation between years in the proportion of young fledged that were later recorded breeding in the colony (Figure 5.4.11.1). For birds fledged between 1987 and 1992, variation between years continued but the peaks of recruitment did not attain the levels recorded in earlier years.

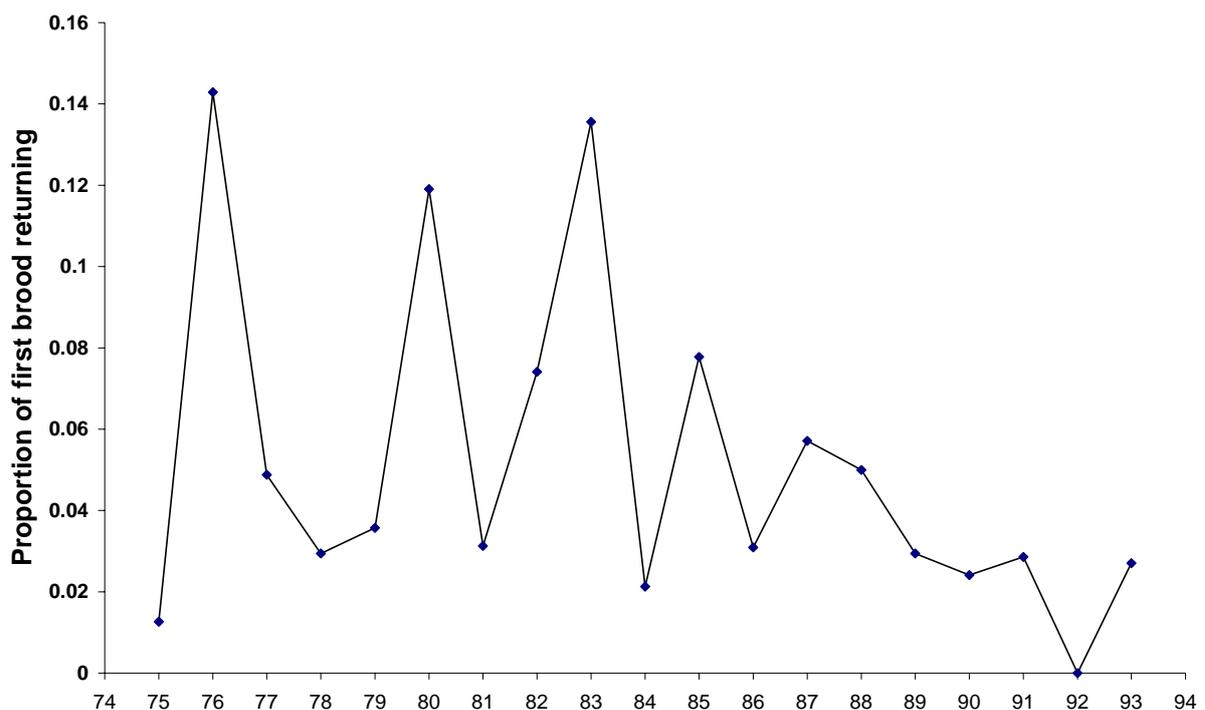


Figure 5.4.11.1 The proportion of birds fledged each year, in first clutches, that was subsequently recorded breeding in the colony.

5.4.12 Recruitment to the colony

Figure 5.4.11.1 shows that few Starlings reared in the colony were subsequently recorded breeding there. Many breeding adults were unringed when first recorded, indicating that they had immigrated, either from nests elsewhere in the local area, or from further afield. The number of immigrants greatly outnumbered the recruitment from local production (Figure 5.4.12.1) in all years of the study. However, from 1989 onwards both the number of immigrants to the colony and the number of birds that had previously bred in the colony declined and this therefore contributed to the decrease in the breeding population that utilised the Worpleston nestboxes, in addition to decreased production from the nestbox colony.

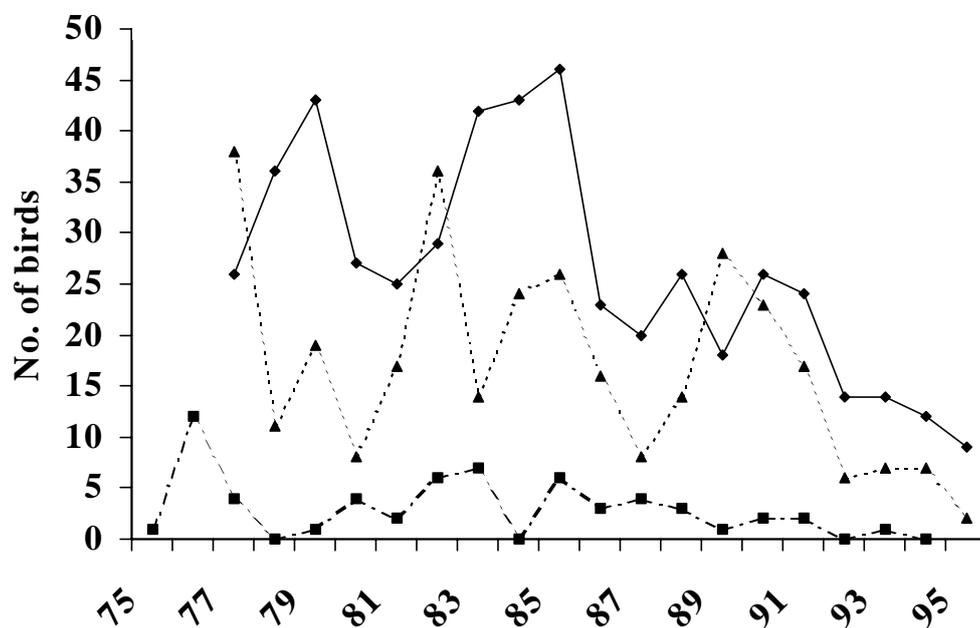


Figure 5.4.12.1 Annual variation in the number of recruits to the Worpleston study area that had been ringed as nestlings in the colony (squares), and in breeding adults that were first recorded as unringed birds and which were therefore immigrants (triangles), together with the number of adults that had bred in the colony previously (diamonds).

5.4.13 Emigration from the colony

The few recoveries of birds ringed in the Worpleston colony indicate both fidelity to the area and dispersal further afield. Five birds ringed as nestlings and found dead in May or June of the same year were all found within 6km of the colony. Four birds ringed as nestlings in the colony and recovered during the breeding season in subsequent years (three the next year and one seven years later) were found within 4km of the colony. Two birds ringed in the colony, one as a nestling and the other as a first year, were recovered the following year during the breeding season 27 and 56km away respectively.

5.5 DISCUSSION

5.5.1 Number of nestboxes occupied each year

The BTO's Common Birds Census, that first revealed the Starling's decline in Britain, was limited in the habitats that were covered well, being largely restricted to farmland and woodland. In both of these habitats declines were recorded in the late 1960s and from 1980 onwards (Marchant *et al.* 1990). At Worplesdon, numbers of occupied nestboxes remained fairly stable from the inception of the study until 1991, but thereafter the decline was sudden, followed by apparent stability at a considerably lower level until the end of the study. This decline thus differed from that recorded in farmland and woodland, being later and more sudden. Possible causes for such a sudden event include: a breeding failure in the immediately preceding years, failure of young from the previous two to three years to survive to breeding age, unusually high mortality of adults in 1990 and 1991, a severe shortage of food during these breeding seasons, a failure to recruit Starlings from surrounding areas, or a movement of Starlings away from the Worplesdon area. The remainder of this discussion examines these options in the light of the results of this study.

5.5.2 Date of laying, inter-clutch intervals, clutch size and fledging success

Crick *et al.* (1997) reported that the BTO's Nest Records Scheme had shown that Starlings were among 20 British species whose laying seasons had advanced, on average by about nine days over the period 1971-1995. The Worplesdon study, based on a much smaller sample of nests and from a singly locality, indicated that there was variation of up to 17 days in the date of initiation of laying between years, but that no trend in laying dates was apparent between 1975 and 1995. Feare (1984) indicated that the laying of second clutches was dependent on the date of initiation of first clutches, with a failure to lay second clutches in years when the initiation of first clutches was late. The absence of a trend in laying dates at Worplesdon, and thus the absence of a trend in the production of second clutches, suggests that failure to produce second clutches is not a factor in the observed decline in breeding numbers.

The absence over time of any trend in inter-clutch intervals indicated that females were not finding increasing difficulty in finding resources to lay second clutches at or before the decline in numbers of breeding birds.

Clutch size in first, intermediate and second clutches did not show any trends over the course of the study and, more importantly, there were no sudden changes during or immediately before the 1991-1992 decline in nest numbers that could have accounted for this decline. Similarly, there were no trends over time in the number of young fledged, as indicated by the mean brood size at 16 days, and there were no sudden changes at or just before the decline in nest numbers. Changes in breeding success thus cannot account for the change in breeding numbers in this colony.

5.5.3 Fledgling body mass

The mass attained by nestlings before departure from the nest might influence their subsequent survival (Perrins 1979, Newton 1989) and the return to Worplesdon of more heavier chicks at fledging that those that fledged at lighter body masses suggests that this also applies to Starlings. This study confirmed previous findings (Feare 1984) that each year most fledglings were produced from first clutches and least from second clutches, and also showed that mean body masses of first clutch chicks tended to be heavier than second clutch chicks. However, in none of the clutches were there any trends over time or sudden changes at or before the decline in nest numbers in the colony.

5.5.4 Return to the colony as breeding adults

In this study it was not possible to measure post-fledging survival directly. The number of fledged birds that returns to breed in later years is determined by post-fledging survival, together with emigration to other breeding colonies. Few Starlings that had been ringed at Worplesdon were recovered but most of those that were found dead were found within 6km of the colony. Two birds were found dead the following breeding season further away, suggesting that these birds had emigrated to breed elsewhere. Even local dispersal, however, would have led to failure to record birds that survived to breed but that bred elsewhere in Worplesdon/Guildford. Within the grounds of the laboratory where the nestboxes were available only two nest sites were identified where nesting adults could not be caught. Elsewhere in Worplesdon, however, potential nest sites in trees and buildings were used and these were not accessible to us for catching birds. Thus the recorded return of fledged birds from the nestbox colony represents a minimum return rate but there is no reason to believe that the birds' selection of our nestboxes, in relation to the other nest sites available, should have changed during the study. Consequently, the return of birds fledged from the colony should indicate any trends or sudden changes in survival or emigration.

Too few birds from intermediate ($n = 6$) and second ($n = 2$) clutches returned to nest in the colony to determine whether any changes had occurred. The proportion of chicks that fledged from first clutches between 1975 and 1985 and returned in subsequent years showed great variation. From 1986 onwards, however, the amplitude of inter-annual variation was reduced but the proportion that returned was generally lower than in the earlier years, with peaks never attaining the magnitude of those in 1976, 1980, 1983 and 1985. This suggests that from 1986 onwards, either post-fledging survival fell, in that there were no further "good" years, or that emigration was more consistently high in all years.

A change in survival or fidelity to the colony is also suggested in the late 1980s by the abrupt reduction in the number of years in which females returned to breed, and a less abrupt but nevertheless clear reduction in the number of years in which males bred.

The ages at which young Starlings returned to breed at Worplesdon were highly variable, ranging from one to five years for females and one to seven years for males. The longer delays in returning to breed could have resulted from these birds having bred nearby, but not in the nestboxes, during their early years. Coulson (1960) concluded from ring recoveries that females normally first bred when one year old, while males normally did not breed until two years old. At Worplesdon, many birds of both sexes bred at one year old but males did show a tendency to return later than females (Table 5.4.9.1). Coulson (1960) considered that non-breeding by males in their first year led to greater survival than females, and that this contributed to the well-established sex bias of approximately 2:1 in favour of males, observed in many Starling populations. Together with the observation that some males are polygynous, this implies that there must be a substantial non-breeding section of the male Starling population.

5.5.5 Return of breeding adults

The inability to distinguish between mortality and emigration in relation to the return of young applies also to the return of established breeding adults. Relatively few of the birds that were recruited to the colony as breeding adults had been reared in the colony; the majority of new recruits were first recorded as unringed birds (Figure 5.4.12.1), indicating substantial immigration from nests in the surrounding area or from further afield. The nestbox colony at Worplesdon was thus part of a more open breeding system, whose size and geographical area we do not know, but this was sufficient to preclude the estimation of annual survival of adults that bred in Worplesdon. A decline in the number of immigrating adults to the Worplesdon breeding population from 1989 onwards paralleled the decline in the number of birds that had bred in the colony before, and both clearly contributed to the reduction in the size of the nestbox breeding colony. This indicates that the decline in the Starling

population is likely to have affected a wider area than that immediately surrounding the study site, but again the geographical extent of this area is unknown.

5.5.6 What caused the decline?

As no environmental variables were monitored during this study, factors responsible for the post-1987 change in the apparent survival of breeding adults, and for the 1991 decline in the population, cannot be established. Major changes in habitat, however do not appear to have been responsible. The main change in habitat, due to the building of housing, was completed by 1980. Over most of the area within 1.5km of the nestbox colony (the foraging area of nestbox-breeding Starlings during the breeding season – C.J. Feare pers. obs.) there appeared to have been no changes in woodland structure or land use that might have rendered the study site less attractive to Starlings in relation to other areas in the vicinity.

The winter of 1991 was one of the coldest winters of this study. However, even colder and more prolonged winters, such as those of 1947 and 1962, do not appear to have caused substantial mortality in Starlings, in that large numbers of Starlings were not found dead (Feare 1984), unlike several other species. Summer may be more likely to represent a time of hardship for Starlings, in that many soil surface invertebrates become unavailable due to emergence as adults or to drying of the soil surface this time juveniles disperse from their natal range and many move to more peripheral habitats, possibly avoiding competition from adults for scarce resources near the nesting area (Feare 1984). After the 1976 summer, which was exceptionally hot and dry, the Worplesdon Starling breeding numbers did not decline, and a higher proportion of 1976-reared juveniles returned to breed in later years than from any other year group, suggesting that 1976 juveniles survived well. These extremes, of cold winter and hot summer, did not appear to have contributed to changes in population of the magnitude seen between 1991 and 1992. The relationship between annual survival in Starlings and climatic factors remains to be investigated.

Most of the nestbox-breeding Starlings fed during the breeding season in the permanent grass fields grazed by horses and donkeys. In the mid-1980s, a new vermicide, Ivermectin, became available and rapidly came into widespread use for horses and cattle. The compound remains active in dung for over 140 days and prevents the development of insect larvae (Errouissi *et al.* 2001) and thus could have affected one of the sources of food, coprophagous insects and their larvae, that are exploited by Starlings. During the breeding season Starlings rely predominantly on subterranean or surface-dwelling invertebrates but in summer, when this food resource diminishes due to the emergence of insect imagines and the inability of Starling bills to penetrate hard dry soils in search of sub-surface prey (Feare 1984), Starlings utilise other food sources, including invertebrates from dung. The importance of this source of food for Starlings in summer has not been established but, if it is important, depletion through the advent of Ivermectin might have had an impact on the survival of adults and also on the post-fledging survival of young.

A viral infection, Starling pox, was evident from lesions on juveniles, mainly on the face. Infected birds were seen in most years but in insufficient numbers to assess annual variations. We were not aware of other diseases in Worplesdon Starlings, but did not examine birds for these, or for parasitic infections. The possibility that disease could have been involved in the decline thus cannot be eliminated.

5.6 CONCLUSION

This study has demonstrated a severe decline in a local suburban population of Starlings in Southern England. The decline was abrupt, occurring in 1991-1992. The study provided no evidence that events during the breeding season were responsible for the decline, suggesting that juvenile or adult survival at other times of year must have increased to such an extent that the population could not be self-sustaining at its former level.

Before the decline, the proportion of young that returned from each year's breeding season was highly variable, with "good" and "bad" years. There had been no trend over years in the output of young each year, suggesting that the failure of young to return from "bad" years was due to either mortality or emigration, or a combination, factors that themselves were highly variable. The data from the returns of breeding adult birds in subsequent years were inadequate to provide estimates of annual adult mortality and its variation. However, the reduction in the ages of known age birds that bred in the colony after 1987 suggested that conditions for adults had changed, either leading to lower survival, or to a tendency to emigrate after breeding in the colony for one or two years.

Following the population decline, the data set was small due to the smaller number of breeding pairs each year and to the short run of years for which data were available. However, the population did appear to stabilise at a lower level.

The small proportion of fledglings that returned to breed in the colony (overall fewer than 4%) may indicate that this suburban colony was never self-sustaining, and that numbers of breeding adults were sustained by immigration from other habitats. This was supported by the number of unringed breeding adults that were recorded in most years. However, Figure 5.4.12.1 shows that in addition to the decline in the number of Worplesdon-bred birds entering the nestbox population after 1991 and in the number of birds that had bred previously in the colony, the number of unringed immigrants also declined, suggesting more widespread, if still local, effects. If this were the case, then the decline in this suburban area might have been a sequel to declines in more productive habitats, e.g. farmland and woodland, where less abrupt declines have been recorded over a longer time scale, and at different times, by the BTO Common Birds Census. If this conclusion is correct, suburban habitats must be regarded as sub-optimal for Starlings. This is of concern for the future of Starlings breeding in Britain, where a substantial part of the starling population is now believed to nest in urban/suburban areas (see Chapter 2), where this study has demonstrated that sudden falls in numbers can occur. Alternatively, the earlier declines in woodland and farmland populations could indicate that suburban areas are now the optimal habitats for Starlings. In this case, the scale of the reduction in numbers at Worplesdon emphasises the need for studies of other suburban populations in order to understand their population dynamics and identify factors important for the survival of these populations.

6 NATIONAL TRENDS IN THE BREEDING PERFORMANCE OF STARLINGS *Sturnus vulgaris*

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6.1 CHAPTER SUMMARY

1. This study uses the Nest Record Scheme archive to investigate temporal and spatial patterns in the breeding performance of Starlings, to investigate whether changes in any aspect of breeding performance might have helped to drive population change.
2. Breeding performance of Starlings per nesting attempt has tended to improve over the past 40 years.
3. We analysed breeding performance with respect to blocks of years in which population monitoring schemes (Common Birds Census (CBC) and Garden Bird Feeding Survey (GBFS)) show consistent patterns of stability, increase or decrease.
4. Breeding performance was negatively correlated with population growth rate of Starlings on CBC and GBFS plots. These results suggest that changes in breeding performance are unlikely to have played a role in determining population changes of Starlings.
5. Breeding performance was highest in the South West and West of Britain. It has improved most rapidly in the West, North and East of Britain and shown least improvement in the South East, where densities are currently greatest but where population declines have been steepest, both historically and currently.
6. Although there was little difference in average breeding performance between birds nesting on arable, pastoral or mixed farming systems, the breeding performance of Starlings has improved over the past 30 years in mixed farming areas.
7. The breeding performance of Starlings was higher when nesting in or near human habitation in rural situations compared to suburban areas and was lowest in urban areas. Furthermore, some aspects of breeding performance have declined in suburban and urban habitats.
8. Starling breeding performance showed a complex response to livestock levels, which indicates that different factors may influence breeding performance at different stages of the nesting cycle.

6.2 INTRODUCTION

The Starling is a cavity-nesting species that has become adapted to living commensally with man. Starlings show a strong preference for feeding on grassland preferably with short swards, having specialised mandibular apparatus that allows them to probe and extract soil-living invertebrates efficiently (Feare 1984). Man provides abundant quantities of this habitat in towns and also through improved pasture, and thus these are the habitats where a large proportion of Starlings are found in

Britain (Chapter 2). The nestling diet is more restricted than that of the adults and in Britain is dominated by crane-fly larvae (leatherjackets, Tipulidae; Whitehead 1994).

Significant changes in land management over the past few decades, particularly in the management of pasture, are likely to have affected the invertebrate populations that birds, such as Starling, feed on. The review of Vickery *et al.* (2001) showed that significant changes in grassland management over the past 30 years include a doubling in the use of inorganic nitrogen, increased stocking densities and a switch from hay to silage. These factors have the potential to affect Starlings foraging during the breeding season and, thus, to affect their breeding performance. Whilst the addition of inorganic fertilisers tend to decrease the numbers and diversity of grassland invertebrates generally (Fenner & Palmer 1998), tipulid larvae appear to be unaffected by fertiliser application (Linzell & Madge 1986). Silage production, with its increased frequency of cutting, may increase prey availability for Starlings by making it easier for them to reach through shorter swards, although the swards tend to be denser. Increased stocking densities may produce short sward heights that improve the accessibility of soil invertebrates for Starlings and dunging is probably an important factor in increasing the abundance of sub-surface soil invertebrates (Fuller & Gough 1999). On the other hand, increased stocking densities may cause soils to dry out more rapidly because of reduced vegetation cover in response to trampling, decreasing the availability of soil invertebrates.

The declines in Starling numbers in Finland have been ascribed to declines in dairy farming (Tiainen *et al.* 1989; Solonen *et al.* 1991). Cattle tend to bite, pull and tear ground vegetation and maintain a longer sward as a result. Sheep are able to graze close to the ground level and are able to produce very short swards exposing the surface soil more (Crofts & Jefferson 1999). The gradual decline of cattle numbers in Britain, while sheep numbers have increased (Vickery *et al.* 2001), may be detrimental to Starling breeding performance because of the differences in their effect on grassland characteristics.

We have shown that population declines in Britain to differ in different habitats and regions (Chapter 2) and that these differences may be linked to differences in breeding performance in response to differences in land management. Here we analyse the BTO's Nest Record Scheme (NRS) archive for Starling to investigate temporal and spatial patterns in the breeding performance, to investigate whether changes in any aspect of breeding performance might have helped drive population change. It should be noted that data from the NRS can only provide information per nesting attempt. Information on the numbers of broods raised by a pair per year is not obtainable for the dataset. Thus, this analysis is able to report on average laying dates, clutch sizes, hatching success, brood sizes and nest failure rates at egg and chick stages. These variables can be combined to produce a measure of the number of fledglings raised per nesting attempt.

Periods of population increase, decline and stability were identified in Chapter 2 from significant changes in the direction of population trends measured in different habitats by the Common Birds Census (CBC) or the Garden Bird Feeding Survey (GBFS). If breeding performance is higher during population increases and lower during population declines, this would be consistent with the possibility that changes in breeding performance had helped to drive population changes. If a converse pattern occurs, this would suggest that breeding performance changes as a result of a broadly density-dependent response to population change after a change in another demographic factor.

In addition, we analyse differences in breeding performance between different broad regions and habitats to investigate how breeding performance relates to differences in apparent suitability (as shown by population density) and population trajectory, as measured by CBC, GBFS and the BTO/JNCC/RSPB Breeding Bird Survey (BBS) (Chapter 2). Finally, we undertake some specific tests of how breeding performance varies in relation to spatial differences in various key agricultural variables. In particular, as a specialist feeder on pasture, the Starling might be expected to be affected by the levels of livestock in a county, as discussed above. Increased grazing pressure that maintains lower sward heights might permit Starlings to probe into soils for invertebrates more easily than where sward heights are taller, although differences in the effect of grazing by cattle and sheep have

to be borne in mind. In addition, the differences in grazing pressure exerted by cows and sheep might be reflected in differences in the way breeding performance changes in response to livestock densities.

6.3 METHODS

The NRS (reviewed in detail by Crick & Baillie 1996) comprises a national network of volunteer observers who submit standardised records of nest contents, location, habitat and evidence of success or failure, derived from one or more visits to a nest site. Some or all of first egg date, clutch and brood size, chick:egg ratio (a measure of hatching success) and daily nest failure rates can be estimated for each nest record card (NRC), depending on the information provided. NRCs records also contain habitat data recorded using a hierarchical scheme in which a nest is assigned first to a general category (woodland, grassland, farmland, etc.) and then to a combination of three further levels of habitat detail (Crick 1992; Crick, Dudley & Glue 1994). Prior to 1990, habitat data were recorded differently (using a single code representing one of around 100 habitat types, together with additional information about key components of the habitat).

We have analysed Starling nest record data from 1960 to 2000 to investigate temporal variation in breeding success and the influence of habitat. Temporal changes in breeding performance were assessed by means of both categorical and continuous time variables (blocks of years and linear/quadratic trends, respectively), while habitat variation was investigated using categorical variables defining groups of NRCs from similar habitats.

The variation in breeding performance per breeding attempt was investigated using the following nest record-derived variables:

- First egg date (the date on which the first egg in the clutch is likely to have been laid, excluding cases where the date is not known within ± 5 days; day 1 = 1 January).
- Clutch size (the maximum number of eggs found in a nest). Clutch size data were rejected if egg laying could have continued after the last visit of the recorder.
- Brood size (the maximum number of young found in a nest). This is likely to overestimate the brood size at fledging, but will approach it if mortality early in nestling life (when chicks are most vulnerable) is the most significant form of partial brood loss.
- Chick:egg ratio (the ratio of brood size to clutch size where the whole nest did not fail). This incorporates early losses of chicks, as well as hatching success (the proportion of the eggs in the clutch that hatch successfully).
- Daily nest failure rates before and after hatching (see below).

The number and timing of the visits (relative to nest progress) recorded on each NRC determines which of the above variables can be calculated, so the sample sizes for our analyses differed between variables and are given in Appendix 6.1.

The variation in each nest record variable was investigated using generalised linear models in the GENMOD procedure of SAS (SAS Institute, Inc. 1996). Daily nest failure rates were estimated using a formulation of Mayfield's (1961, 1975) method as a logistic model with a binomial error term, in which success or failure over a given number of days (as a binary variable) was modelled with the number of days over which the nest was exposed during the egg, nestling and whole nest (egg and nestling combined) periods as the binomial denominator (Crawley 1993; Etheridge, Summers & Green 1997; Aebischer 1999). The number of exposure days during the egg, nestling and whole nest (egg and nestling) periods were calculated as the mid-points between the maxima and minima possible, given the timing of nest visits recorded on each NRC (note that exposure days refer only to the timespan for which data were recorded for each nest and do not represent the full length of the egg and/or nestling periods). Chick:egg ratio was also modelled using a logit link and binomial errors, brood size forming the numerator and clutch size the binomial denominator. Individually, clutch and brood sizes were modelled with identity links and normal errors, as were first egg dates.

Because the NRS is unstructured, the acquisition of data from different parts of Britain has never been controlled and it is possible, therefore, that apparent changes in breeding performance parameters could merely reflect geographical variation and changes in the sample over time. To account for this, we added, as controls, continuous terms for latitude, longitude and the interaction between them to each of our models that investigated temporal variation in breeding performance (see below). Latitude and longitude were assigned to NRCs at the county level (values for the centre of each county) because finer-scale information on location was not recorded on most NRCs prior to 1985. The significance of the variation with respect to the continuous or categorical predictors of interest was assessed by comparing the fit of a model incorporating these predictors with a simplified model omitting them using a likelihood-ratio test (SAS Institute, Inc. 1996).

In order to reveal the net effects of the variation in each variable, we combined the category-specific estimates of clutch size, chick:egg ratio and daily nest failure rates from each comparison of temporal or habitat classifications to estimate the number of fledglings produced per breeding attempt. This was done according to the formula (Hensler 1985, Siriwardena *et al.* 2000a):

$$FPA_i = CS \times HS \times (1 - EFR)^{EP} \times (1 - NFR)^{NP},$$

where FPA_i is the number of fledglings produced per breeding attempt, CS is clutch size, HS is hatching success (chick:egg ratio), EFR and NFR are the egg and nestling period daily nest failure rates, respectively, and EP and NP are the lengths of the egg and nestling periods in days. EP and NP were taken to be the mid-points of the ranges given in Cramp & Perrins (1994) for populations in or near the British Isles, respectively: 16 and 21 days (N.B. egg period includes four days to allow for egg-laying). Confidence intervals for the FPA_i values were calculated following the methods in Siriwardena *et al.* (2000a).

6.3.1 Descriptive Comparisons and Hypothesis Tests

Variation in breeding performance with respect to time was investigated using both categorical and continuous variables. Annual samples were combined into blocks of years using two blocking regimes. Firstly, years were combined in simple five-year blocks from 1960-1964 to 1995-1999. Secondly, blocks were defined using periods of consistent population trend direction, as delimited by the significant turning points in each species' CBC or GBFS trends (see Chapter 2). The year-blocks defined by each population trend are shown in Table 6.3.1.1; each analysis using these blocks made use of the appropriate set of NRCs, for example farmland CBC blocks were used to classify cards from farmland. We also investigated whether significant trends have occurred in each variable over time by fitting simple linear functions to the data. These simple functions are the most efficient and easily interpreted way to summarise long-term trends (especially when data are sparse), although they may over-simplify the variation. Block analyses allow more complex variation with time: five-year blocks allow considerable flexibility in the temporal pattern that is produced, while blocks based on population trends have an objective basis because demographic rates can reasonably be assumed to have been constant within periods of consistent trend direction.

Table 6.3.1.1 Blocks of years used for analyses of Starling nest record data with respect to time.

Source of blocking information	Blocks used	NRC sample used
Five-year blocks	Pre-1965, 1965-69, 1970-1974, ... 1995-99	All
All Plots CBC	1962-66, 1967-73, 1974-79, 1980-99	All
Farmland CBC	1962-64, 1965-70, 1971-74, 1975-78, 1979-91, 1992-99	Farmland
Woodland CBC*	1965-69, 1970-99	Woodland
All Gardens GBFS	1970-73, 1974-80, 1981-85, 1986-88, 1989-92, 1993-99	All
Rural GBFS	1970-73, 1974-78, 1979-82, 1983-85, 1986-88, 1989-96, 1997-99	Farmland
Suburban GBFS	1970-73, 1974-80, 1981-85, 1986-88, 1989-92, 1993-99	Human

* No significant turning points at the 95% level but the one shown was significant at the 90% level.

The potential for variation in block-specific breeding performance parameters and FPA_t to have driven long-term population trends was assessed both graphically and by calculating correlation coefficients between the variables in question and block-specific CBC or GBFS trend slopes. The latter were estimated as the block-specific mean values of the first derivative of each species' long-term CBC or GBFS trend (see Siriwardena *et al.* 2000a for further details): a positive correlation with breeding performance (i.e. a negative correlation with a failure rate) would show that the variation in the parameter concerned is consistent with it having played a role in driving the observed population trend. It should be borne in mind that this approach does not allow for different demographic mechanisms to have occurred at different times. Statistical significance is not provided because sample sizes of blocks are all small ($n \leq 8$), thus the correlations are only illustrative.

6.3.2 Variation in breeding performance with respect to habitat

Habitat information on NRCs is now coded according to the scheme of Crick (1992), but for data from 1989 and earlier, translations from the preceding, less systematic scheme must be used (see, e.g., Siriwardena *et al.* 2000a,d). These habitat codes were used to classify NRCs into the categories described in Table 6.3.2.1 and breeding performance was then compared between the categories described. Tests were then conducted using models similar to those described for the temporal analyses above, with each of first egg date, clutch size, brood size, chick:egg ratio and the daily nest failure rates in the egg, nestling and whole nest periods being modelled (individually) as a function of each (categorical) habitat variable. Likelihood ratio tests against a constant model were used to identify significant habitat-specific effects and habitat-specific estimates of FPA were calculated. To control for possible temporal biases in the NRC samples (a possible consequence of the unstructured nature of the scheme), for example if farmland cards tended to be older than suburban cards, we repeated these analyses with the addition of a continuous time trend variable (a linear year effect).

To test for differences in the pattern of temporal change between habitat categories, we fitted further models of each component of breeding performance incorporating habitat \times linear time trend interaction terms. Because significant results from these tests could actually reflect geographical changes in the nest record sample rather than true differences in time trends, we repeated the tests with controls for interactions between trends and latitude, longitude and the interaction between them.

Table 6.3.2.1 Nest record habitat divisions used to investigate variations in breeding performance.

Test	Categories compared
Broad habitat	Farmland, Suburban/urban
Farm type	Arable, Grazing, Mixed
Human site type	Urban, Suburban, Rural

6.3.3 Variation in breeding performance between regions

NRCs were grouped into the regions defined for our analyses of CBC data (see Chapter 2) in order to investigate large-scale spatial variation in breeding success. Simple tests using region as a categorical variable were used to identify average regional values, as described for other categorical variables above. Further analyses controlling for possible temporal biases in the sample, using a linear time trend, were also conducted. We then examined the data for differences in temporal trends between the regions using models in which different linear time-trends were allowed for each region.

6.3.4 Variation in breeding performance with respect to agriculture

The June Agricultural Census conducted annually in England and Wales by DEFRA provides data on various features of agriculture that could affect Starling breeding performance. The data are most easily accessed as county-level summaries and we have used these data as covariates in analyses of breeding performance, using models similar to those described above. Specifically, we tested whether breeding performance was affected by (i) the proportion of farmland under arable (as opposed to pastoral) management, (ii) the proportion of barley that is sown in spring (no other cereals are split by sowing time in the June Census data), (iii) grazing intensity, measured in terms of the number of cows, the number of sheep and a combined grazing index (assuming one cow = three sheep). The latter was also tested using data only from NRCs from pastoral habitats, in order to isolate direct effects of livestock densities from broader geographical patterns. The tests conducted are summarised in Table 6.3.4.1.

Table 6.3.4.1 Agricultural Census variables used to investigate variation in breeding performance.

Variable	Variable name	Years Data Available
Proportion of Arable	GRABRAT	1963-2000
Proportion of Barley Sown in Spring	BARLRAT	1978-2000
Number of Cows	COWS	1977-2000
Number of Sheep	SHEEP	1970, 1977-2000
Grazing Intensity	GRAZIND	1977-2000
Number of Cows (Pastoral Habitats)	COWS2	1977-2000
Number of Sheep (Pastoral Habitats)	SHEEP2	1970, 1977-2000
Grazing Intensity (Pastoral Habitats)	GRAZIND2	1977-2000

6.4 RESULTS

6.4.1 Long-term trends

Long-term trends in the various aspects of Starling breeding performance are shown in Figures 6.4.1.1 and 6.4.1.2 and tests of linear trends over time are explored in Table 6.4.1.1. It can be seen that there are significant but shallow long-term trends towards larger clutch and brood sizes over time. Chick:egg ratio has also improved over time and failure rates of nests at all stages have fallen.

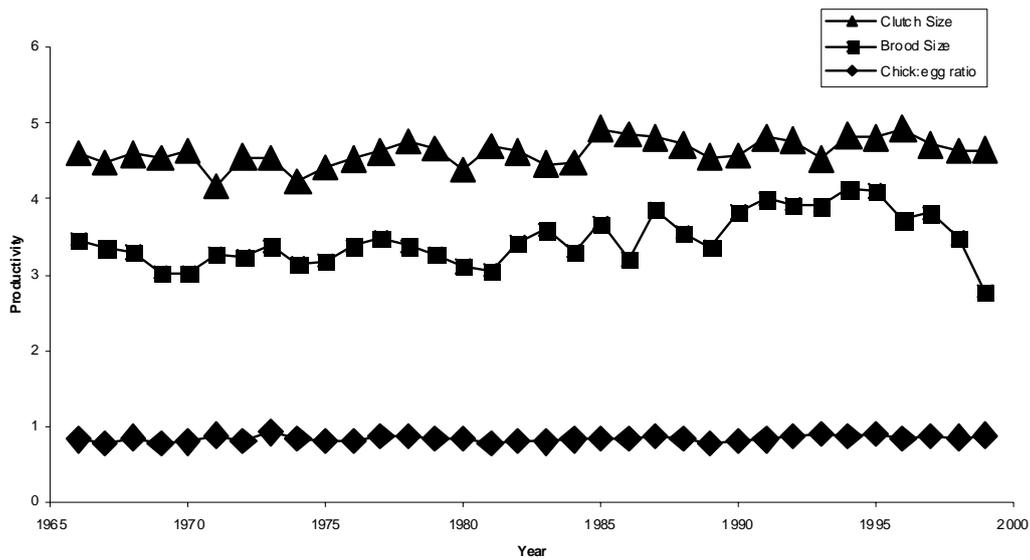


Figure 6.4.1.1 Mean annual estimates of clutch and brood size and chick:egg ratio for Starling.

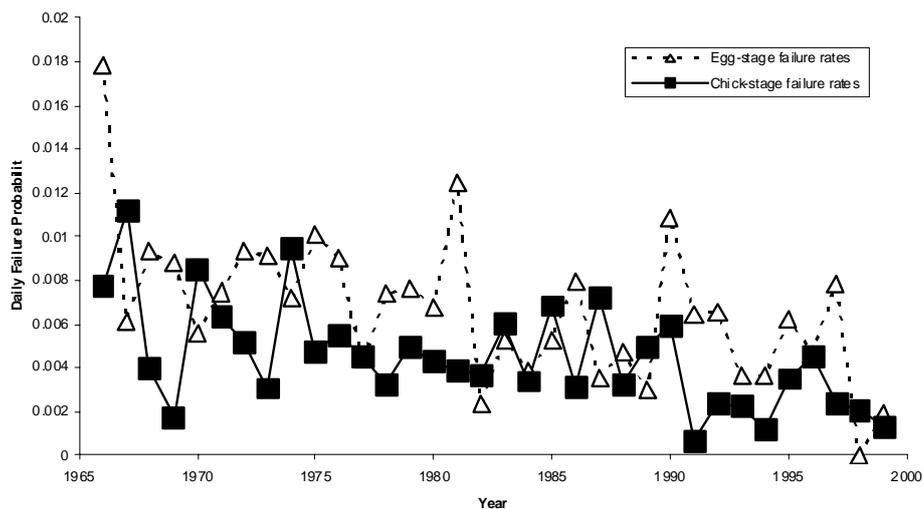


Figure 6.4.1.2 Annual estimates of the failure rates of nests at egg and chick stages for Starlings.

Table 6.4.1.1 Tests for linear trends in all NRCs for Starling (controlling for changes in latitude and longitude). LRT is the Likelihood Ratio Test for the significance of the slope.

Breeding performance parameter		Slope (SE)	LRT	
			χ^2_1	<i>P</i>
First Egg Date		-0.043 (0.032)	1.85	0.174
Clutch Size		0.011 (0.002)	29.27	<0.001
Brood Size		0.010 (0.002)	29.37	<0.001
Chick:egg Ratio		0.009 (0.003)	9.04	0.003
Daily Nest Failure Rate	Egg Period	-0.023 (0.007)	11.11	<0.001
	Nestling Period	-0.029 (0.007)	18.54	<0.001
	Whole Nest Period	-0.023 (0.004)	31.13	<0.001

6.4.2 Analysis of block-specific breeding performance in relation to trends in abundance

Six different sets of year-blocks were investigated (Table 6.3.1.1), five were related to periods of decline, stability and increase determined from CBC and GBFS trends and one was based on five-year periods. Sample sizes are provided in Appendix 6.1.

6.4.2.1 Five-year blocks

When nest record data were divided up into five-year blocks, significant differences between blocks were found for all variables except egg-stage nest failure rate (Table 6.4.2.1.1). Correlations with population growth rates (λ) for CBC and GBFS showed a consistent pattern of better breeding performance when populations were declining most. Thus there was a strongly negative relationship between FPA and both CBC and GBFS block-specific trends (Figure 6.4.2.1.1).

Table 6.4.2.1.1 Likelihood Ratio Tests (LRT) for heterogeneity between five-year blocks (controlling for changes in latitude & longitude) and correlations with block-specific population growth rates (λ).

Breeding performance parameter	LRT		Correlations with λ		
	χ^2_7	<i>P</i>	CBC	GBFS	
First Egg Date	32.79	<0.001	0.424	0.595	
Clutch Size	49.93	<0.001	-0.643	-0.436	
Brood Size	156.68	<0.001	-0.494	-0.399	
Chick:egg Ratio	32.09	<0.001	-0.622	-0.780	
Daily Nest Failure Rate	Egg Period	12.42	0.088	0.836	0.487
	Nestling Period	28.83	<0.001	0.651	0.206
	Whole Nest Period	39.05	<0.001	0.784	0.433

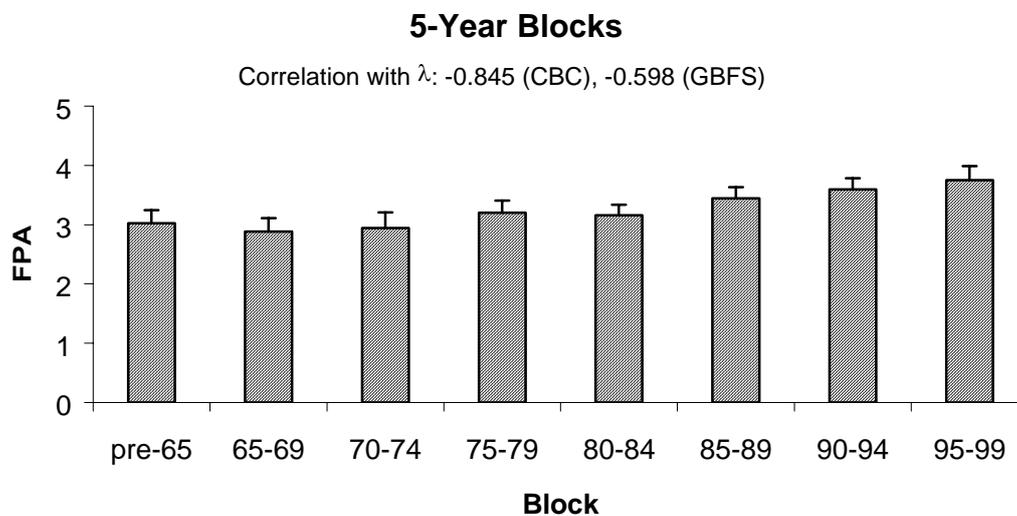


Figure 6.4.2.1.1 Block-specific estimates of fledglings per breeding attempt (FPA) in five-year blocks.

6.4.2.2 CBC blocks

When breeding performance was related to the periods of differing population change, as measured on all CBC plots, breeding performance (as measured by nest failure rates and clutch size, but not brood size) tended to be better when population changes tended to be more positive (Table 6.4.2.2.1). Although there was a positive correlation between brood size and λ , the coefficient was very small, indicating only a weak association. As a result the effect of the other aspects of breeding performance prevailed when population growth rates were correlated against estimates of FPA (Figure 6.4.2.2.1). A similar result for overall breeding performance was found for blocks of years defined from the farmland CBC trend, although it was brood size and egg-stage failure rates that were worse when the population growth was more positive (Table 6.4.2.2.2 and Figure 6.4.2.2.2). Finally, we analysed two blocks of years defined by the trend in population size measured on woodland CBC plots. Although the trend in abundance showed a pattern of continuous decline (Chapter 2), a turning point was detectable between 1969 and 1970 at the 90% significance level, when there was a brief period of stability. The woodland CBC results also suggested that breeding performance tended to be better when the population was declining most rapidly (Figure 6.4.2.2.3) with greater clutch sizes and chick:egg ratios and smaller egg-stage failure rates (Table 6.4.2.2.3).

Table 6.4.2.1 Likelihood Ratio Tests (LRT) for differences in breeding performance between blocks of population increase, stability or decline on all CBC plots (controlling for changes in latitude & longitude) and correlations with block-specific population growth rates (λ).

Breeding performance parameter		LRT		Correlation with λ
		χ^2_3	<i>P</i>	
First Egg Date		1.57	0.666	-
Clutch Size		23.72	<0.001	-0.740
Brood Size		30.67	<0.001	0.037
Chick:egg Ratio		3.30	0.347	-
Daily Nest Failure Rate	Egg Period	12.82	0.005	0.840
	Nestling Period	10.98	0.012	0.842
	Whole Nest Period	28.37	<0.001	0.946

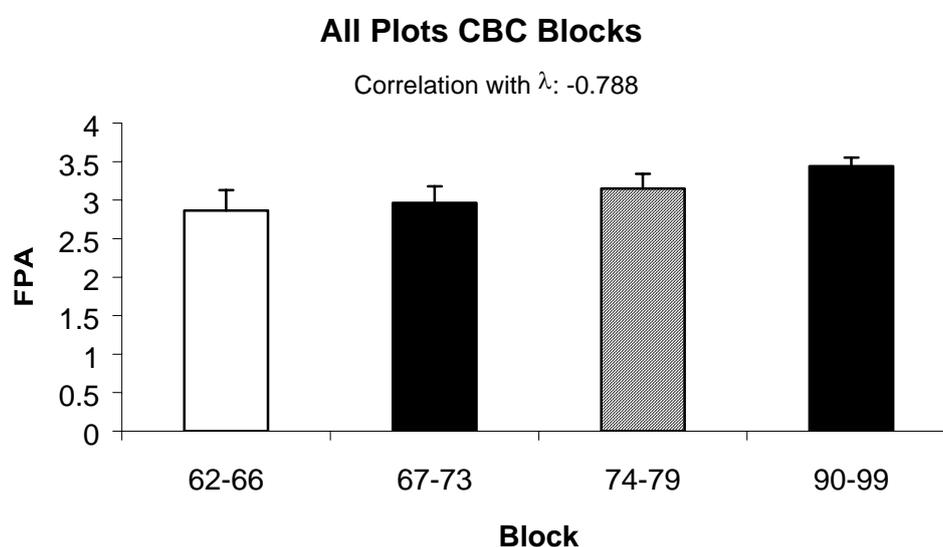


Figure 6.4.2.2.1 Block-specific estimates of fledglings per nesting attempt (FPA) in blocks of population increase (white), stability (hatching) or decline (black), as measured from all CBC plots.

Table 6.4.2.2.2 Likelihood Ratio Tests (LRT) for differences in breeding performance between blocks of population increase, stability or decline on farmland CBC plots (controlling for changes in latitude and longitude) and correlations with block-specific growth rates (λ).

Breeding performance parameter	LRT		Correlation with λ	
	χ^2_5	<i>P</i>		
First Egg Date	11.80	0.038	0.238	
Clutch Size	6.05	0.301	-	
Brood Size	42.67	<0.001	-0.324	
Chick:egg Ratio	33.74	<0.001	0.012	
Daily Nest Failure Rate	Egg Period	11.96	0.035	0.729
	Nestling Period	9.38	0.095	-
	Whole Nest Period	16.61	0.005	0.831

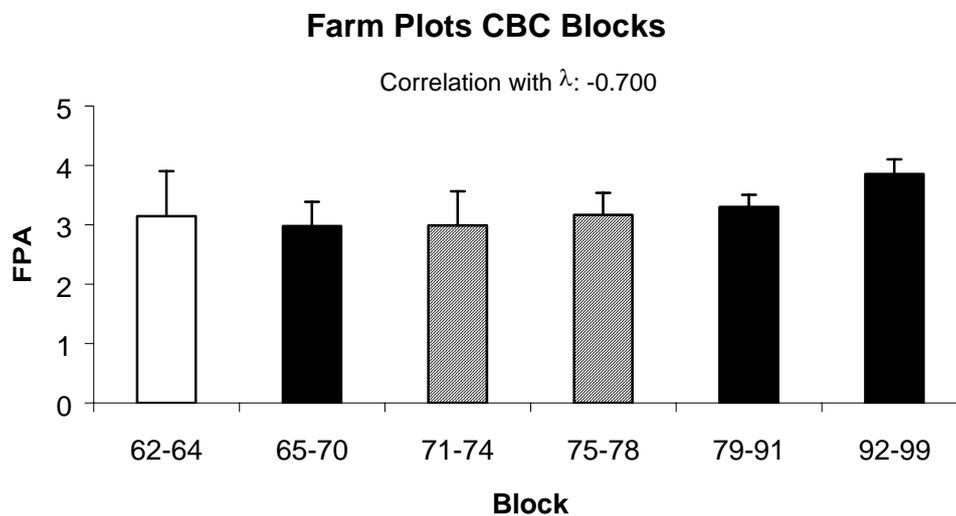


Figure 6.4.2.2.2 Block-specific estimates of fledglings per nesting attempt (FPA) in blocks of population increase (white), stability (hatching) or decline (black), as measured from farmland CBC plots.

Table 6.4.2.2.3 Likelihood Ratio Tests (LRT) for differences in breeding performance between blocks with different rates of population decline on woodland CBC plots (controlling for changes in latitude and longitude) and correlations with block-specific population growth rates (λ).

Breeding performance parameter		LRT		Correlation with λ
		χ^2_1	<i>P</i>	
First Egg Date		0.15	0.703	-
Clutch Size		6.86	0.009	-1
Brood Size		0.47	0.491	-
Chick:egg Ratio		12.11	<0.001	-1
Daily Nest Failure Rate	Egg Period	3.63	0.057	1
	Nestling Period	0.56	0.453	-
	Whole Nest Period	0.31	0.577	-

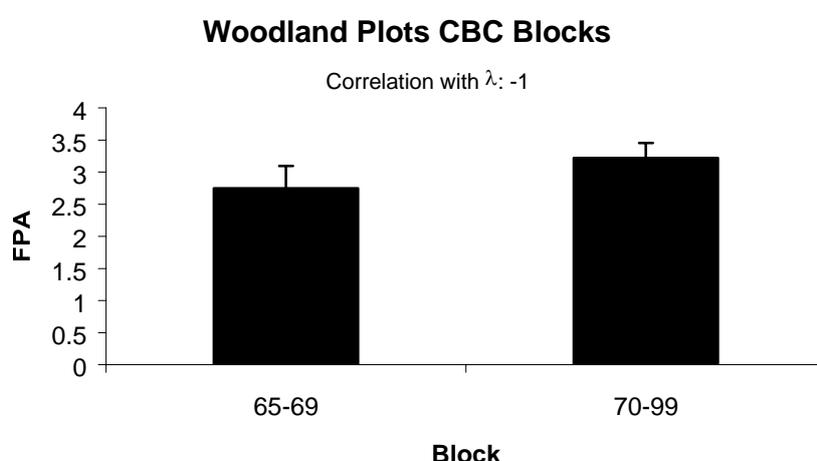


Figure 6.4.2.2.3 Block-specific estimates of fledglings per nesting attempt (FPA) in blocks of differing population decline, as measured from woodland CBC plots.

6.4.2.3 GBFS blocks

Clutch size, brood size and chick:egg ratio all tended to be lower, and chick-stage nest failure rates higher when GBFS population changes were more positive for all GBFS gardens (Table 6.4.2.3.1; Figure 6.4.2.3.1). In rural gardens (Table 6.4.2.3.2), brood size tended to be larger and egg-stage nest failure rate was lower when population changes were more positive, but these were counteracted by strongly declining chick:egg ratios, such that overall productivity (FPA) was not correlated with population growth rate (Figure 6.4.2.3.2). In suburban/urban GBFS gardens, brood size again tended to be larger when population growth rates were more positive, but failure rates at the chick-stage and overall, from egg-laying to fledging, were also higher. The latter pattern had the predominant effect on the correlation between population growth rate and the number of fledglings produced per nesting attempt (Figure 6.4.2.3.3). (N.B. The paradoxical result that brood size was negatively correlated with population growth rate for all GBFS gardens, but positively correlated for suburban/urban and rural gardens separately arose because the all-gardens analysis included records from habitats that are not included in the strict habitat definitions used for the other analyses).

Table 6.4.2.3.1 Likelihood Ratio Tests (LRT) for differences in breeding performance between blocks of population increase, stability or decline on all GBFS gardens (controlling for changes in latitude and longitude) and correlations with block-specific population growth rates (λ).

Breeding performance parameter		LRT		Correlation with λ
		χ^2_5	<i>P</i>	
First Egg Date		29.09	<0.001	0.469
Clutch Size		31.02	<0.001	-0.242
Brood Size		98.45	<0.001	-0.390
Chick:egg Ratio		41.34	<0.001	-0.831
Daily Nest Failure Rate	Egg Period	6.85	0.232	-
	Nestling Period	14.28	0.014	0.391
	Whole Nest Period	35.73	<0.001	0.242

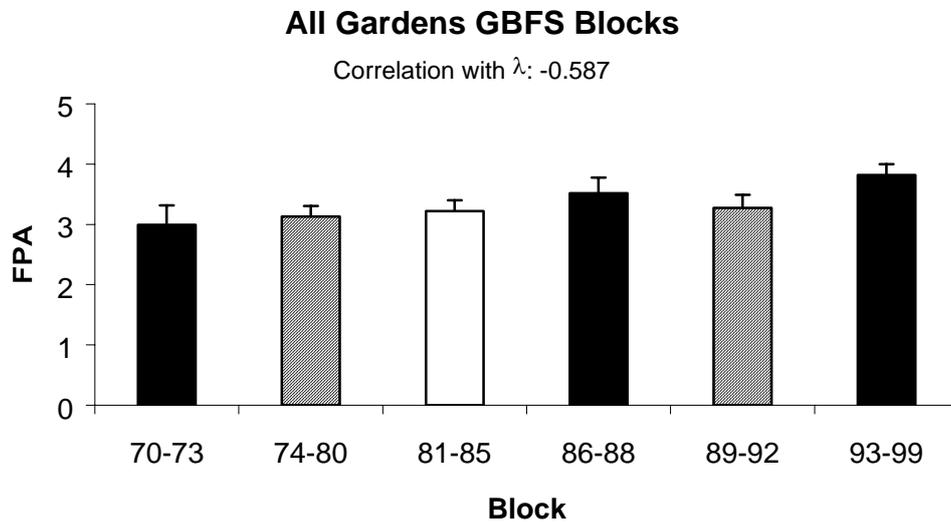


Figure 6.4.2.3.1 Block-specific estimates of fledglings per nesting attempt (FPA) in blocks of population increase (white), stability (hatching) or decline (black), as measured from all GBFS gardens.

Table 6.4.2.3.2 Likelihood Ratio Tests (LRT) for differences in breeding performance between blocks of population increase, stability or decline on rural GBFS gardens (controlling for changes in latitude and longitude) and correlations with block-specific population growth rates (λ).

Breeding performance parameter		LRT		Correlation with λ
		χ^2_6	<i>P</i>	
First Egg Date		15.20	0.019	0.530
Clutch Size		9.96	0.126	-
Brood Size		55.50	<0.001	0.156
Chick:egg Ratio		36.87	<0.001	-0.587
Daily Nest Failure Rate	Egg Period	21.76	0.001	-0.491
	Nestling Period	10.22	0.116	-
	Whole Nest Period	35.47	<0.001	-0.294

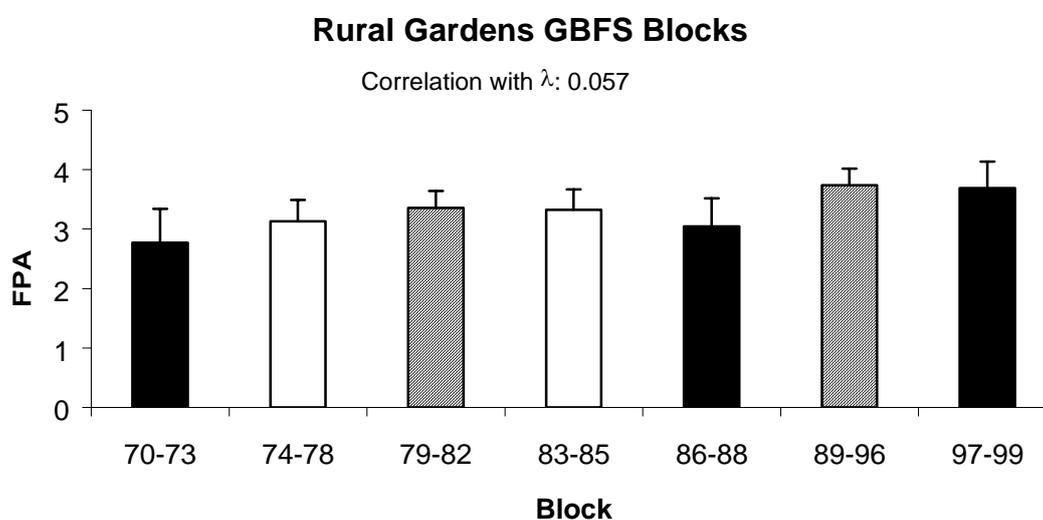


Figure 6.4.2.3.2 Block-specific estimates of fledglings per nesting attempt (FPA) in blocks of population increase (white), stability (hatching) or decline (black), as measured from rural GBFS gardens.

Table 6.4.2.3.3 Likelihood Ratio Tests (LRT) for differences in breeding performance between blocks of population increase, stability or decline on suburban GBFS gardens (controlling for changes in latitude and longitude) and correlations with block-specific population growth rates (λ).

Breeding performance parameter		LRT		Correlation with λ
		χ^2_5	<i>P</i>	
First Egg Date		14.29	0.014	0.028
Clutch Size		2.33	0.801	-
Brood Size		23.00	<0.001	0.266
Chick:egg Ratio		7.81	0.167	-
Daily Nest Failure Rate	Egg Period	2.66	0.752	-
	Nestling Period	12.32	0.031	0.300
	Whole Nest Period	14.62	0.012	0.549

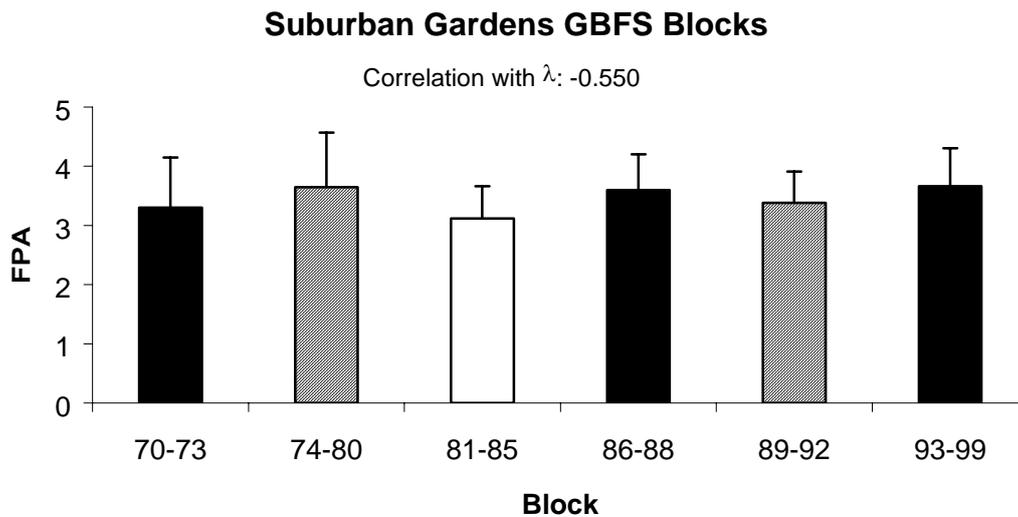


Figure 6.4.2.3.3 Block-specific estimates of FPA fledglings per nesting attempt (FPA) in blocks of population increase (white), stability (hatching) or decline (black), as measured from suburban GBFS gardens.

6.4.3 Variation in breeding performance with respect to habitat

Sample sizes are provided in Appendix 6.1.

6.4.3.1 Comparison of Starlings in farmland and suburban/urban habitats

Nest failure rate, measured from egg-laying to fledging was higher on farmland than in suburban/urban areas (24% vs 18%); although clutch and brood sizes were also slightly larger (by 0.1 egg and 0.25 young) (Table 6.4.3.1.1). Overall, these effects appeared to cancel out, such that there was minimal difference in breeding performance (FPA) between farms and towns (Figure 6.4.3.1.1). These results were not confounded by trends through time.

Table 6.4.3.1.1 Likelihood Ratio Tests (LRT) for differences in breeding performance between Starlings nesting on farmland and those in suburban/urban habitats (with and without controls for linear trends through time).

Breeding performance parameter	Basic LRT		Control for linear year LRT		
	χ^2_1	<i>P</i>	χ^2_1	<i>P</i>	
First Egg Date	0.44	0.507	0.49	0.485	
Clutch Size	4.22	0.040	3.84	0.050	
Brood Size	27.25	<0.001	32.28	<0.001	
Chick:egg Ratio	1.71	0.191	1.27	0.259	
Daily Nest Failure Rate	Egg Period	0.99	0.319	1.35	0.245
	Nestling Period	1.11	0.291	0.68	0.409
	Whole Nest Period	5.82	0.016	4.96	0.026

Starling breeding performance

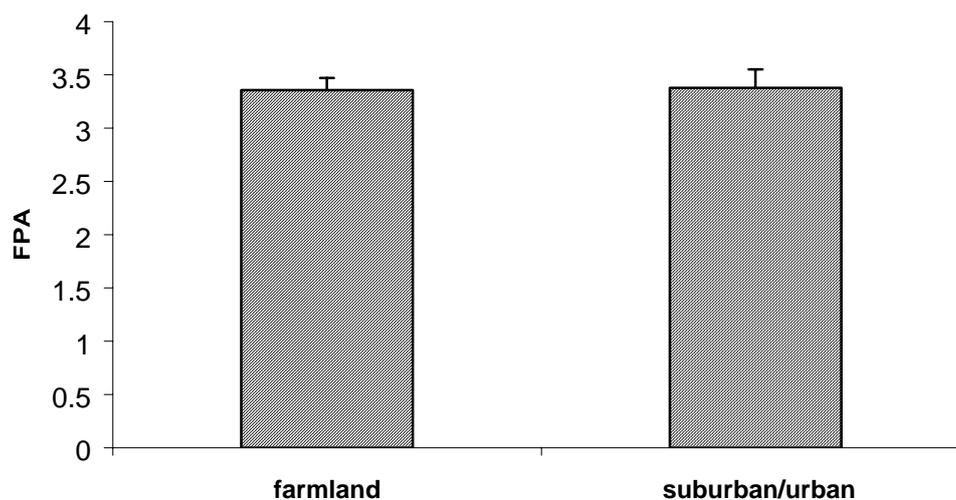


Figure 6.4.3.1.1 Estimates of fledglings per nesting attempt (FPA) for Starlings nesting in farmland and suburban/urban habitats.

Comparison of differences in trends in breeding performance trends between Starlings nesting in farmland and suburban/urban habitats (Table 6.4.3.1.2) showed that while clutch size, brood size and chick:egg ratio have tended to increase on farms, they have declined in suburban/urban situations. Nestling period failure rates have fallen in both habitats, but more steeply in suburban/urban habitats (but this result was confounded with geographical changes in the sample).

Table 6.4.3.1.2 Comparison of linear trends in breeding performance between Starlings nesting on farmland and those in suburban/urban habitats (with and without controls for changes in the geographical distribution of samples through time). Where the Likelihood Ratio Test (LRT) indicates a significant difference in trends, the slopes of the trends are provided.

Breeding performance parameter	Basic LRT		Slope Estimates (SE)	
	χ^2_1	<i>P</i>	Farms, Suburban/Urban	
First Egg Date	0.41	0.522	-	
Clutch Size	1.44	0.230	-	
Brood Size	35.47	<0.001	0.019 (0.003), -0.009 (0.004)	
Chick:egg Ratio	8.10	0.004	0.012 (0.004), -0.011 (0.007)	
Daily Nest Failure Rate	Egg Period	0.14	0.711	-
	Nestling Period	6.27	0.012	-0.012 (0.010), -0.053 (0.013)
	Whole Nest Period	1.60	0.206	-
<i>Controlling for geographical changes in the sample</i>				
First Egg Date	0.66	0.417	-	
Clutch Size	3.50	0.062	0.009 (0.003), -0.002 (0.005)	
Brood Size	24.54	<0.001	0.015 (0.003), -0.009 (0.004)	
Chick:egg Ratio	20.25	0.001	0.015 (0.005), -0.012 (0.007)	
Daily Nest Failure Rate	Egg Period	0.04	0.839	-
	Nestling Period	2.69	0.101	-
	Whole Nest Period	1.46	0.227	-

6.4.3.2 Comparison of Starlings in different farmland types

We looked at arable, pastoral and mixed farm types and found that average brood sizes were marginally lower for Starlings nesting in pastoral farmland than in the other farmland types, while nest failure rate at the egg-stage tended to be lowest in arable areas (4% of nests fail vs. 10% in pastoral and 13% in mixed farming areas)(Table 6.4.3.2.1). These patterns were not confounded by temporal trends, but the overall effect on productivity per nesting attempt was to show no real difference between the three habitats (Figure 6.4.3.2.1).

Table 6.4.3.2.1 Likelihood Ratio Tests (LRT) for differences in breeding performance between Starlings nesting in arable, mixed or pastoral farmland habitats (with and without controls for linear trends through time).

Breeding performance parameter	Basic LRT		Control for linear year LRT		
	χ^2_2	P	χ^2_2	P	
First Egg Date	2.65	0.266	1.24	0.537	
Clutch Size	1.24	0.538	1.49	0.474	
Brood Size	11.62	0.003	24.53	<0.001	
Chick:egg Ratio	2.37	0.238	0.70	0.703	
Daily Nest Failure Rate	Egg Period	5.37	0.068	6.85	0.033
	Nestling Period	2.24	0.326	1.41	0.494
	Whole Nest Period	1.72	0.422	2.83	0.243

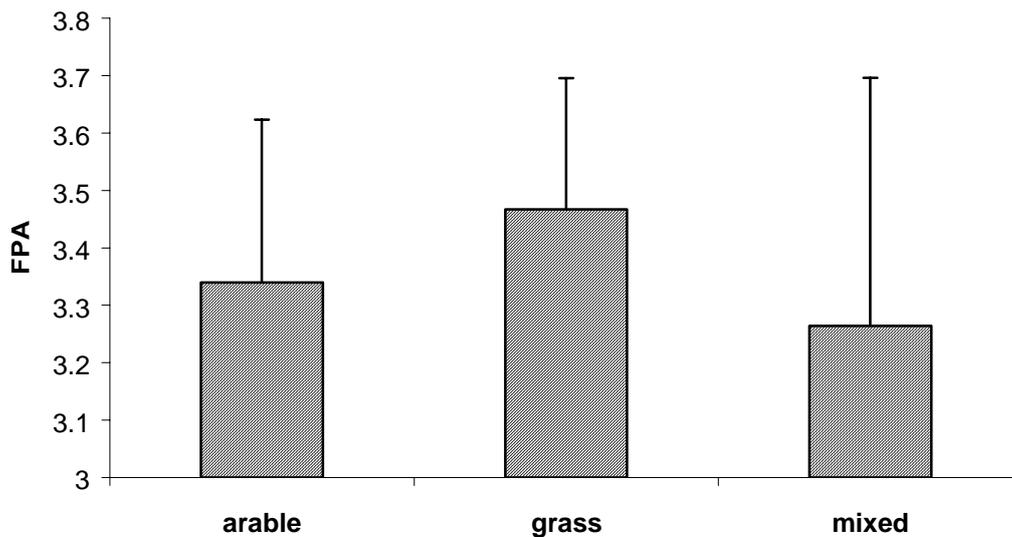


Figure 6.4.3.2.1 Estimates of fledglings per nesting attempt (FPA) for Starlings nesting in three broad farmland habitat types.

Table 6.4.3.2.2 shows that linear trends in brood size and chick:egg ratio were positive for birds nesting in arable and pastoral farms, but were stable or declining on mixed farms. However, this pattern may be an artefact of changes in the geographical samples over time. After controlling for changes in sampling, there was a weak pattern indicating a steeper fall in nestling-stage failure rate over time on mixed farmland, compared with the other habitats.

Starling breeding performance

Table 6.4.3.2.2 Comparison of linear trends in breeding performance between starlings nesting in arable, mixed or pastoral farmland habitats (with and without controls for changes in the geographical distribution of samples through time). Where the Likelihood Ratio Test (LRT) indicates a significant difference in trends, the slopes of the trends are provided.

Breeding performance parameter		Basic LRT		Slope Estimates (SE)
		χ^2_2	<i>P</i>	Arable, Grazing, Mixed
First Egg Date		2.31	0.316	-
Clutch Size		3.01	0.222	-
Brood Size		5.46	0.065	0.028 (0.009), 0.031 (0.006), 0.006 (0.009)
Chick:egg Ratio		6.37	0.041	0.036 (0.014), 0.021 (0.009), -0.013 (0.015)
Daily Nest Failure Rate	Egg Period	3.08	0.214	-
	Nestling Period	3.95	0.139	-
	Whole Nest Period	0.09	0.955	-
<i>Controlling for geographical changes in the sample</i>				
First Egg Date		1.10	0.578	-
Clutch Size		0.69	0.708	-
Brood Size		0.51	0.776	-
Chick:egg Ratio		3.72	0.156	-
Daily Nest Failure Rate	Egg Period	3.66	0.160	-
	Nestling Period	4.86	0.088	-0.023 (0.038), -0.018 (0.031), -0.105 (0.033)
	Whole Nest Period	1.14	0.565	-

6.4.3.3 Comparison of Starlings nesting near human habitation in rural, suburban and urban situations

Although there were no statistical differences between human-related habitats in nest failure rates, clutch size tended to be relatively low for urban Starlings (mean \pm 95% confidence limits = 4.1 ± 0.34 vs. 4.6 ± 0.11 suburban and 4.7 ± 0.12 rural). A different pattern was evident for chick:egg ratio, which was greatest for urban Starlings (0.95), intermediate for rural Starlings (0.91) and lowest for suburban Starlings (0.86) (Table 6.4.3.3.1). These patterns were not confounded by temporal patterns and, overall breeding performance (FPA) appeared to have declined with increasing urbanisation although it should be noted that the FPA estimate for urban Starlings is estimated with lower precision (longer error bar) than for the other habitats (Figure 6.4.3.3.1). Average laying dates were earlier in urban situations than in the other habitats (20 April \pm 5.4 days vs. rural 26 April \pm 2.0 days and suburban 28 April \pm 1.7 days).

Table 6.4.3.3.1 Likelihood Ratio Tests (LRT) for differences in breeding performance between Starlings nesting in or near human habitation in rural, suburban and urban situations (with and without controls for linear trends through time).

Breeding performance parameter		Basic LRT		Control for linear year LRT	
		χ^2_2	<i>P</i>	χ^2_2	<i>P</i>
First Egg Date		10.30	0.006	8.90	0.018
Clutch Size		13.09	0.001	12.20	0.002
Brood Size		28.71	<0.001	28.91	<0.001
Chick:egg Ratio		13.45	0.001	12.63	0.002
Daily Nest Failure Rate	Egg Period	0.22	0.896	0.30	0.860
	Nestling Period	0.91	0.635	2.23	0.328
	Whole Nest Period	0.16	0.922	0.35	0.839

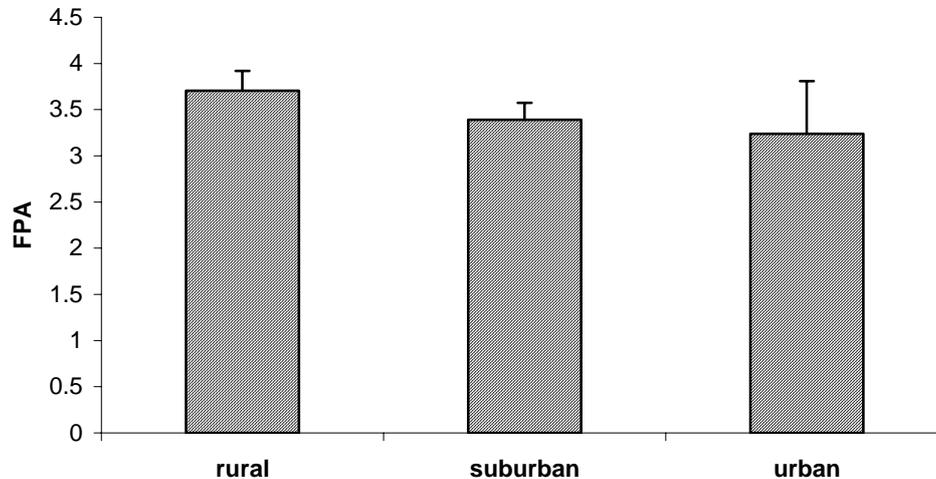


Figure 6.4.3.3.1 Estimates of fledglings per nesting attempt (FPA) for Starlings nesting near human habitation.

Analysis of trends over time (Table 6.4.3.3.2), after allowing for possible confounding effects of geographical changes in the samples through time, showed that clutch and brood sizes had increased in rural situations compared with the other two habitats, and that brood size has decreased in urban situations. However, the failure rate of nests from egg-laying to fledging had decreased most rapidly for urban Starlings and least rapidly in rural situations.

Table 6.4.3.3.2 Comparison of linear trends in breeding performance between Starlings nesting in near rural, suburban and urban human habitation (with and without controls for changes in the geographical distribution of samples through time). Where the Likelihood Ratio Test (LRT) indicates a significant difference in trends, the slopes of the trends are provided.

Breeding performance parameter		Basic LRT		Slope Estimates (SE)
		χ^2_2	<i>P</i>	Rural, Suburban, Urban
First Egg Date		0.06	0.973	-
Clutch Size		2.76	0.251	-
Brood Size		11.00	0.004	0.010 (0.004), -0.008 (0.004), -0.026 (0.015)
Chick:egg Ratio		5.70	0.058	0.014 (0.008), -0.011 (0.007), -0.026 (0.031)
Daily Nest Failure Rate	Egg Period	1.68	0.432	-
	Nestling Period	3.74	0.154	-
	Whole Nest Period	6.53	0.038	-0.021 (0.012), -0.033 (0.010), -0.107 (0.032)
<i>Controlling for geographical changes in the sample</i>				
First Egg Date		0.04	0.979	-
Clutch Size		5.08	0.079	0.013 (0.007), -0.006 (0.006), 0.009 (0.017)
Brood Size		11.08	0.003	0.016 (0.006), -0.005 (0.005), -0.023 (0.015)
Chick:egg Ratio		3.61	0.165	-
Daily Nest Failure Rate	Egg Period	0.94	0.625	-
	Nestling Period	3.30	0.192	-
	Whole Nest Period	6.62	0.037	-0.016 (0.006), -0.026 (0.018), -0.104 (0.032)

6.4.4 Variation in breeding performance between regions

There were significant differences between the regions in brood size and chick-stage nest failure rates (Table 6.4.4.1). Overall breeding performance (FPA) was highest in the South West and West (Figure 6.4.4.1). There was no evidence that the results were confounded by temporal biases in the sample. Sample sizes are provided in Appendix 6.1.

Table 6.4.4.1 Likelihood Ratio Tests (LRT) for differences in breeding performance between Starlings nesting in five geographical regions (with and without controls for linear trends through time).

Breeding performance parameter		Basic LRT		Control for linear year LRT	
		χ^2_4	<i>P</i>	χ^2_4	<i>P</i>
First Egg Date		16.22	0.003	16.48	0.002
Clutch Size		8.61	0.072	7.72	0.102
Brood Size		93.14	<0.001	89.00	<0.001
Chick:egg Ratio		8.20	0.085	7.36	0.118
Daily Nest Failure Rate	Egg Period	0.39	0.098	1.26	0.868
	Nestling Period	19.98	<0.001	19.81	<0.001
	Whole Nest Period	24.33	<0.001	25.70	<0.001

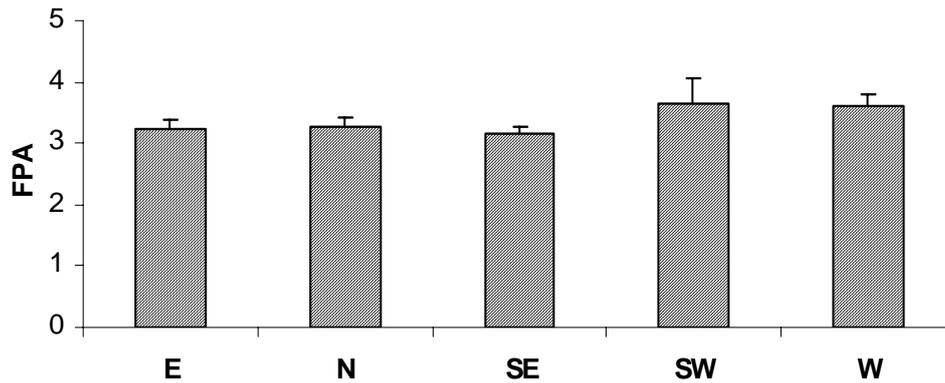


Figure 6.4.4.1 Estimates of fledglings per nesting attempt (FPA) for Starlings nesting in five broad geographical regions.

There were significant differences in trends in all aspects of breeding performance except for the failure rate of nests at the chick-stage (Table 6.4.4.2). Clutch size has increased most in the East, North, and South West, and has been relatively stable in the South East and West. Average brood size has increased substantially in the East and North, and less so in the other regions. Chick:egg ratio has also increased most in the East, less so in the South East and North, and showed little trend in the West and South West. Egg-stage nest failure rate has declined most in the East and West, less so in the North, remained approximately constant in the South East but increased in the South West. This pattern was essentially maintained when considering failure rate over the whole nest cycle. Thus, productivity appears to be improving fastest in the East, North and West, but showing little change in the South of Britain.

Table 6.4.4.2 Comparison of linear trends in breeding performance between Starlings nesting in five main regions of Britain: East, North, South East, South West and West. Where the Likelihood Ratio Test (LRT) indicates a significant difference in trends, the slopes of the trends are provided.

Breeding performance parameter		Basic LRT		Slope Estimates (SE)
		χ^2_4	<i>P</i>	E, N, SE, SW, W
First Egg Date		6.44	0.169	-
Clutch Size		15.11	0.005	0.019 (0.004), 0.008 (0.003), 0.001 (0.003), 0.015 (0.009), -0.001 (0.006)
Brood Size		9.82	0.044	0.035 (0.004), 0.030 (0.004), 0.019 (0.004), 0.023 (0.012), 0.022 (0.004)
Chick:egg Ratio		53.29	<0.001	0.047 (0.005), 0.016 (0.004), 0.013 (0.004), 0.011 (0.010), - 0.005 (0.007)
Daily Nest Failure Rate	Egg Period	17.37	0.002	-0.049 (0.014), -0.022 (0.011), -0.002 (0.012), 0.040 (0.038), -0.074 (0.019)
	Nestling Period	6.22	0.184	-
	Whole Nest Period	43.74	<0.001	-0.032 (0.009), -0.026 (0.007), 0.002 (0.007), 0.015 (0.021), -0.080 (0.012)

6.4.5 Variation in breeding performance with respect to agriculture

Table 6.4.5.1 provides the results of the various tests undertaken to investigate whether Starling breeding performance varies with respect to various key agricultural variables (listed in Table 6.3.4.1).

The first test investigated whether the proportion of arable habitat in a county (GRABRAT) influences breeding performance. Clutch size tended to be smaller in counties containing more arable habitat, but nest failure rates from egg-laying to fledging was lower. These contradictory results are likely to cancel each other in terms of overall productivity.

The relationship between breeding performance and the proportion of spring-sown barley (BARLRAT) (in relation to autumn-sown barley) in a county was generally negative. Although brood size and failure rate measured over the whole nest cycle were poorer in counties containing a greater proportion of spring barley, chick:egg ratio tended to be higher.

The relationships between breeding performance and livestock levels in counties was carried out over Britain as a whole (COWS, SHEEP, GRAZIND) as well as with respect to NRCs just from pastoral habitats (COWS2, SHEEP2, GRAZIND2). The results were generally contradictory. Brood size and chick:egg ratio tended to be higher in counties with fewer livestock regardless of whether all NRCs were used or just those of Starlings nesting in pastoral habitats. But nest failure rate at the chick stage was also higher in counties with fewer livestock, when all nest records were used. However, the latter relationship did not hold for Starlings nesting in pastoral habitats. Thus more intensive livestocking practices appeared to be associated with poorer hatching success but also, possibly, with a lower likelihood of total nest failure.

Table 6.4.5.1 Tests for trends in Starling breeding performance with respect to gradients in key agricultural variables. Where significant results were obtained in relation to livestock, the slopes were often extremely small (as measured on a per-animal basis), thus the direction of the relationship is provided.

Breeding performance parameter		GRABRAT			COWS			COWS2		
		χ^2_1	<i>P</i>	Slope (SE)	χ^2_1	<i>P</i>	Slope (SE)	χ^2_1	<i>P</i>	Slope (SE)
First Egg Date		2.27	0.132	-	1.95	0.163	-	2.46	0.116	-
Clutch Size		7.45	0.006	-0.277 (0.101)	0.98	0.321	-	0.00	0.994	-
Brood Size		0.54	0.464	-	84.82	<0.001	Negative	34.21	<0.001	Negative
Chick:egg Ratio		0.12	0.727	-	2.27	0.132	-	23.04	<0.001	Negative
Daily Nest	Egg Period	1.82	0.177	-	0.74	0.391	-	0.17	0.676	-
Failure	Nestling Period	0.97	0.325	-	4.90	0.027	Negative	0.10	0.749	-
Rate	Whole Nest Period	7.51	0.006	-0.609 (0.222)	2.09	0.148	-	0.00	0.998	-

Breeding performance parameter		SHEEP			SHEEP2			BARLRAT		
		χ^2_1	<i>P</i>	Slope (SE)	χ^2_1	<i>P</i>	Slope (SE)	χ^2_1	<i>P</i>	Slope (SE)
First Egg Date		0.73	0.393	-	0.37	0.541	-	3.00	0.083	3.92 (2.26)
Clutch Size		0.02	0.896	-	1.68	0.194	-	0.35	0.554	-
Brood Size		29.38	<0.001	Negative	23.06	<0.001	Negative	48.04	<0.001	-0.839 (0.121)
Chick:egg Ratio		6.64	0.010	Negative	22.89	<0.001	Negative	4.35	0.037	0.400 (0.191)
Daily Nest	Egg Period	0.38	0.539	-	0.24	0.622	-	1.79	0.181	-
Failure	Nestling Period	10.38	0.001	Negative	0.02	0.880	-	0.77	0.381	-
Rate	Whole Nest Period	5.97	0.015	Negative	1.37	0.241	-	11.93	<0.001	0.971 (0.276)

Breeding performance parameter		GRAZIND			GRAZIND2		
		χ^2_1	<i>P</i>	Slope (SE)	χ^2_1	<i>P</i>	Slope (SE)
First Egg Date		0.94	0.333	-	0.54	0.461	-
Clutch Size		0.00	0.976	-	1.30	0.255	-
Brood Size		33.49	<0.001	-0.0009 (0.0009)	22.48	<0.001	-0.0015 (0.0002)
Chick:egg Ratio		6.94	0.008	-0.0007 (0.0003)	23.16	<0.001	-0.0034 (0.0008)
Daily Nest	Egg Period	0.50	0.481	-	0.07	0.796	-
Failure	Nestling Period	9.05	0.003	-0.003 (0.001)	0.01	0.940	-
Rate	Whole Nest Period	5.06	0.025	-0.001 (0.0005)	0.72	0.395	-

6.5 DISCUSSION

The long-term NRS data for Starling provide a unique insight into the changes and trends in breeding performance that have occurred nationally and regionally over the past 40 years. While the geographical spread of records and occurrence of volunteer observers who have specialised on Starlings have varied over time, this can be controlled for statistically in the analyses. The potentially confounding influence of underlying trends can also be controlled statistically in the comparison of records from different habitats. The only aspect that cannot be investigated with Nest Record data is that of the number of broods attempted per pair per season. Thus the discussion that follows must be considered to refer to breeding performance per nesting attempt, not that of a pair over the course of the nesting season.

6.5.1 Trends in breeding performance

Overall, the analysis of NRCs showed that Starling breeding performance has tended to increase over time and that this has occurred in all regions. However, the increases appeared to be least rapid in the South East, the part of the country where the population has declined most rapidly in the long-term (as measured by the CBC and where declines are still the most rapid in the short-term (as measured by the BBS, Chapter 2).

In Chapter 2, we determined turning points in the trajectories of population abundance measured by the CBC and GBFS. These were used to define blocks of time when Starling populations were statistically stable, increasing or decreasing. This allowed us to analyse how breeding performance varied in relation to population growth rate. Although different aspects of breeding performance might show positive or negative correlations with population growth rate, in general the key variables for determining the correlation with overall productivity were the nest failure rates. The over-riding pattern was one in which overall productivity, as measured by the number of fledglings raised per nesting attempt is higher during periods when population growth is negative (declining abundance). This suggests that breeding performance is likely to be responding in a broadly density-dependent manner to Starling abundance, a relatively common pattern among declining birds in Britain (e.g. Siriwardena *et al.* 2000c).

There are a number of reasons why breeding performance might increase in response to declines in population size. Supplementary feeding experiments show that extra food at the nestling stage can increase hatching success, chick weight and the number of young fledged per Starling pair (Crossner 1977). Thus, increased breeding performance might suggest that food supplies during the breeding season had improved. However, all available evidence suggests that changes in farming practice are unlikely to have increased the total food available (e.g. Wilson *et al.* 1997; Benton *et al.* in press), but per capita food supply per breeding pair could still have increased as populations have declined. Broadly, density-dependent processes are likely to operate in the regulation of the population of most species of small-bodied birds found in Britain (Greenwood & Baillie 1991, Holyoak & Baillie 1996a,b). Competition for resources may be relaxed, allowing birds to feed more efficiently. In addition, at lower population densities, competition and aggressive encounters around nest holes may be lower and there may be a lower incidence of attempts by conspecifics to parasitise nests by laying extra eggs (Feare 1984). Such activities are likely to interfere with the efficiency with which Starlings can care for their eggs and young, as has been found for other species (e.g. Koenig 1982).

Another possibility is that, as populations decline, birds that are of lower quality and those that are in lower quality or marginal habitats or regions are likely to disappear first. If such birds had contributed to the nest record sample in earlier years, then their loss will increase average breeding performance. The analysis of trends in breeding performance in Britain as a whole (Table 6.4.1.1), showed significant trends of improvement despite controls for geographical changes in the samples, so declines in the numbers of records from a particular region are unlikely to have resulted in overall improvements in average breeding performance. Similarly, breeding performance in the different broad-scale habitats analysed in this chapter has also generally improved through time. However,

there were significant differences in breeding performance between urban/suburban and rural habitats, the former showing lower productivity. Thus the trend of improving breeding performance could be explained simply by a decrease in the proportion of urban/suburban records through time. However, the reverse has happened, the proportion having increased from 10-15% of the records in the 1970s to 30-35% in the 1990s. Although it seems unlikely, given the strength of the general pattern, it is still possible that there may have been changes in the proportion of records received from habitats of differing quality have occurred if habitat quality for Starlings is patchy at a scale too small to be revealed from broad-scale regional or habitat analyses (Siriwardena *et al.* 2000a).

Increases in Starling breeding performance through time would arise if breeding performance had been depressed in the 1960s by the effects of wide-spread use of organochlorine pesticides, which were phased out progressively over the next two decades (Newton 1979). The impact on predatory birds, through embryotoxicity and egg-shell thinning, is well known (Newton 1979; Crick 1994; Ratcliffe 1994). However, there are also indications that populations of farmland passerine were also depressed in areas where pesticide usage was highest (Newton 1972; Parslow 1973; O'Connor & Shrubbs 1986) and there is laboratory evidence for the sensitivity of passerines to such effects (Jefferies 1973). Feare (1984) reported that Starlings appeared to have suffered little direct mortality from eating either insects that have been sprayed with pesticide or from eating grain that has been dressed with insecticides and fungicides. So this is perhaps less likely to be a factor affecting long-term trends in breeding success of Starlings than for other species.

6.5.2 Breeding performance in different habitats and regions

The comparison of breeding performance between different habitats is likely to reflect broad differences that exist between large regions of Britain. There is a general east-west gradient, with pastoral farming occurring more to the west and arable farming predominating in the East, and mixed farming occurring in central Britain (Chamberlain *et al.* 2000; Robinson *et al.* 2001). Arable farming benefits from the better soil quality and drier weather found in the East, whereas conditions for pastoral farming are enhanced by the wetter conditions found in the West. Over the past 20 to 30 years, regional farming practices have become more specialised and farms have tended to lose livestock in the east and lose arable cropping in the west. Furthermore, there are large-scale spatial patterns of agricultural practice in Britain (Siriwardena *et al.* 2000b) that mean that regional and habitat differences will often be inter-related.

The regional analysis showed that breeding performance was highest in the South West and West regions, and that productivity has increased most in the West, North and East and has shown little change in South East and South West. Given that the Starling is a bird that feeds preferentially in pastoral land, it is perhaps not surprising that breeding performance is highest in the more productive pastoral regions. However, when considering the country as a whole, there was little overall difference between farms of different type. This contradicts the strong pattern shown by Tiainen *et al.* (1989), who studied 15 nests in areas of specialised arable cultivation and 38 nests in areas of more traditional mixed farming in Finland. He found that, although clutch size, hatching success and nestling growth did not differ between the sites, the number of young that fledged per nest in the mixed farming areas was about twice that in the arable areas. Chicks in the latter area were also more likely to be badly fouled by wet faeces in the nest, thought to be due to the type of food they were fed. It is possible that results of Tianen *et al.* may only apply to their specific study area and not to general conditions in Britain.

Breeding performance tended to be generally improving for birds on mixed farms, but not on arable or pastoral farms. Siriwardena *et al.* (2000d) found that breeding performance for a number of granivorous species was better in mixed farming systems which, they suggested, might be due to the availability of a greater range of foraging opportunities within a local area. Mixed farming systems are also associated with more extensive farming practices (Siriwardena *et al.* 2001a) that appear to benefit a range of species (Chamberlain & Fuller 2001).

Starlings occur at higher densities in pastoral areas than in arable areas (Chapter 2). Different aspects of their breeding performance responded differently to the presence of greater populations of livestock in a county. Where livestock densities were low Starlings enjoyed better hatching success and reared larger broods. Although nest failure rates were generally higher for counties with lower densities of livestock, this did not hold for Starlings recorded as nesting in pastoral habitats. Thus, it is possible that contradictory results found for all Nest Records might be an artefact of some other factor correlated with livestock density. Alternatively, Starlings nesting in pastoral locations may be subject to quite different stocking densities than the county average. Areas where low stocking rates occur may be indicative of less intensive pasture management and less intensive livestock husbandry practices. There have been widespread changes in grassland management in Britain in recent decades (Vickery *et al.* 1999). These have resulted in considerable uniformity of management to increase yields, with the replacement of hay with silage and increased fertiliser treatments, that have negative impacts on invertebrate abundance (Wilson *et al.* 1999). Silage, with its earlier and more frequent cuts may provide better foraging conditions for Starlings, allowing them to benefit from shorter grass swards and thereby decreasing the failure rate of nests. On the other hand, less intensive livestock husbandry might be associated with less careful control of livestock food provisioning to avoid spoiling and loss to Starlings and other animals (see Chapter 11) - which might be important for increasing brood size. The influence of stocking density on Starling breeding performance can only be fully elucidated by further comparative studies in areas with different stocking densities or by experimental manipulation of stocking densities.

The South East of Britain holds about a quarter of Britain's Starling population, and nearly one half of this occurs in suburban areas (Chapter 2). The lack of a substantial improvement in breeding performance during a time of the most rapid population declines of any region, suggests that breeding performance may be relatively depressed and unable to increase. Breeding performance is poorer in suburban and urban situations than in the countryside or near rural housing. The decline in certain aspects of breeding performance for suburban/urban Starlings suggests that the suitability of this habitat has declined, despite the high densities of Starlings found there. In particular, clutch and brood size and hatching success have declined, although the proportion of nests producing at least one offspring has increased. Supplementary feeding experiments have shown that food supply can influence different aspects of breeding performance, depending on the timing of food provision with respect to the nesting cycle (Newton 1998). The pattern of changes found for suburban/urban Starlings would be consistent with the possibility that early-season food supplies (prior to egg-laying) have declined but that food supplies required to ensure successful fledging have been maintained or increased. Investigation of differences in the seasonal patterns of food availability for breeding Starlings in different habitats would be a useful area for further research.

Appendix 6.1 Sample sizes of Starling Nest Record Cards used in the analyses in Chapter 6.**Table A6.1.1** Sample sizes of Starling Nest Record Cards used in the analysis of five-year blocks (Table 6.4.2.1.1).

Years	First Egg Date	Clutch Size	Brood Size	Chick:Egg Ratio	Egg-stage Failure Rates	Chick-stage Failure rates	Whole Nest Failure Rates
Pre-65	425	378	1014	319	533	600	836
65-69	363	372	811	311	486	559	751
70-74	225	231	581	204	328	393	462
75-79	359	362	910	319	473	589	732
80-84	578	453	1287	419	645	724	894
85-89	447	427	1147	395	715	778	851
90-94	401	331	1035	309	553	669	712
95-99	221	206	613	188	354	415	417
Total	3019	2760	7398	2464	4087	4727	5655

Table A6.1.2 Sample sizes of Starling Nest Record Cards used in the analysis of year blocks for All CBC Plots (Table 6.4.2.2.1).

Years	First Egg Date	Clutch Size	Brood Size	Chick:Egg Ratio	Egg-stage Failure Rates	Chick-stage Failure Rates	Whole Nest Failure Rates
62-66	290	279	605	234	365	418	576
67-73	374	386	951	328	524	637	800
74-79	431	432	1051	383	567	688	846
90-99	1647	1417	4082	1311	2267	2586	2874
Total	2742	2514	6689	2256	3723	4329	5096

Table A6.1.3 Sample sizes of Starling Nest Record Cards used in the analysis of year blocks for Farmland CBC Plots (Table 6.4.2.2.2).

Years	First Egg Date	Clutch Size	Brood Size	Chick:Egg Ratio	Egg-stage Failure Rates	Chick-stage Failure Rates	Whole Nest Failure Rates
62-64	43	41	84	31	52	57	82
65-70	118	121	344	105	172	251	284
71-74	57	53	157	49	89	103	137
75-78	99	98	287	88	122	164	230
79-91	547	461	1315	423	722	757	948
92-99	278	264	636	244	418	401	423
Total	1142	1038	2823	940	1575	1733	2104

Starling breeding performance

Table A6.1.4 Sample sizes of Starling Nest Record Cards used in the analysis of year blocks for Woodland CBC Plots (Table 6.4.2.2.3).

Years	First Egg Date	Clutch Size	Brood Size	Chick:egg Ratio	Egg-stage Failure Rates	Chick-stage Failure Rates	Whole Nest Failure Rates
65-69	164	166	310	134	213	189	316
70-99	874	809	1853	736	1162	1157	1316
Total	1038	975	2163	870	1375	1346	1632

Table A6.1.5 Sample sizes of Starling Nest Record Cards used in the analysis of year blocks for All GBFS Plots (Table 6.4.2.3.1).

Years	First Egg Date	Clutch Size	Brood Size	Chick:Egg Ratio	Egg-stage Failure Rates	Chick-stage Failure Rates	Whole Nest Failure Rates
70-73	153	161	440	140	234	294	348
74-80	511	514	1284	459	679	816	1003
81-85	611	496	1370	462	718	837	1007
86-88	264	241	635	219	400	392	433
89-92	268	238	762	221	407	501	506
93-99	424	360	1082	333	630	728	771
Total	2231	2010	5573	1834	3068	3568	4068

Table A6.1.6 Sample sizes of Starling Nest Record Cards used in the analysis of year blocks for Rural GBFS Plots (Table 6.4.2.3.2).

Years	First Egg Date	Clutch Size	Brood Size	Chick:Egg Ratio	Egg-stage Failure Rates	Chick-stage Failure Rates	Whole Nest Failure Rates
70-73	62	58	179	53	96	119	145
74-78	115	108	324	97	142	188	263
79-82	168	178	380	165	211	211	279
83-85	210	127	471	119	233	254	341
86-88	96	107	250	92	155	135	165
89-96	284	253	670	239	427	456	477
97-99	67	60	180	52	114	102	109
Total	1002	891	2454	817	1378	1465	1779

Table A6.1.7 Sample sizes of Starling Nest Record Cards used in the analysis of year blocks for Suburban/Urban GBFS Plots (Table 6.4.2.3.3).

Years	First Egg Date	Clutch Size	Brood Size	Chick:Egg Ratio	Egg-stage Failure Rates	Chick-stage Failure Rates	Whole Nest Failure Rates
70-73	29	32	74	28	41	59	65
74-80	48	40	127	35	58	91	91
81-85	88	72	175	67	117	125	131
86-88	75	64	205	61	120	169	165
89-92	84	75	236	68	119	181	185
93-99	48	29	298	27	85	239	226
Total	372	312	1115	286	540	864	863

Table A6.1.8 Sample sizes of Starling Nest Record Cards used in the comparison of Farmland vs. Suburban/Urban habitats (Table 6.4.3.1.1).

Years	First Egg Date	Clutch Size	Brood Size	Chick:Egg Ratio	Egg-stage Failure Rates	Chick-stage Failure Rates	Whole Nest Failure Rates
Farm	1121	1017	2381	871	1549	1705	2076
Suburban/urban	345	317	932	264	514	878	888
Total	1466	1334	3313	1135	2063	2583	2964

Table A6.1.9 Sample sizes of Starling Nest Record Cards used in the comparison of Arable, Mixed and Pastoral farmland habitats (Table 6.4.3.2.1).

Years	First Egg Date	Clutch Size	Brood Size	Chick:Egg Ratio	Egg-stage Failure Rates	Chick-stage Failure Rates	Whole Nest Failure Rates
Arable	139	164	306	155	210	248	282
Pastoral	263	223	554	184	352	452	486
Mixed	67	74	185	64	118	143	151
Total	469	461	1045	403	680	843	919

Table A6.1.10 Sample sizes of Starling Nest Record Cards used in the comparison of nests near human habitation in Rural, Suburban and Urban habitats (Table 6.4.3.3.1).

Years	First Egg Date	Clutch Size	Brood Size	Chick:Egg Ratio	Egg-stage Failure Rates	Chick-stage Failure Rates	Whole Nest Failure Rates
Rural	247	232	632	210	414	471	500
Suburban	313	286	839	240	468	808	807
Urban	33	31	96	24	47	71	82
Total	593	549	1567	474	929	1350	1389

Starling breeding performance

Table A6.1.11 Sample sizes of Starling Nest Record Cards used in the comparison of British regions: East, North, South East, South West and West (Table 6.4.4.1).

Years	First Egg Date	Clutch Size	Brood Size	Chick:Egg Ratio	Egg-stage Failure Rates	Chick-stage Failure Rates	Whole Nest Failure Rates
East	700	658	1259	568	920	1035	1244
North	595	553	1202	470	781	775	939
South East	941	806	1504	703	1172	1078	1291
South West	95	85	169	64	125	145	158
West	268	276	1099	224	476	930	1065
Total	2599	2378	5233	2029	3474	3963	4697

7 POPULATION DYNAMICS OF STARLINGS *Sturnus vulgaris* BREEDING IN BRITAIN: AN INTEGRATED ANALYSIS

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7.1 CHAPTER SUMMARY

1. Data on the abundance of Starlings on Common Birds Census plots are modelled here in relation to changes in breeding performance, measured using Nest Record Scheme data, and changes in adult, first-year and post-fledging survival, measured from ringing recoveries. We also, for the first time, produce regional population models.
2. Post-fledging survival, i.e. survival in the first 44 days following hatching, was low and poorly estimated. First-year and adult survival varied between years, but showed no overall trend. However, survival rates of both age classes tended to be lower during the period of major population decline and higher subsequently.
3. The importance of changes in productivity and survival for determining the population trend were assessed by allowing each to vary while holding the other constant in the population models. This showed that changes in survival produced the better fit to the observed population trend.
4. Although changes in adult survival could reproduce the overall decline in the Starling population index, changes in first-year survival produced a much better description of the shorter-term changes in population index. Thus, changes in first-year survival have probably caused the starling population decline.
5. Population trends were analysed separately for three regions within Britain: Northern, Western and Eastern. Data, particularly Nest Record data, were limited for each region, but population models with survival varying over time could be fitted.
6. Population trends were similar in Northern and Western Britain and in each case, changes in first-year survival seemed the best candidate to explain the population changes. A combined analysis of these two regions further supported this conclusion. However, changes in Eastern Britain were more likely to have been a result of changes in adult survival. These differences might reflect differences in habitat availability and juvenile dispersal.

7.2 INTRODUCTION

As was demonstrated in Chapter 2, there have been widespread declines in the numbers of breeding Starlings *Sturnus vulgaris* in the wider countryside of Britain, although these declines have not been equal across the country. As the British breeding population of Starlings is largely resident (Feare in press), changes in population size will occur through either changes in productivity or changes in survival. Trends in productivity are discussed in Chapter 6. Changes in survival could occur through, for example, reductions in foraging opportunities or increased prevalence of disease, whereas changes in productivity may relate to the survival of nestlings or the number of broods that an individual can raise during the breeding season. Here we use an Integrated Population Modelling approach (Baillie 1990; Greenwood *et al.* 1993) to combine measures of breeding performance and survival in a single

population dynamics model to assess the relative importance of the different demographic factors in determining Starling population change.

The BTO Integrated Population Monitoring programme was developed to investigate the demographic and environmental factors affecting the population changes of breeding birds in Britain. Indices of abundance are evaluated from wide-scale census data, survival rates from national ring-recovery data and various components of productivity from the Nest Record Scheme. Previous analyses have been carried out for Spotted Flycatcher (Freeman & Crick 2002), Bullfinch (Siriwardena *et al.* 2001), Song Thrush (Thomson *et al.* 1997) and Reed Bunting (Peach *et al.* 1999). These analyses have been useful in identifying stages of the life or reproductive cycles at which crucial changes have taken place, by fitting population models derived from the demographic variables to the estimated abundance indices. This approach, however, ignores sampling covariances between the abundance indices. A preferable approach is to fit demographic population models directly to the individual bird counts gathered under the survey on which abundance indices have been based. We introduce here a novel method for doing this. The method is based on maximum likelihood, hence standard comparative measures of goodness-of-fit, such as maximised log-likelihood values can be calculated for any fitted model. This provides an efficient means of identifying the significant demographic changes for the species of interest, here the Starling.

In this chapter, we integrate annual estimates of breeding success (derived from Chapter 6) with information on annual survival, to investigate the demographic causes of changes in the population trend of Starlings breeding in Britain using integrated population models. Chapter 2 also identifies populations in pastoral habitats as declining particularly markedly. In order to investigate the causes of this more closely we construct regional population models separately for the largely pastoral North and West of Britain and the more arable and urbanised South East.

7.3 METHODS

7.3.1 Nest Record data

We derived annual estimates of productivity per breeding attempt from data gathered under the BTO's Nest Record Scheme (Crick & Baillie 1996). Cards are completed by volunteer observers, who record a number of variables relating to nesting success: clutch and brood sizes, hatching success (the proportion of eggs in a clutch that hatch or, more strictly, the chick:egg ratio), the period under observation and the status (successful, failed or ultimate outcome unknown) when the nest was last surveyed.

The nest status and the length of the observation period can be used to obtain estimates of nest survival via the method of Mayfield (1961, 1975) and standard errors via those of Johnson (1979). Such estimates were calculated separately for the days when the birds were incubating ('egg stage') or feeding chicks ('nestling stage'), since different ecological factors may influence changes in each. The method assumes that the daily failure probabilities are constant within the period in question. Violation of this assumption may bias the estimated probability of ultimate nest success, but any bias is unlikely to vary from year to year and annual comparisons and temporal trends should not be affected (Crick & Baillie 1996). Full methods and a detailed analysis can be found in Chapter 6.

7.3.2 Ring-recovery data

In Britain, large numbers of Starlings of various ages are caught and marked throughout the year by about 2,000 licensed volunteer ringers. Annually, one to two thousand birds are ringed as chicks in the nest, as are around 10,000 full-grown birds which are caught in nets and traps. The data location and age at ringing have been computerised for all birds ringed since 1965 (Chapter 1). Recoveries (ringed birds found dead and reported to BTO) of birds up to 31 May 2000 are included. While the British breeding population of Starlings is largely sedentary, continental European populations are migratory; those that breed around the shores of the Baltic winter in Britain (Fliege 1984; Feare in

press). Although the number of winter immigrants is not known and may vary between years, they are likely to form a substantial part of the wintering population. In order to concentrate on the British breeding population, we consider only those birds ringed between April and September (inclusive), when continental birds are largely absent (Figure 7.3.2.1); these birds can, of course, be recovered at any time of year.

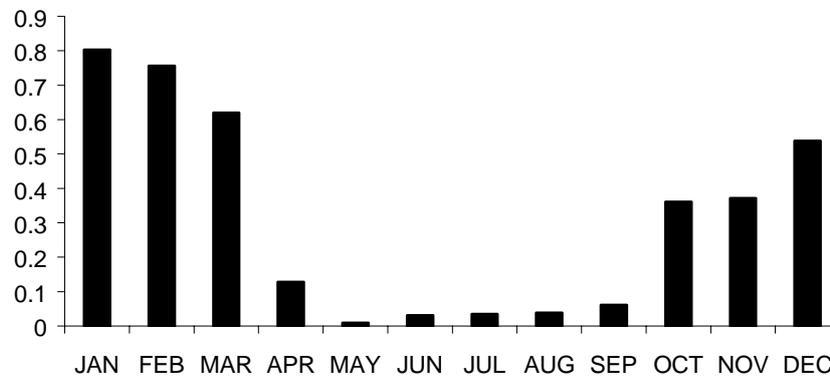


Figure 7.3.2.1 Percentage of birds ringed in Britain each month subsequently reported from abroad (either dead, or caught by another ringer).

All nestling birds ringed, with the exception of those subsequently found dead in or next to the nest, were included in the analyses. In practice, very few of these were ringed before 1 April. A small number of uncertain or unusual ringing or recovery records, together with records of birds ringed while sick or injured were also excluded, following the criteria listed in Baillie & McCulloch (1993).

Three age-classes were defined: adult, first-year and post-fledging. Most full-grown birds can be reliably aged as either juvenile (first-year) or adult (1yr +) on the basis of feather shape and colour (Svensson 1992). Birds caught as adults (between April and September) and recovered before 31 May the following year were classed as having been recovered in the year of ringing. Subsequent recovery periods ran from 1 June to the following 31 May, reflecting the median ringing date of adult birds. Birds ringed as independent juveniles were considered as first-year birds until 31 May in the year following hatching, after which they were classed as adults. The post-fledging period was defined as 44 days following the date of ringing of nestlings, which represented the difference between the median dates of birds ringed as chicks in the nest and birds ringed as fledged independent first-year birds. Recoveries between 44 days after ringing and 31 May in the following year were classed as independent first-years, subsequent recoveries were classed as adult.

Survival rates over the post-fledging and juvenile periods, and annual survival probabilities of adult birds were calculated using a range of ring-recovery models for birds of three age classes (Thomson *et al.* 1999), with numerical model fitting by the package MARK of White & Burnham (1999).

7.3.3 Common Birds Census data

Populations of Starlings in the wider countryside of Britain have been monitored by the BTO's Common Birds Census (CBC) since its inception in 1962 (Baillie *et al.* 2001). Each year, between 200 and 300 survey plots are visited 10 to 12 times a year by volunteer observers and the territories present are mapped. The number of territories on each plot can then be modelled using a generalised linear model as a log-linear function of plot and year with a Poisson error term to provide an annual

index of numbers in a given habitat (e.g. ter Braak *et al.* 1994; Peach *et al.* 1998). Full details of the methods used to calculate the population trends can be found in Chapter 2.

In this chapter, population models based on demographic parameters estimated from ring-recovery and Nest Record data were fitted to the CBC territory counts from 1966 to 2000. This period coincides with that for which indices of abundance are regularly published (e.g. Baillie *et al.* 2001); data from earlier years, when the recording protocol was still under development, are excluded.

7.3.4 Population models

Our population models combine information on survival and productivity to predict inter-annual population changes. We begin with a base-line model of the population changes measured by the CBC, which is independent of any demographic (i.e. productivity or survival) data. The base-line model is calculated as follows:

We assume the territory count c_{ij} at CBC site i in year j has a Poisson distribution and is given, in expectation, by

$$c_{ij} = S_i N_j \quad (1)$$

where S_i and N_j are respectively factors specific to site and year. The model therefore assumes that the population numbers fluctuate proportionately at all sites, though naturally some sites generally contain more birds than others. This geographical variability is accounted for by the S_i . Alternatively,

$$\ln(c_{ij}) = \ln(S_i) + \ln(N_j) = s_i + n_j \quad (2)$$

and annual indices \hat{N}_j can readily be calculated by maximum likelihood; this is a Generalised Linear Model (GLM) based on a logarithmic link function (McCullagh & Nelder 1990; ter Braak *et al.* 1994). Such indices are routinely calculated from CBC data and adopted as annual estimates of abundance (e.g. Baillie *et al.* 2001). These estimates of abundance are clearly independent of any demographic parameters as no information on survival or productivity is present. This model we denote $\{S_i, N_j\}$; it is the most general time-varying model that can be fitted, without expanding upon the simple assumption that the site and year effects are additive on the log scale and is equivalent to the standard CBC index. However, the annual population size is clearly related to productivity and survival in the preceding year. The GLM in (2) is readily modified to impose simple trends upon the estimates N_j . We show here that it is also possible to fit a population model within this framework and, hence, model the relationship between counts and the demographic parameters, effectively by imposing alternative constraints on the N_j . This is preferable to estimating the year effects under model (2) and undertaking a separate modelling exercise, since only by incorporating the population model directly into the GLM are sampling covariances of these parameters accounted for.

We establish a deterministic population model

$$N_{j+1} = N_j (\phi_{aj} + \phi_{1j} \phi_{PFj} p FPA_j) \quad (3a)$$

$$FPA_j = CS_j \times HS_j \times (1 - EFR_j)^{EP} \times (1 - NFR_j)^{NP} \quad (3b)$$

where N_j is an index proportional to the species' abundance in year j , ϕ_{aj} , ϕ_{1j} , ϕ_{PFj} and FPA_j are respectively adult, first-year and post-fledging survival probabilities, and productivity (fledglings) per breeding attempt in year j . FPA_j is further broken down into demographic variables calculable from nest record data: clutch size (CS), hatching success (HS, the ratio of brood size to clutch size, or

chick:egg ratio) and, daily nest failure rate at the egg (EFR) and nestling (NFR) stages. The exponents EP and NP are the lengths of the incubation and nestling periods, here taken to be 16 and 21 days respectively (Cramp & Perrins 1994). Total productivity in a season differs from that per breeding attempt, as the latter does not include repeat broods. These are difficult to quantify in the field, and are represented in (3a) by a parameter p , assumed constant across years.

The various population models in this chapter consider demographic parameters either in their time-varying forms as above, or replaced by average values over the period modelled (i.e. 1966 to 2000). We denote these average constant values in the paper by dropping the subscript j in the above definitions.

Applying (3a) recursively over T years we have

$$N_j = N_1 k_j \quad j = 2,3,4,\dots,T \quad (4a)$$

$$k_j = \prod_{i=1}^{j-1} (\phi_{ai} + p FPA_j \phi_{li} \phi_{pFi}) \quad j = 2,3,4,\dots,T \quad (4b)$$

hence

$$\ln(N_j) = \ln(N_1) + k'_j \quad (5a)$$

$$k'_j = \sum_{i=1}^{j-1} \ln(\phi_{ai} + p FPA_j \phi_{li} \phi_{pFi}) \quad (5b)$$

Substituting (5) into (2) gives

$$\ln(c_{ij}) = s_i + \ln(N_1) + k'_j \quad (6)$$

If survival probabilities and productivity per breeding attempt are regarded as known (in practice, replaced by their estimates from ringing and nest record data), the only unknown parameters in (6) are site effects s_i , the population N_1 in year 1 and P , the unknown component of productivity. The various demographic models fitted in this chapter differ in the sets of values used for survival and productivity per breeding attempt, according to which variables are assigned constant and time-dependent values; that is, each model employs different explanatory variables k'_j .

For fixed p , equation (6) therefore retains a GLM form, and an estimate \tilde{N}_1 of N_1 conditional on p is readily evaluated via equation (6) and any GLM software, since k'_j becomes an offset variable and \tilde{N}_1 is calculated via the model intercept. An iterative search provides unconditional maximum likelihood estimates (MLE) N_1 and \hat{p} .

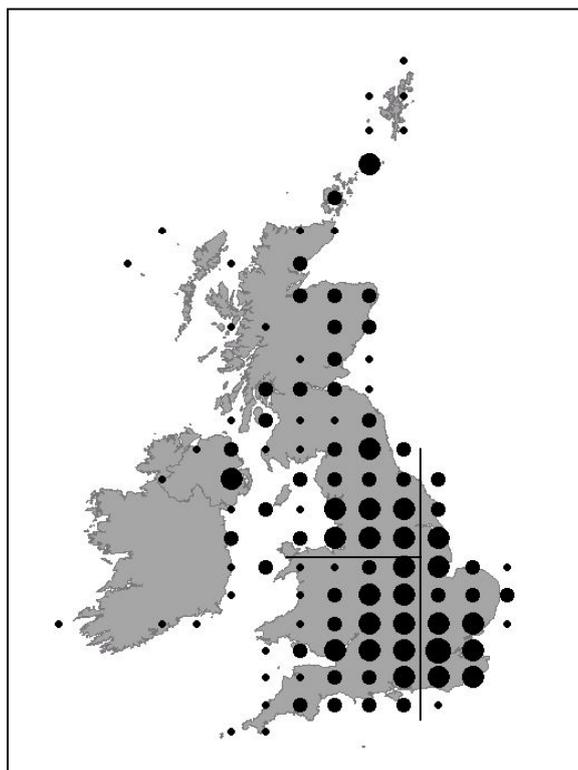


Figure 7.3.4.1 Number of Starlings ringed in Britain and Ireland in the breeding season (April to mid-July) and subsequently recovered. The size of the dots is proportional to the number of birds ringed in each 10km square (from Wernham *et al.* in press).

7.3.5 Regional Analyses

Population models were also fitted separately to data from each of three regions, following the regional divisions of Chapter 2, such that the ringing was approximately equal in each region (Figure 7.3.4.1). These were: Eastern Britain (regions East and South East of Chapter 2); Western Britain (regions West and South West) and Northern Britain, which has the same definition as in Chapter 2. Of these regions, Eastern Britain encompasses the major arable growing areas in Britain, and the Starling's population stronghold. The largely pastoral Western and Northern regions have seen more sustained declines in Starling numbers (Chapter 2). These are very broad differences, but there were insufficient numbers of birds recovered and nests recorded to permit a more detailed regional analysis. The modelling of survival rates also assumes that there is no mixing of populations between regions. In Britain, Starlings can be considered sedentary, generally moving only a few kilometres during their lifetime (Feare in press), thus with these broadly defined regions, movement between regions will be negligible.

As the regional sub-division increases the relative sparseness of the data on post-fledging rates, we restrict this part of the analysis to birds ringed as adults and juveniles only. The ring-recovery data were therefore used to estimate trends in juvenile and adult survival, employing models for two age classes similar in form to those used in the national analyses. Because of relatively sparse data, the model for birds ringed in the West produced a boundary estimate (i.e. $\phi = 0$) for adult birds in the final year. Thus, we constrained adult survival to be equal in the final two years which had a negligible effect upon the values taken by survival in the earlier years, and only trends based on this constrained form are used in the subsequent population models post-fledging survival is assumed constant in these models and is effectively subsumed in the parameter, P . As there were too few Nest Record Cards to estimate annual productivity separately for each region, an overall value for productivity was calculated for each region and included as a constant in the population models.

7.4 RESULTS

7.4.1 Demographic parameters

For completeness, annual estimates of productivity parameters from Nest Record data are given in Figure 7.4.1.1 as these are used in the population modelling process. See Chapter 6 for a full discussion of these results.

In all of the survival models, we assume different survival and reporting probabilities apply to each of the three age classes, i.e. for post-fledging, first-year and adult birds. The most general model that can be applied to such data has temporally varying parameters without any constraints upon annual estimates of either survival or reporting probabilities. This performs poorly because of the sparseness of the data and the large number of parameters (two sets x three age-classes x 35 years = 210 parameters, though some are confounded in the model structure). Because of this, many parameters took maximum likelihood estimates at a boundary to the parameter space (i.e. 0 or 1).

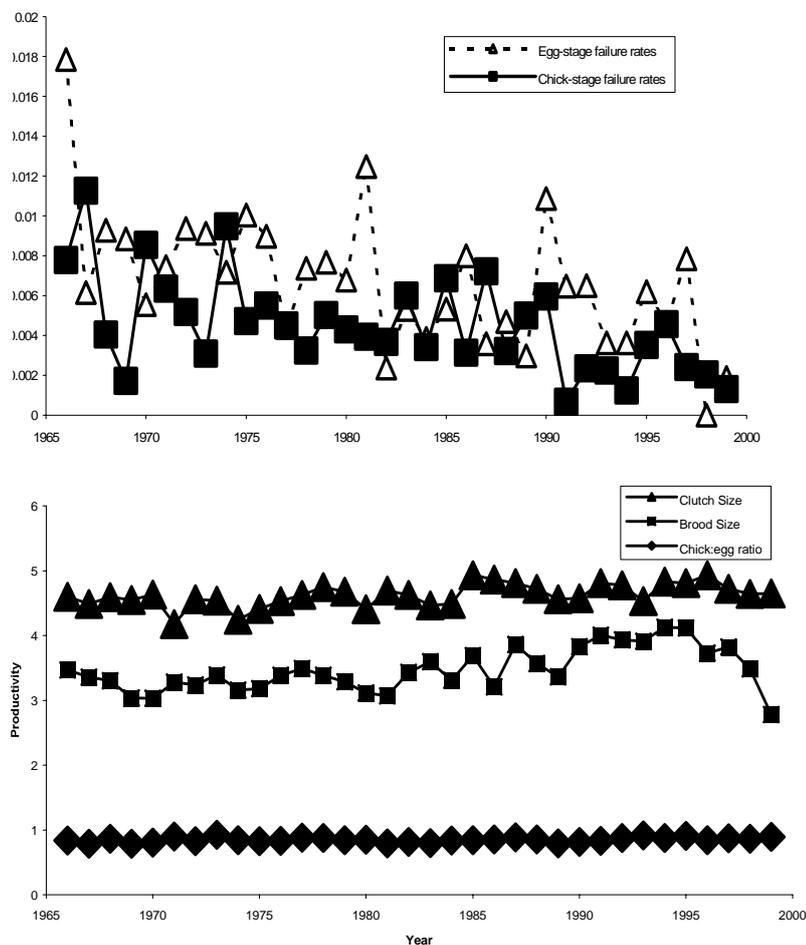
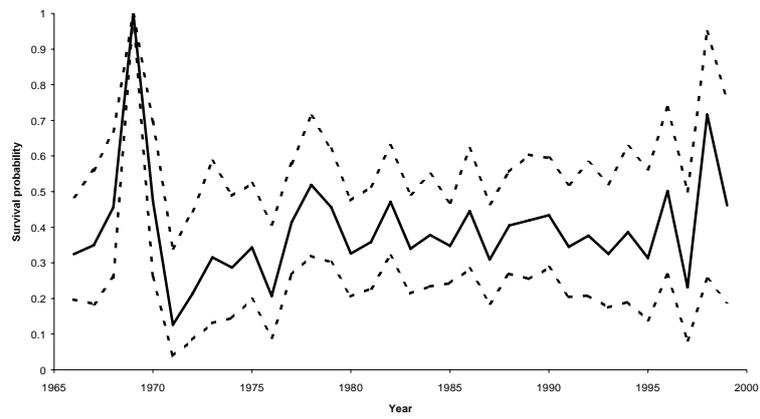
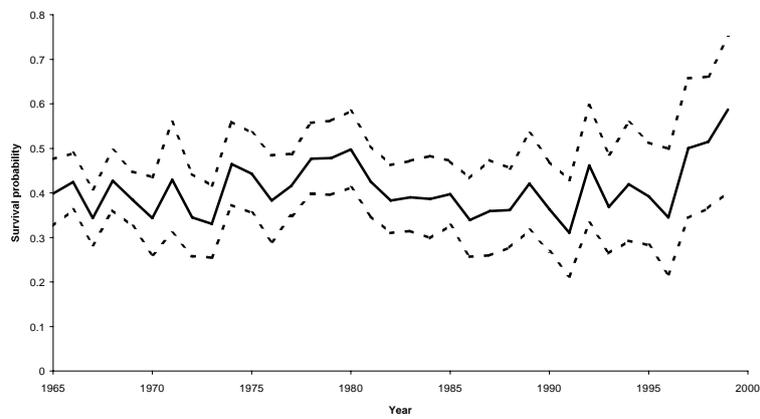


Figure 7.4.1.1 Annual estimates of Starling productivity parameters

(a)



(b)



(c)

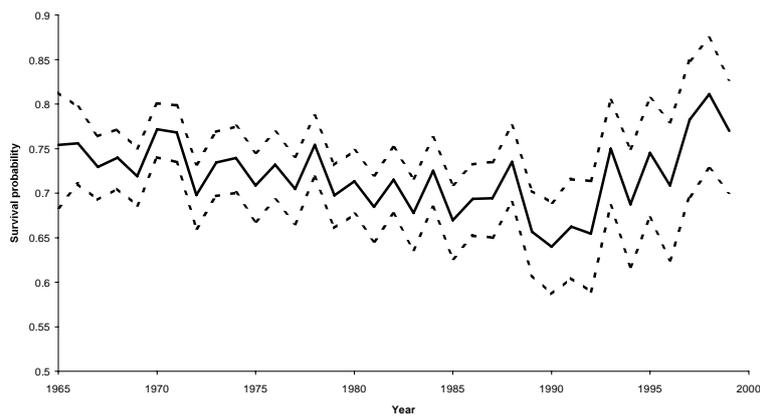


Figure 7.4.1.2 Annual estimates of survival for three age-classes of Starlings (a) post-fledging, (b) first-year and (c) adult birds. Dashed lines represent 95% confidence limits.

As a more practical model, we permitted survival rates to vary freely between years, but constrained the reporting rates, for the three ages separately, to change linearly (on the logit scale) over the period of the study. Reporting rates of ringed birds found dead have declined markedly (Baillie & Green 1987; Dunn 2001), and applying this constraint ensured that any such decline in the reporting rate of ringed Starlings subsequently found dead did not bias the trends in survival. Indeed, under this model estimated reporting rate declined for birds of all ages: from 1.2% of ringed birds found dead in 1966 to 0.6% in 2000 at the post-fledging stage, from 2.7% to 1.7% for first-year birds and from 5.9% to 1.8% for adult birds.

Average survival rates over the period 1966 to 2000 differed between the three age classes. Comparing daily survival rates to avoid the problem of birds surviving for time periods of different length, survival was lowest during the period immediately following fledging (0.978 day^{-1}), but survival of first-winter (0.997 day^{-1}) and adult (0.999 day^{-1}) was similar. Overall, survival during the first twelve months of life (0.147) was much lower than in subsequent years (0.694).

Although a simplified scenario for estimating reporting rates is used, the annual estimates of post-fledging survival have little precision and adult survival in the final year (2000) was estimated to be zero; that in the immediately preceding years also appear unrealistically low, given the relatively small year-to-year changes throughout the earlier part of the series (Appendix 7.1). More realistic estimates could be obtained by the use of constraints in these years, but it is important to ensure that these did not unduly influence estimates in earlier years. In order to circumvent the problematic estimation of parameters in the final years, a further model (the “constrained” model) was therefore considered. The adult survival rate for the final year was set to equal the average survival rate over the three preceding years. Results of this model appeared more realistic and, importantly, differed negligibly from previous estimates over the main part of the series, appearing a little high only when the major population changes had already taken place (Appendix 7.1). Estimates of first-year and post-fledging survival were also unaffected by these constraints until the very final years. Thus, in building the population models we used survival rates from constrained ring-recovery models only (Figure 7.4.1.2); conclusions from using the unconstrained model (Appendix 7.1) are, however, almost identical.

7.4.2 Population models

Starlings were recorded holding territory on a total of 883 CBC sites at least once during the period 1966 to 2000. Annual population estimates across all these sites were derived from the model $\{S_i, N_j\}$, which is equivalent to the annual GAM models fitted in Chapter 2 (Figure 2.4.2.1). This shows three periods (also identified by the turning point analysis in Chapter 2) during which the annual changes in population size were broadly similar, at least in direction. An initial steep population decline in the late 1960s and a further period of decline since the early 1980s were broken by a period of a decade or so when the population index changed little. Imposing a constant rate of decline (on the log scale) significantly worsens the fit ($\chi^2_{33} = 273.37$, $P < 0.01$), which confirms that the population trends observed differ significantly between the three periods. We use the indices of abundance derived from this model as a ‘base’ model against which to compare population models in which the annual population indices are calculated by incorporating demographic (i.e. survival and productivity) information. We stress, however, that the following population models are not *fitted* to these annual indices in any sense. Each set of indices is derived by independently fitting models to the counts made on each site in each year as part of the CBC. This comparison still provides a useful visual assessment of the quality of each of the demographic population models.

We initially fitted a model in which all demographic parameters took their most general, fully time-dependent form (i.e. annual estimates of survival for each of the three age classes and annual estimates for each of the productivity parameters) to the CBC data. The resulting model (Figure 7.4.2.1) shows a decline from 1980 onwards, but otherwise little resemblance to the abundance indices from the more general $\{S_i, N_j\}$ model, which is derived solely from the census data. It also shows considerably greater changes, from year to year, than are implied by the census indices.

However, this lack of fit proved to be largely due to the large variation in annual post-fledging survival rates, which are determined in the ring-recovery model from a limited amount of data. Fitting a model with post-fledging survival rate held constant, and annual time variation in the other parameters performs considerably better (Figure 7.4.2.1). Henceforth, we set post-fledging survival constant in all population models.

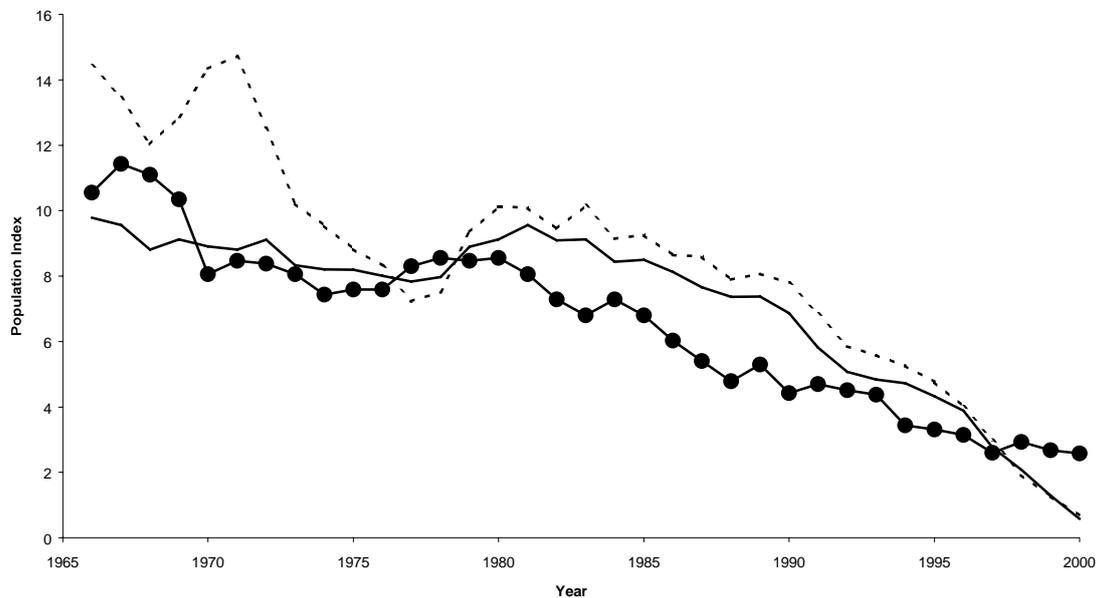


Figure 7.4.2.1 Overall population model for the Starling CBC index. The line with circles gives the annual CBC index (model $\{S_i N_j\}$), the dashed line gives index values predicted by the model in which all parameters take their annual estimate and the solid line gives index values predicted from the model in which post-fledging survival is held constant and all other parameters take their annual estimates.

It follows that setting all demographic parameters constant, equal to their average values simultaneously, reduces the model to a simple log-linear trend, since equation (4) becomes simply $N_{j+1} = aN_j$, where a is a constant. Formally, the log-likelihood values show that this very simple model fits the data better than either of the alternative models with time-varying survival rates discussed above (Table 7.4.2.1). This model inevitably reproduces the long-term decline over the duration of the period considered, but cannot capture shorter term changes in population size, such as the alternating periods of decline and stability. We therefore now extend this model by allowing each demographic parameter in turn to take its varying annual values, while the remainder are kept constant. This way, we hope to identify those parameters whose annual fluctuations produce the greatest improvement in fit, and the most accurate reproduction of changes in the population trend.

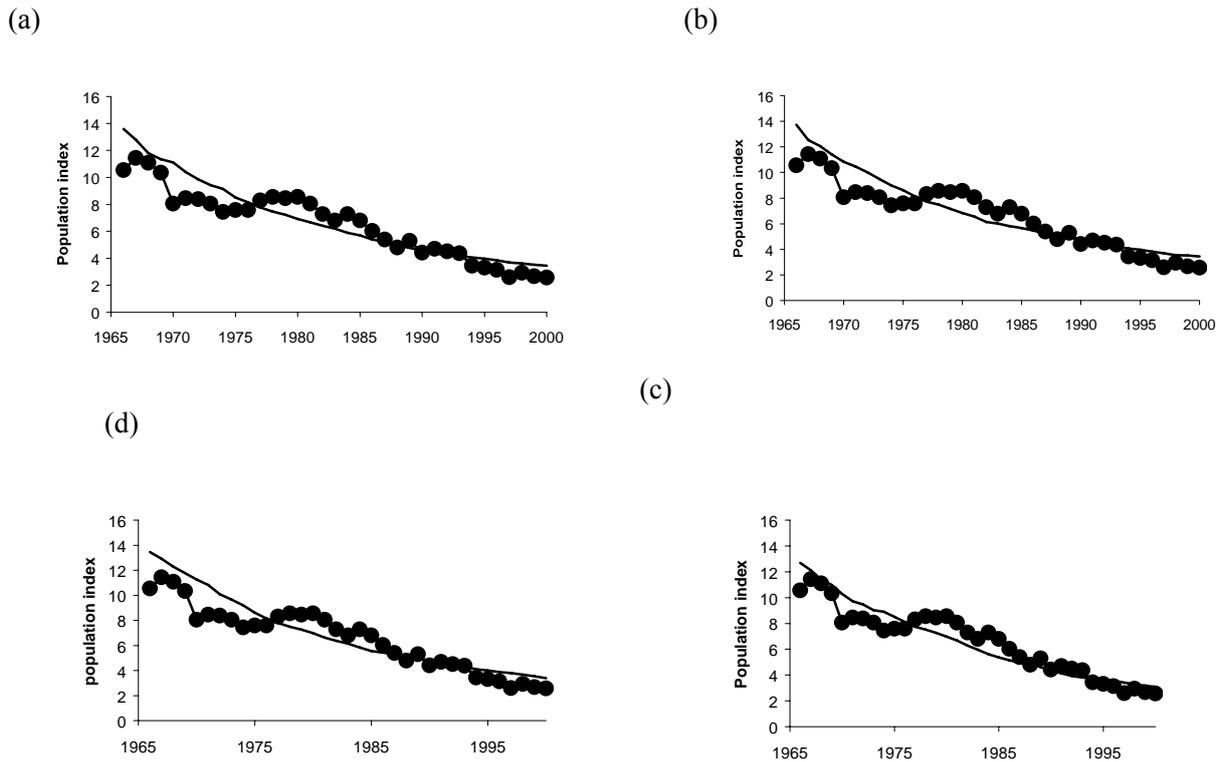


Figure 7.4.2.2 Population models for Starlings constructed using annual estimates for each of four breeding productivity parameters in turn, all other variables held constant. (a) Nest failure at the egg stage (b) nest failure at the young stage (c) hatching success (d) clutch size.

Table 7.4.2.1 Maximised log-likelihood values for a range of models, fitted to British Starling data. Models are identified by which parameters are set constant (C) or permitted to change over time (T). The models are compared using the relative value of l' the negative of the maximised log-likelihood, such that the best-fitting model has $l' = 0$; this model is highlighted in bold.

Φ_{PFj}	Φ_{Ij}	Φ_{Aj}	CS_j	HS_j	EFR_j	NFR_j	l'
T	T	T	T	T	T	T	487
C	T	T	T	T	T	T	309
C	C	C	C	C	C	C	29
C	C	T	C	C	C	C	16
C	T	C	C	C	C	C	0
C	C	C	C	C	T	C	71
C	C	C	C	C	C	T	69
C	C	C	C	T	C	C	36
C	C	C	T	C	C	C	75

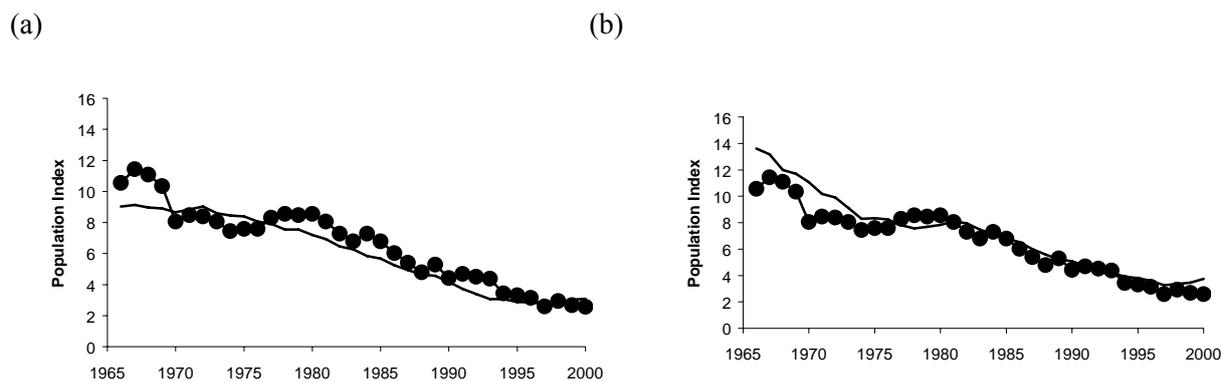


Figure 7.4.2.3 Population models for Starlings constructed using annual estimates for each of two survival parameters in turn, all other variables held constant. (a) Adult survival time-varying, (b) first-year survival time-varying.

The change in the trajectory of the population model is negligibly altered by varying any of the four parameters derived from nest record data (Figure 7.4.2.2). Each of these four models results in an approximately constant rate of decline throughout the study period. This implies that none of these parameters are implicated in the decline observed since the stable period of the 1970s.

Conversely, by permitting the survival rates of either first-year or adult birds to vary, whilst holding the productivity parameters constant, the population model produces a decline that begins at exactly the same time as that shown by the CBC index series (Figure 7.4.2.3). Note that the period of decline in first-year survival rates largely coincides with that of the period of major population decline since 1980 and whilst adult survival appears to be marginally lower during this period, it is lowest from 1989 to 1993. Of the two, varying first-year survival provides a much closer reflection of the extent of this decline, and this model, alone of those considered, also reproduces the period of stability between the two phases of decline. Of all models fitted, it also provides much the best fit (Table 7.4.2.3). This model provides an estimate of 1.2 nesting attempts per pair in the breeding season and will include a 'contribution' from non-breeding individuals (i.e. zero attempts), which will mostly be first-year birds (Chapter 5).

7.4.3 Regional Analyses

For each of three separate regions we fitted the $\{S_j, N_j\}$ model usual and the constrained models with constant survival and productivity. Population trends in the North and West were quite similar and declined throughout the period considered, though at a decelerating rate (Figure 7.4.3.5). The population in the East only began a marked decline in the mid 1980s (Figure 7.4.3.2). This decline was, however, then substantially greater than elsewhere in the country. We then fitted two further models, permitting first-year and adult survival, each in turn, to vary between years.

In the East, survival of both first-year and adult birds was quite variable from year to year (Figure 7.4.3.1). Over most of the period, there is no discernible pattern in the annual survival rates of first-year birds, but survival rates do seem to increase in the late 1990s there appears to be a decline in adult survival rate during the 1980s, such that the average annual survival rate for 1979 to 1981 (0.74) is much higher than the average survival rate for the period 1990-1992 (0.66). After this decline, adult survival rates apparently increased markedly. The population model allowing first-year survival to vary annually fitted much less well than a model with all survival rates constant (change in log likelihood, -23.3), while the model allowing for annual time variation in adult survival fitted appreciably better (change in log likelihood, 26.2). The model with annual variation in adult survival rate does show, to a certain extent, a period of slow decline accelerating in about 1985, reproducing

the shape of the $\{S_i, N_j\}$ model quite well (Figure 7.4.3.2). Thus, on the basis of this analysis, in the Eastern region, adult survival is the most likely candidate for driving the population decline.

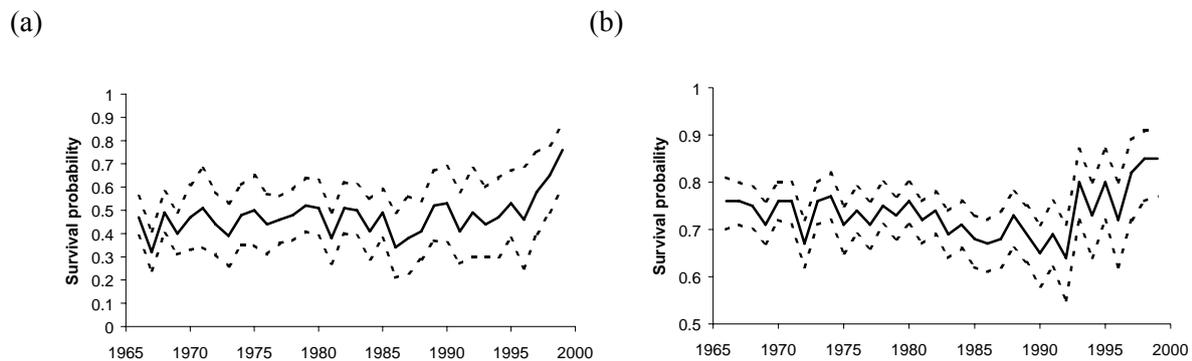


Figure 7.4.3.1 Annual estimates of (a) first-year survival and (b) adult survival in Eastern England. Solid lines represent annual estimates, dashed lines the 95% confidence limits.

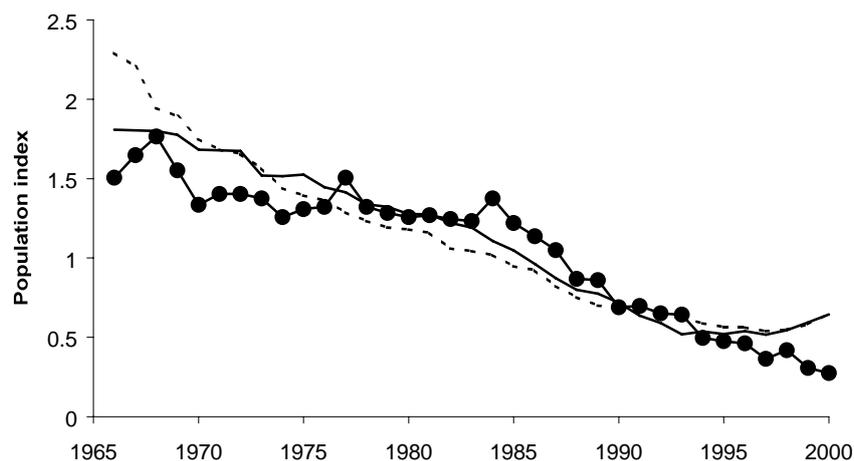


Figure 7.4.3.2 Models of Starling population index for Eastern England. Solid line with closed symbols represents the model $\{S_i, N_j\}$, equivalent to the standard CBC index, the solid line allows for time-varying adult survival, the dashed line time varying first-year survival. All other parameters are held constant.

Although we attempted to define the regions, such that ringing effort was approximately equal in each region (Figure 7.4.3.1), recovery data were sparser for the North and West regions than for the East region. Consequently, the annual survival rates were estimated with somewhat poorer precision for these regions (Figures 7.4.3.3 and 7.4.3.4). The model incorporating first-year survival for the Northern region reproduced many of the features of the general trend from $\{S_i, N_j\}$, including the initial decline and subsequent period of stability (1965-77) and the final period of decline (1991-99), but produced much higher estimates in the 1980s (Figure 7.4.3.5). The model including annual estimates for adult survival, on the other hand, produced a much more linear decline. Although the power to compare trends is very low, this does suggest that changes in juvenile survival might be a better candidate for determining population trend in this region. Similarly, in Western region the decrease in fit for a model allowing for time varying first-year survival (change in log likelihood, -

2.45) was rather small, and much less than for the model with time-varying adult survival (change in log likelihood, -33.6).

These conclusions were supported by a population model which combined these two regions, which benefited from larger sample sizes (Figure 7.4.3.6). The combined population index $\{S_i N_j\}$ was similar to that in the two regions and a population model with annual first-year survival estimates resembled this trend much more closely than a model with annual adult survival rates. In particular, allowing first-year survival to vary produced the two periods of decline separated by a period of relative population stability.

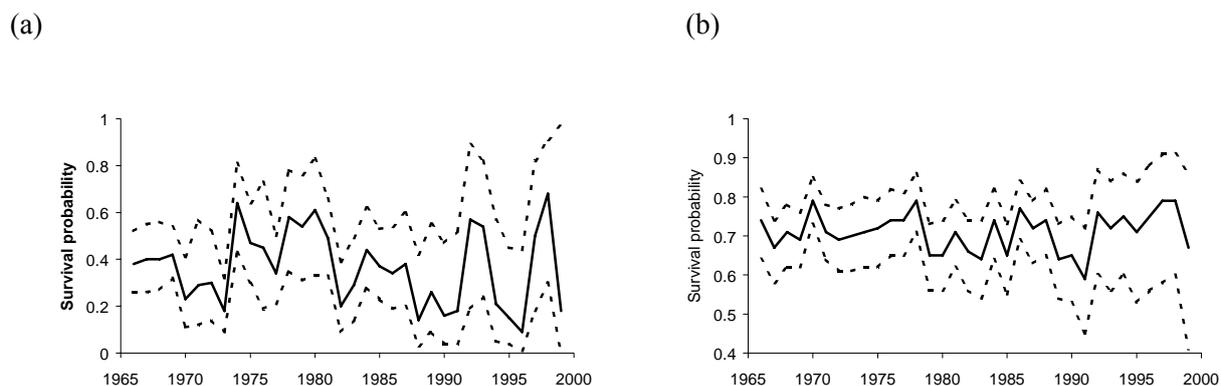


Figure 7.4.3.3 Annual estimates of (a) first-year survival and (b) adult survival in Northern England. Solid lines represent annual estimates, dashed lines the 95% confidence limits.

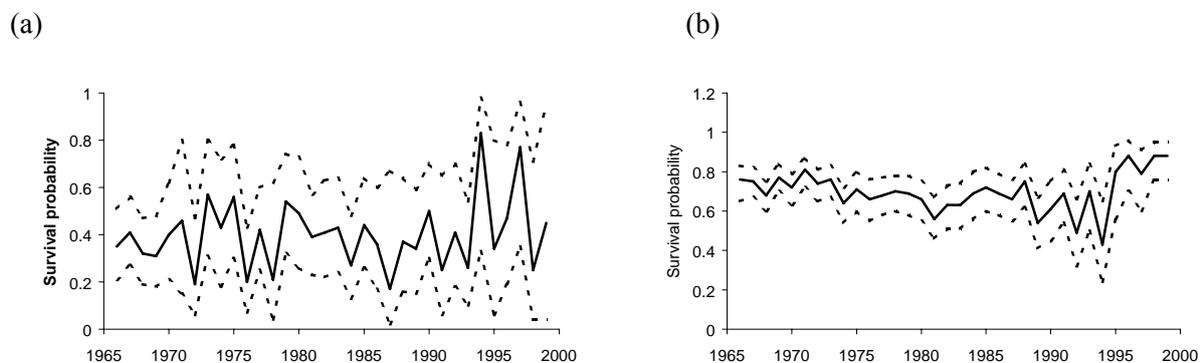


Figure 7.4.3.4 Annual estimates of (a) first-year survival and (b) adult survival in Western England. Solid lines represent annual estimates, dashed lines the 95% confidence limits.

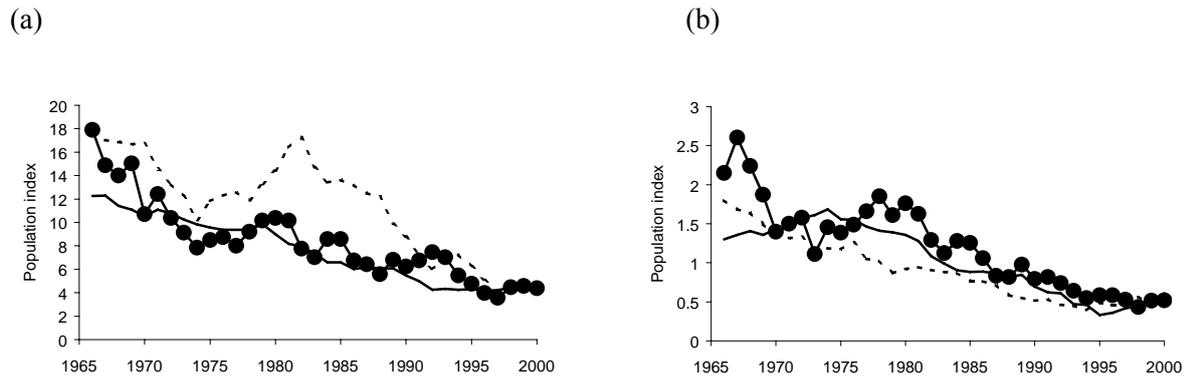


Figure 7.4.3.5 Models of Starling population index for (a) Northern England and (b) Western England. Solid line with closed symbols represents the model $\{S_i N_j\}$, equivalent to the standard CBC index, the solid line allows for time-varying adult survival, the dashed line time varying first-year survival. All other parameters are held constant.

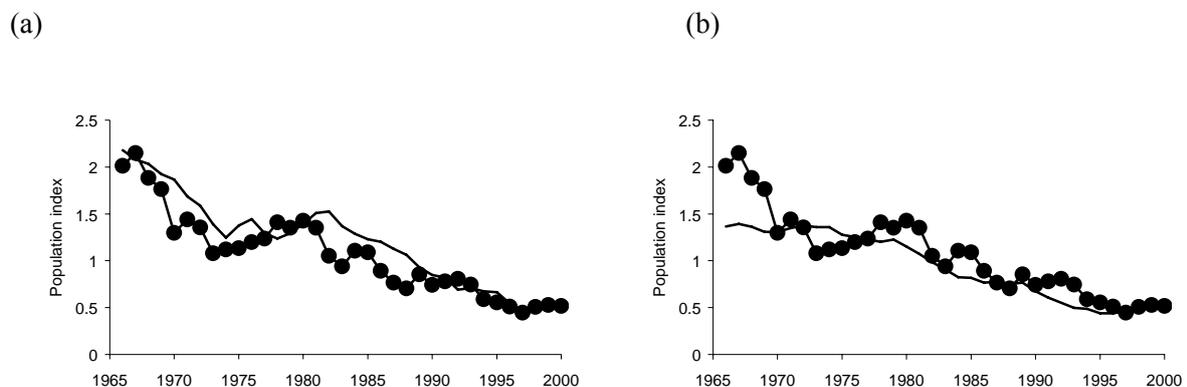


Figure 7.4.3.6 Models of Starling population for Northern and Western Britain combined in one region. (a) model allowing for time-varying first-year survival, (b) model allowing for time-varying adult survival. In each case, the solid line with closed symbols represents the model $\{S_i N_j\}$ equivalent to the standard CBC index, and the solid line the model incorporating time-varying survival.

7.5 DISCUSSION

The population modelling reported in this chapter combined the demographic processes of survival and productivity with the full observed census data, rather than a derived index, for the first time. This shows that the two periods of population decline in the national index series are likely to be caused by changes in the survival of birds following the post-fledging period. Survival of birds over their first autumn and winter following hatching seems to be particularly important in determining the population status of this species.

The last thirty years have seen declines in a large range of passerine bird species, with a number of the declines, including that of the Starling, sufficiently large to merit listing as species of conservation concern (Gibbons *et al.* 1996; Siriwardena *et al.* 1998a). As a rule, many of these declines appear to be broadly associated with changes in survival rates, rather than changes in productivity (Siriwardena *et al.* 1998b). More detailed studies have confirmed this general pattern, with declines in both seed-eating (Siriwardena *et al.* 1999) and non seed-eating passerine species (e.g. Thomson *et al.* 1997) apparently having been driven by changes in survival, and particularly the survival of birds during their first winter after hatching, though there are exceptions to this pattern (Siriwardena *et al.* 1999).

The survival of first-winter birds is likely to be particularly susceptible to environmental stress since these birds are to be less efficient at foraging and have a poorer knowledge of the environment. They are also likely to be competitively excluded from the best quality habitats by more dominant birds resulting in decreased intake rates and hence increased chances of starvation (e.g. Ekman & Askenmo 1984; Goss-Custard *et al.* 1984); this is also likely to have other costs, such as an increase in predation risk which may also adversely affect survival probabilities (e.g. Cresswell 1994).

The survival rate of individual birds might be expected to vary in a density-dependent manner. When densities are reduced below the carrying capacity of the environment, survival rates would be higher than otherwise due to, for example, reduced competition for resources or reduced incidence of disease transmission (Newton 1998). This can lead to problems in diagnosing the demographic cause of a decline, particularly as it means the reduction in survival or productivity may be relatively transient (Green 1999). Survival rates in first-year Starlings, at least, appear to exhibit such density dependence, in the later years of this study, when the population had been reduced significantly (Figure 7.4.1.2), survival rates increase substantially and the population decline appears to proceed less steeply in the late 1990s; this is also apparent in the regional analysis. However, the main period of decline in survival is sustained, occurring throughout the 1980s, leading to a clear demographic diagnosis of the cause of the population decline.

These analyses show that the Starling appears to be similar to many other species that forage on farmland, in that marked population declines in the recent past have been driven by changes in survival. The estimates of survival for each age-class (averaged over the period 1966-2000) are broadly what would be expected for a passerine bird of this size (Siriwardena *et al.* 1998b). Thus it might be reasonable to conclude that the environmental factors causing the declines in other farmland species may also be relevant to the Starling population. Where over-winter survival is important, as appears to be the case here, declines in food resources have often been implicated, as this will not only increase the probability that an individual will starve, but may also make it more susceptible to predation, disease contraction, or less able to respond to other environmental stresses such as cold temperatures (Newton 1998). This has been particularly true of the seed-eating passerines, for which the level of food availability has declined substantially (Robinson & Sutherland 2002).

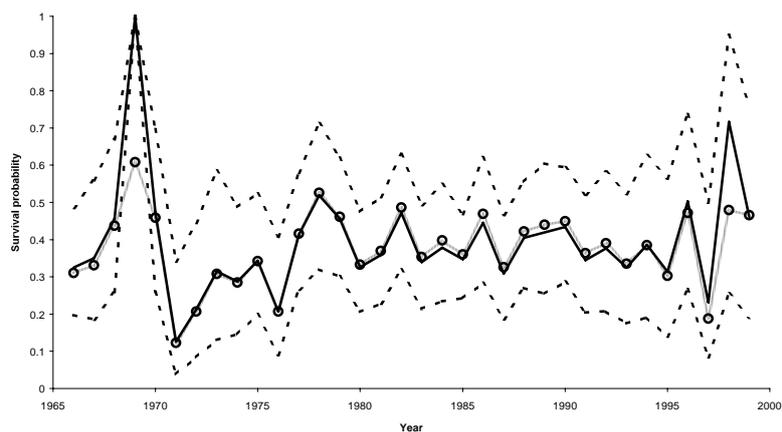
Although Starlings do forage on seeds, particularly in the autumn and winter, their primary prey are soil invertebrates (Feare 1984). There is no clear evidence that the density of these has declined in recent years, though large annual fluctuations in numbers mask any trend and sampling at a sufficient scale is extremely challenging (Wilson *et al.* 1999). However, densities of soil invertebrates are typically highest in permanent pasture, and Starlings prefer to forage there (Whitehead *et al.* 1985; Bruun 2002). In Britain, the area of permanent pasture has declined by 5% since 1965 (DEFRA statistics), which will have reduced the amount of preferred foraging habitat available. The main period of decline in juvenile survival also coincides with a decline in the number of dairy cattle kept on British farms; between 1980 and 1990, numbers of dairy cattle in Britain fell by 21%, from 2.9 million to 2.3 million head (DEFRA statistics). Starlings frequently forage in association with cattle, and will also forage in crops grown for stock fodder (Feare 1984); reductions in the prevalence of either, thus have the potential to impact on Starling survival.

The results of the regional analysis suggest that the underlying demographic causes of the decline may be slightly more complicated. Changes in adult survival seemed more important in Eastern England, whereas in the North and West regions, the results suggested that changes in first-year survival had the greater effect. Although adult Starlings are, in general, relatively sedentary (median dispersal distance from recoveries, 5km) first-year birds may roam quite widely (median distance from recoveries, 20km, Feare (1984, in press)). This could suggest that in the Eastern region, first-year birds have sufficient habitat to disperse into during the autumn, but that this is not true in Northern and Western Britain. Consequently, provision of suitable habitat in Northern and Western Britain might help ameliorate the decline in Starling numbers.

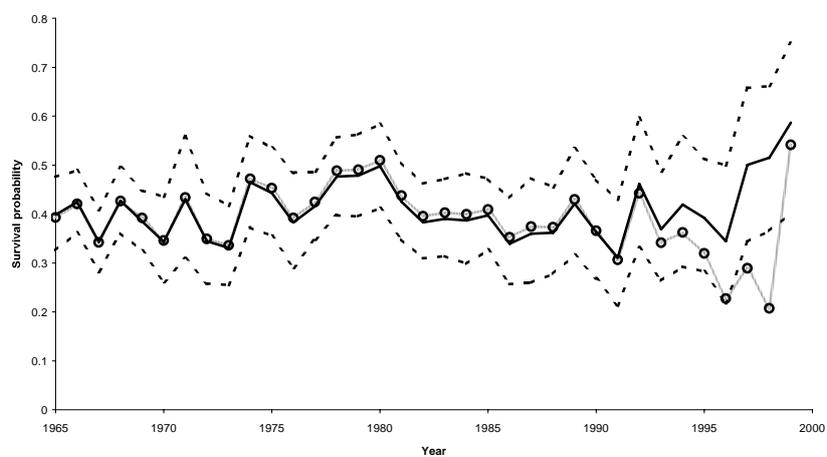
Having clearly identified the cause of the decline as a reduction in survival (particularly first-year survival though changes in adult survival may also be relevant) means that the range of environmental changes that are likely to have caused the population decline can be considerably narrowed. These will be discussed in the final chapter, in the context of the other results presented in this report.

Appendix 7.1 Graphical comparison of survival for each of the three age-classes under the full annual model and under a constrained model. In this model, adult survival was constrained to equal the average survival for the three preceding years (which were free to vary). In each case the unconstrained model is given by the dotted line with symbols, the constrained model by a solid line (with dashed lines representing the 95% confidence limits). (a) Post-fledging, (b) first-year and (c) adult survival.

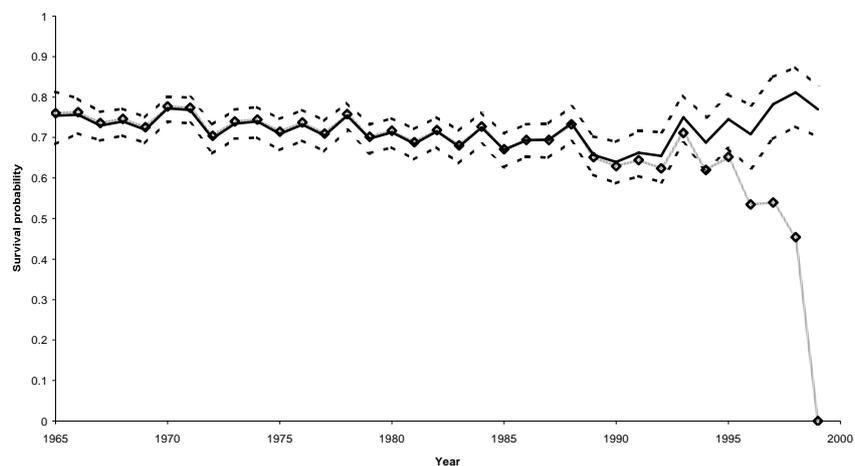
(a)



(b)



(c)



8 COMPARATIVE BREEDING ECOLOGY OF THE HOUSE SPARROW *Passer domesticus* BEFORE AND DURING POPULATION DECLINE IN BRITAIN

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8.1 CHAPTER SUMMARY

1. Knowledge of demographic rates exhibited by a declining population can be an important aid in identifying the causal factor(s) behind the decline and in reducing the risk of incorrect diagnosis. In this study we investigated whether changes in breeding performance could be the proximate demographic mechanism driving the decline of the House Sparrow on farmland in Britain.
2. Comparison of House Sparrow breeding ecology parameters collected on farms in Oxfordshire in periods before and during the national population decline provided evidence of a later start to the breeding season in recent years. This could be a result of reduced resource availability overwinter and/or early in the breeding season.
3. However, we found no evidence of any significant differences in the majority of breeding ecology parameters investigated, including the number of breeding attempts made by females during the breeding season, or in overall annual productivity.
4. There are three possible scenarios to explain the observed declines in numbers at the Oxford University Farm. (a) A temporary reduction in breeding performance may have been followed by population stabilisation at a new, lower carrying capacity. (b) Breeding adults have maintained breeding performance during the breeding season despite a reduction in resource availability between periods one and two, but have incurred reduced survival rates later in the year. (c) The decline was caused by a demographic mechanism other than breeding performance.
5. The available evidence suggests that the demographic mechanism driving the decline of the House Sparrow at the Oxford University Farm was a reduction in survival rate, probably during the non-breeding season.

8.2 INTRODUCTION

There is now considerable evidence that agricultural intensification has contributed to the declines of many farmland bird species in Britain (e.g. Fuller *et al.* 1995; Chamberlain 2000; Siriwardena *et al.* 2000b) and Europe (e.g. Pain and Pienkowski 1997; Donald *et al.* 2001) since the mid 1970's. Changes in the agricultural environment such as increased agrochemical usage, the simplification of crop rotations, the intensification of grassland management and the loss of overwinter stubbles could have reduced the carrying capacity of farmland in a variety of ways, acting through survival and/or breeding success (Siriwardena *et al.* 2000a; Robinson & Sutherland 2002).

If these declines are to be halted or reversed – a key Public Service Agreement target for the Government (DETR 1999) – an understanding of the key demographic mechanism(s) driving the declines is crucial. Studies have frequently used associations between rates of population change and external variables to indicate causation (Caughley 1994; Green 1995). However, as with all methods that rely upon correlation, an observed association may arise because of changes in a factor different from, but correlated with, the supposed agent of decline. Information on demographic rates can therefore be used as both an aid in identifying the causal factor(s) and to reduce the risk of incorrect diagnosis (Green 1999).

The exact nature of the interaction between agricultural intensification and population decline is likely to be species specific (Siriwardena *et al.* 1998a; Krebs *et al.* 1999). However, indirect evidence suggests that a reduction in food supply, as a result of intensification and specialisation of arable and grassland systems (Wilson *et al.* 1999; Robinson & Sutherland 2000), may be a significant causal factor underlying the declines in a number of species (Chamberlain *et al.* 2000). Loss of food resources may impact on demography through changes in the overall breeding performance of a species, mediated by reductions in, for example, fledging success, nestling body condition or the number of breeding attempts being made during a season, as well as reduction in survival probabilities in the non-breeding season.

Analyses of national data-sets held by the BTO found little evidence of reduced breeding success per attempt during periods of population decline in 12 granivorous bird species (Siriwardena *et al.* 2000a). However, these analyses were unable to detect changes in the number of attempts being made – a major component of overall productivity that is likely to be highly susceptible to environmental change (Kyrkos 1997; Wilson *et al.* 1997; Bradbury *et al.* 2000; Siriwardena *et al.* 2000a). Indeed, few autecological studies have managed to measure this parameter accurately in natural populations, because of the difficulty in marking and following individual birds between breeding attempts.

In this study, we capitalise on the availability of detailed long-term breeding ecology data for the House Sparrow *Passer domesticus*. Traditionally regarded as a farmland bird, despite its widespread use of urban and suburban habitats (Siriwardena *et al.* 1999), it declined nationally by 46% between 1976 and 2000 on farmland Common Birds Census plots (Chapter 3). The BTO/JNCC/RSPB Breeding Bird Survey shows that these declines are continuing on farmland in the South East (which contains Oxfordshire, Chapter 3). As a predominantly hole-nesting species (Summers-Smith 1988), provision of nest-boxes allows measurement of both the number of breeding attempts being made and the success of each nesting attempt. Specifically, we test the hypothesis that changes in breeding performance are a proximate cause of the ongoing decline in the House Sparrow in Britain, by providing a comprehensive comparison of breeding ecology data collected in the pre-decline period 1967 to 1971 (although data are limited, evidence suggests the House Sparrow population index was relatively stable pre-1975 (Siriwardena *et al.* 1998b, Chapter 3) with equivalent data collected during the national population decline, in the period 1998 to 2000.

8.3 METHODS

8.3.1 Study population 1967 – 1971 (period one)

House Sparrow breeding ecology was monitored in two previous studies at University Farm (UF), Wytham, Oxfordshire, (grid reference SP4709), in a maximum of 38 nest-boxes and several natural nest sites. The first was carried out between 1967 and 1969 (Cheke unpubl.) and the second between 1969 and 1971 (Dawson 1972). Mean population size during the five years of these studies was approximately 150 individuals.

8.3.2 Study population 1998 – 2000 (period two)

House Sparrow breeding ecology was monitored in 40 nest-boxes (dimensions: h=29cm; w=13cm; d=19cm; hole diameter=3.2cm) at UF for three seasons between 1998 and 2000. During the same period, breeding ecology was also monitored in 25 nest-boxes and up to 30 natural nests at Step Farm (SF), an organic farm near Faringdon, Oxfordshire (SU2695). Mean population size at the two farms over the course of the study was approximately 35 and 170 individuals respectively.

8.3.3 Nest recording

8.3.3.1 Period two: 1998-2000

Nests were checked at three-day intervals from the beginning of April and the following data recorded: date of laying of the first egg in each clutch, clutch size, egg volume, date of hatching, number hatched and number fledged. Nestling day 13 (hatch day = day 0) was taken as the first day on which a nestling was likely to leave its nest-box (Seel 1970; Hole unpubl.). For nests that failed, date of failure was estimated as the mid-point between the date when the nest was last known to be active and the date on which it was found to have failed.

Where nestling age was not known precisely from observation of hatching, it could be accurately estimated by comparing the degree of feather development of the largest nestling with known-age broods. Where first egg date of a clutch was unknown, it was back-calculated from the hatch date, assuming an 11-day incubation period (D.G. Hole, unpubl. data) and the laying of one egg per day (Seel 1968b).

Length and breadth of eggs were measured to the nearest 0.1mm using dial calipers, after clutch completion. Nestling mass (to the nearest 0.1g using a 50g Pesola spring balance) and tarsus (to the nearest 0.1mm using dial calipers and following the procedure of Svensson (1992)) were measured on or around nestling day nine and day 13. Nestlings were ringed with a numbered aluminium ring and a unique combination of three coloured plastic rings on nestling day nine. Nest-boxes were checked on day 17 to determine fledging success.

At UF in period two, House Sparrows were mist-netted throughout the duration of the study in order to uniquely colour-ring adults. The identity of the majority of breeding females could then be determined at each nesting attempt. A minority of birds at SF were also colour-ringed.

8.3.3.2 Period one: 1967-71

Equivalent data were extracted directly from nest record cards produced during the two previous studies at UF (Dawson 1972; Cheke unpubl.).

8.3.4 Parameters investigated

The 12 breeding ecology parameters in Table 8.3.4.1 were investigated to determine whether any significant differences existed in: 1) breeding phenology; (2) breeding success; and (3) nestling quality (i.e. body condition and mass at fledging), between periods one and two. The parameters in Table 8.3.4.1 are given numerical labels to aid reference to them in the text.

Table 8.3.4.1 Breeding phenology, breeding success and nestling quality parameters investigated in periods one and two. Numbers are used to identify separate statistical models referred to in the text.

<i>Parameter</i>	<i>Number</i>
Breeding phenology;	
<i>Length of breeding season</i>	<i>1</i>
<i>First egg date</i>	<i>2</i>
<i>Interclutch interval</i>	<i>3</i>
Breeding success;	
<i>Egg volume</i>	<i>4</i>
<i>Clutch size</i>	<i>5</i>
<i>Proportion hatched</i>	<i>6</i>
<i>Daily survival rate:</i>	
- <i>whole nest period</i>	<i>7.1</i>
- <i>egg stage</i>	<i>7.2</i>
- <i>nestling stage</i>	<i>7.3</i>
<i>Proportion fledged from successful attempts</i>	<i>8</i>
<i>Number of breeding attempts</i>	<i>9</i>
<i>Productivity per female</i>	<i>10</i>
Nestling quality;	
<i>Body condition</i>	<i>11</i>
<i>Fledging mass</i>	<i>12</i>

Length of breeding season was estimated as the interval between the fifth and ninety-fifth percentiles of the first egg date distribution combined across years within period one and within each site in period two. First egg date was defined as the mean first egg date of the first 30% of clutches in each year (to reduce the influence of second and replacement clutches (Bradbury *et al.* 2000)). Interclutch interval was defined as the time in days between the laying of the first egg in successive successful clutches (i.e. clutches that fledged young).

Egg volume was calculated using the following equation (Hoyt 1979):

$$\text{egg volume} = (\text{breadth})^2 \times \text{length} \times 0.51 \quad (1)$$

Daily survival rate was calculated over the 'egg stage' (parameter 7.2 considered to span the interval from laying of the first egg to hatching), the 'nestling stage' (parameter 7.3 spanning the interval from hatching to fledging) and combined to give failure rate over the 'whole nest period' (parameter 7.1), using an extension of the Mayfield method (Aebischer 1999).

In order to estimate the number of attempts made in a season by an individual female ⁽⁹⁾, it was assumed that in period one multiple attempts at a single nest-site were all made by the same female (Summers-Smith 1963; McGillivray 1983). In period two at UF, the number of attempts made by individual females was known precisely from detailed colour-ring observations, which also indicated significant movement between nest-sites during successive breeding attempts. Observation of a small number of colour-ringed females at SF in period two also indicated similar movement. However, this

sample was too small to be used as a population-level estimate and therefore an accurate assessment of the number of breeding attempts at SF is unavailable.

Productivity per female (and by inference per pair – House Sparrows are generally monogamous (Summers-Smith 1988), although see (Griffith *et al.* 1999)) was calculated using the following formula:

$$P = \phi \cdot \sigma \cdot \beta \quad (2).$$

where P = productivity; ϕ = survival rate over the whole nest period (cumulative errors calculated according to Crick & Baillie (1996)); σ = mean number fledged per successful attempt; β = mean number of breeding attempts per female. Cumulative errors around productivity estimates were calculated, assuming day-to-day and nest-to-nest independence (Hensler 1985), using the following general formula (Mood *et al.* 1982):

$$SE(\delta) = \sqrt{([SE(\gamma)^2 \cdot \theta^2] + [SE(\theta)^2 \cdot \gamma^2] + [SE(\gamma)^2 \cdot SE(\theta)^2])} \quad (3).$$

where δ is the product of γ and θ ; and γ and θ are two independent random variables. Substituting γ and θ for ϕ and σ from (2), gives the SE of an intermediate product δ . The process is repeated using $SE(\delta)$ and $SE(\beta)$ (2) to give $SE(P)$.

Body condition was calculated for nestling day 9 as the residual from a linear regression of \ln (fledging mass) on \ln (fledging tarsus length), to account for the probable allometric relationship between a measure of mass and a measure of length (i.e. $\text{mass} = a[\text{tarsus}^b]$) (Jakob *et al.* 1996).

Due to limited data availability in period one however, broods in the age range nestling day seven to 11 were included. Variation associated with age was controlled for where necessary by including an $\text{age} \times \ln(\text{tarsus length})$ interaction term in the model. If the interaction term had a significant effect on $\ln(\text{mass})$, the residuals of this analysis, which were independent of nestling age, were used as measures of condition. If the interaction was not significant, then the residuals of a regression of $\ln(\text{mass})$ on $\ln(\text{tarsus})$ were used as measures of body condition.

Fledging mass was defined as body mass at nestling day 13. Due to limited data availability in period one, however, broods within the age range day 12 to day 14 were included. Variation due to age was controlled for by placing an age term into the model during subsequent analyses (see below).

8.3.5 Statistical analysis

Analyses to determine whether parameters (2-5, 11 and 12) differed significantly between periods one and two were carried out in Minitab (Version 12). A General Linear Modelling (GLM) approach using normal errors was applied, with each parameter in turn specified as the dependent variable and period as a two-level factor. However, in order to control for seasonal and extraneous effects, the variables in Table 8.3.5.1 were included in the models indicated, regardless of their level of statistical significance.

Parameters (6-9) were modelled in GLIM release 4 (NAG 1993). Daily survival rates (parameters 7.1, 7.2 & 7.3) were modelled using logistic regression (binomial errors and a logit link), with nest fate (failure = 1, success to hatching or fledging = 0) as the binary response variable and the number of days that the nest was exposed to the risk of failure ('exposure days') as the binomial denominator (Aebischer 1999). An assumption of this method is that daily nest survival probabilities remain constant over the interval for which an overall survival rate is calculated. Proportion of young hatched and proportion of young fledged from successful attempts were modelled using a similar approach, with proportion hatched and proportion fledged as the binary response variables and clutch size and number hatched as the binomial denominators respectively. Number of breeding attempts

was modelled using a Poisson error structure (Crawley 1993). Again, in order to control for seasonal and extraneous effects, the variables in Table 8.3.5.1 were included in the models indicated, in addition to period.

To avoid pseudoreplication caused by non-independence of siblings in the modelling of parameters 4,11 and 12 brood mean values were initially used as the dependent variable. These were then substituted for firstly, brood minima and secondly, brood maxima and the modelling procedure repeated to detect any subtle effects that may have been masked by the brood mean (Nilsson and Gardmark 2001).

In order to test for a significant difference in productivity per female (parameter 10) between periods, the following formula was used (Mood *et al.* 1982):

$$Z = \frac{\alpha - \psi}{SE(\alpha) - SE(\psi)} \quad (4)$$

where α and ψ are productivity in periods two and one respectively. A z-score of greater than 1.96 would indicate a significant difference between the two productivity estimates and vice versa.

Prior to analysis of between period variation in parameters 2 to 12, identical modelling procedures (except farm was substituted for period) were used to test for significant differences between UF and SF in period two. If a significant difference was found, UF and SF in period two were then modelled separately. Where none were found, the data for the two farms were pooled.

The construction of separate models for each response variable increases the likelihood of a Type I error. A conservative approach to significance testing was therefore adopted by using the Bonferroni corrected value (Dunn-Sidak method (Sokal and Rohlf 1995)) for 26 repeated tests (length of breeding season is a descriptive statistic and is therefore not a repeat test). Results with a *P*-value less than 0.00197 were therefore regarded as non-significant.

All mean values and standard errors (SE) given in the text and in Table 8.4.1.2 were extracted from the raw data prior to modelling.

Table 8.3.5.1 Variables included to control for seasonal and extraneous effects in the models specified (numbers relate to parameters in Table 8.3.4.1).

Variable	Controls for	Factor or variable	Model(s) variable included in
<i>First egg date</i>	Seasonal variation	Continuous variable	3-7
<i>Hatch date</i>	Seasonal variation	Continuous variable	8,11,12
<i>Attempt</i>	Effects of previous breeding effort	4-level factor	4-8,11,12
<i>Disturbance¹</i>	Observer disturbance during previous breeding attempt	2-level factor	5,6,8
<i>Natural nest</i>	Variation between box and natural nest-sites	2-level factor	5-9,11,12
<i>Brood size</i>	Variation resulting from differing brood sizes	6-level factor (brood sizes of 7 [n=1] & 8 [n=1] pooled with 6)	11,12
<i>Clutch size</i>	Variation resulting from differing clutch sizes	5-level factor (clutch sizes of 7 [n=1] & 8 [n=1] pooled with 6)	4
<i>Age</i>	Variation due to age when measurements taken	Continuous variable	8,12

1 A number of adults were caught in nest-box traps whilst feeding nestlings.

8.4 RESULTS

8.4.1 Breeding phenology

Although the length of the breeding season varied between years, there was a trend towards later clutch initiation in period two, particularly at UF (Table 8.4.1.1 & Figure 8.4.1.1). Mean first egg date at UF in period two (11 May) was significantly later than mean first egg date in both period one (1 May) ($T=5.74$, d.f.=49, $P<0.001$) and at SF in period two (4 May) ($t=4.39$, d.f.=37, $P<0.001$). (Note: multiple t -test is accounted for by Bonferroni correction). There was little variation in the overall length of the breeding season however (Table 8.4.1.1).

There was no significant difference between periods one and two in the interclutch interval between either first and second, or between second and third attempts (Table 8.4.1.2).

Table 8.4.1.1 5th and 95th percentiles of first egg date distributions for University Farm (UF) in period one and two and Step Farm (SF) in period two.

Site	5 th percentile	95 th percentile	Length of season (days)
<i>UF Period two</i>	1 May	31 July	92
<i>SF Period two</i>	25 April	25 July	91
<i>UF Period one</i>	21 April	24 July	94

Table 8.4.1.2 Mean values \pm 1 standard error for parameters where no significant difference (according to a Bonferroni corrected value of 0.00197) was found between periods one and two. Mean values for parameters where a significant difference between periods was found are given in the text. All values are taken from the raw data, prior to modelling. Seasonal trends were similar in both periods. Sample sizes are given in parentheses.

Parameter	Period one		Period two		P-value	Seasonal trend
Interclutch interval (1 st to 2 nd attempts) ³	40 days \pm	0.44 (94)	40 days \pm	0.38 (84)	0.416	-
Interclutch interval (2 nd to 3 rd attempts) ³	38 days \pm	0.51 (54)	40 days \pm	0.52 (34)	0.007	-
Mean clutch size ⁵	4.24 \pm	0.04 (372)	4.30 \pm	0.05 (272)	0.011	Highest for second attempts
Survival rate over whole nest period ^{7.1}	0.7945 \pm	0.0203 (370)	0.8450 \pm	0.0266 (277)	0.159	Decline
Survival rate over nestling stage ^{7.3}	0.7912 \pm	0.0290 (322)	0.7785 \pm	0.0452 (266)	0.511	Decline
Mean number fledged from successful attempts ⁸	2.98 \pm	0.07 (266)	3.14 \pm	0.07 (231)	0.138	Decline
Mean number of breeding attempts ⁹	2.36 \pm	0.07 (138)	2.14 \pm	0.12 (35)	0.179	-
Seasonal productivity ¹⁰	5.60 \pm	0.27	5.68 \pm	0.41	0.216	-
Mean body condition ¹¹	-0.01078 \pm	(78)	0.00938 \pm	(231)	0.188	Decline
Mean fledging mass ¹²	23.82g	0.26 (71)	23.29g	0.20 (176)	0.278	Constant

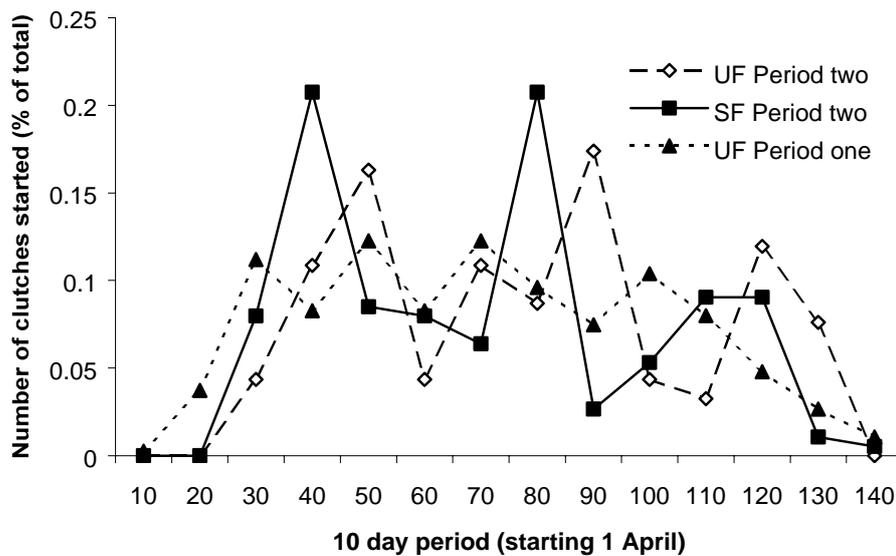


Figure 8.4.1.1 Number of clutches started during ten day periods (1 = 1 April) across the breeding season for House Sparrows at University Farm (UF) in period one and at UF and Step Farm (SF) in period two.

8.4.2 Breeding success

Mean egg volume was significantly higher at SF than at UF in period two ($F=13.98$, d.f.=1, $P<0.001$). Comparisons between period one and UF and period one and SF were therefore carried out separately. However, no significant difference in mean egg volume between period one and UF in period two, nor between period one and SF was found (mean volume at UF in period one = $2652\text{mm}^3 \pm 22$ [n=160]; UF in period two = $2497\text{mm}^3 \pm 36$ [52]; SF = $2713\text{mm}^3 \pm 37$ [n=53]).

Clutch size varied from two to eight eggs in period one and two to six eggs in period two, with a median of four in both (median clutch size for Britain is four (Summers-Smith 1988)). No significant difference in mean clutch size⁽⁵⁾ between periods one and two was found (Table 8.4.1.2). Removal of abandoned clutches from the analysis did not alter the conclusions drawn.

The proportion of eggs laid that hatched in period two was significantly greater ($\chi^2=24.29$, d.f.=1, $P<0.001$) than in period one (mean number of eggs hatched per clutch in period one = 3.34 ± 0.08 [n=368]; period two = 3.67 ± 0.08 [n=272]). However, this variation was primarily due to a larger number of clutches being abandoned during incubation in period one (see discussion). When abandoned clutches were removed from the analysis there was no significant difference between the two periods ($\chi^2=1.158$, d.f.=1, $P=0.282$). The largest number of young hatched from second attempts in both periods, reflecting higher clutch sizes. An overall hatching success of 79% and 85% in period one and two respectively is similar to that found in other British studies (Summers-Smith 1988).

Daily survival rate (DSR) during the egg stage was significantly lower ($\chi^2=9.961$, d.f.=1, $P<0.0017$) in period one than in period two (survival over egg stage in period one = 0.810 ± 0.027 [n=369]; DSR period two = 0.845 ± 0.027 [n=274]), as a result of the larger number of abandoned clutches in period one (see above). There was no significant difference in DSR during the nestling stage, nor when the two stages were combined to encompass the whole nest period (survival rate over both periods given in Table 8.4.1.2). No instances of nest-box predation of eggs or young were recorded in either period, with abandonments and whole-brood starvation accounting for 95% of failures at the egg and nestling

stages respectively (egg removal and apparent infanticide by parent birds or rivals accounted for the remaining 5% of failures).

There were no significant differences between periods one and two in the number fledging from successful attempts, the number of breeding attempts being made by a female in a season, or in productivity (Table 8.4.1.2).

8.4.3 Nestling quality

There were no significant differences between periods one and two in either mean brood body condition at nestling day 9⁽¹¹⁾, or in mean brood fledging mass⁽¹²⁾ (Table 8.4.1.2). Replacing mean brood values with brood minima and maxima for each parameter did not alter this result.

8.5 DISCUSSION

8.5.1 Breeding phenology

Two processes could account for the difference in mean first egg date at UF in period two, compared to period one: 1) a reduction in food supply (either at the start of the breeding season or over the preceding winter), lengthening the time required for adults to achieve breeding condition; and/or 2) climatic change altering the environmental cues that dictate the onset of breeding. Climatic change however, is unlikely to have caused a lag in mean first egg date. Spring temperatures in temperate regions have increased over the past 20 years (Houghton *et al.* 1996), resulting in a general trend for earlier reproduction in a range of bird species (e.g. Crick *et al.* 1997; Bergmann 1999; Dunn and Winkler 1999; Bothand Visser 2001; Coppack *et al.* 2001 but see (Visser *et al.* 1998). A reduction in food resources, as a result of agricultural change, may therefore be the principal factor delaying the onset of breeding at UF in period two. Studies indicate that the intensification and specialisation of arable and grassland systems has indeed reduced the availability of key invertebrate and seed foods for birds (Donald 1998; Sotherton and Self 1999; Wilson *et al.* 1999), although there is little direct evidence as yet that a reduction in food availability *per se* has had a significant influence on the demography of bird populations (Wilson *et al.* 1999; Smart *et al.* 2000). The lack of a similar delay to the start of breeding at SF could be a result of its organic status (food supplies are often more abundant on organic farms – reviewed by Gardner & Brown 1998).

The absence of a significant difference in interclutch interval however (between either first and second, or second and third attempts), suggests that once the breeding season has begun, resources are sufficient to enable adults to maintain breeding condition throughout the season.

Despite the delay in first egg date, there was little difference in the overall length of the breeding season (taken as the interval between the fifth and ninety-fifth percentiles of the first egg date distribution). Figure 8.4.1.1 indicates that a slightly higher proportion of birds are making breeding attempts right up to the end of the season, which could account for the later date corresponding to the ninety-fifth percentile of the distribution. However, this date will also be influenced by repeat clutches after failure of second or third attempts and so must be interpreted with caution.

A later mean first egg date could also be an indirect result of reduced survival of adult females since evidence suggests that first year birds start breeding later than adults (Seel 1968; Summers-Smith 1988). However, detailed records of colour ringed birds at UF in period two indicate that both adult and first-year females are delaying their first breeding attempt (Hole unpubl.).

8.5.2 Nest success and reproductive output

A significantly higher mean egg volume at SF compared to UF in period two also suggests a causal role for food limitation. A positive influence of experimental food provision on egg volume has been demonstrated in a number of species (e.g. Wiebe and Bortolotti 1995; Ramsey and Houston 1997 –

but see Jager *et al.* 2000), with a consequent increase in hatching body mass (Ostnes *et al.* 1997). No significant difference in hatching success or fledging success between UF and SF in period two was evident in this study, however.

The significantly lower proportion of eggs hatching (and consequently the lower DSR during the egg stage) in period one compared to period two, was explained entirely by the higher number of apparent abandonments during incubation. This trend could be a result of the high population density at UF in period one (the population was nest-site limited (Dawson 1972)), leading to increased intraspecific competition for resources and aggressive interactions between individuals, resulting in greater stress, disturbance and consequent abandonments. However, the possibility of a higher level of human disturbance cannot be discounted.

Obtaining an accurate estimate of the number of breeding attempts made by an individual female across the breeding season is essential for calculating overall breeding success in a species (Bradbury *et al.* 2000; Siriwardena *et al.* 2000a;). In studies of House Sparrows, the assumption that successive breeding attempts in a nest-box are made by the same female/pair is a common one (Summers-Smith 1963; McGillivray 1983) and is used in this study to estimate the number of attempts being made in period one. However, at UF in period two, where colour-ringed females could be followed throughout the breeding season, a high rate of movement between boxes was observed between successive attempts (43% between first and second attempts; 33% between second and third). It is plausible that a low population density, coupled with a large number of similar quality nest-sites at UF in period two, in direct contrast to period one, facilitated such behaviour. Birds moving between nestboxes between successive attempts may have done so to be nearer to emerging food supplies or to avoid nest parasites. At UF in period one, however, nest-sites were limiting and the possibility of being forced to accept a lower quality nest-site may have outweighed the benefits of moving. Limited trapping of adults at nestboxes in period one (Dawson 1972) supported this conclusion. The estimates provided in this study are therefore likely to be an accurate reflection of the mean number of breeding attempts made by an individual female in both periods. The lack of any significant difference suggests that the later start to the breeding season in period two has had limited impact on the potential of a female to make three successful attempts in a season.

No evidence of a significant difference in DSR over the whole nest period, the number of young fledging from successful attempts, nor, most importantly, in the productivity of a pair (defined here as an individual female) was found in this study. Indeed, productivity of close to six young per pair per year, in both periods, is at the high end of the recorded range (Summers-Smith 1988).

8.5.3 Nestling quality

A strong positive correlation between body mass at nestling day 13 (i.e. fledging body mass) and survival in the interval between fledging and nutritional independence (approximately ten days later) has previously been demonstrated in the UF and SF House Sparrow populations (Hole unpubl.). The lack of any significant difference between periods one and two in mean fledging body mass (or mean brood condition at nestling day 9) therefore suggests that fledglings in period two had the same intrinsic probability of survival as fledglings in period one, at least in terms of inherent quality as defined in this study. The critical factor determining any variation in post-fledging survival between periods one and two will therefore be the nature and magnitude of changes in the environment into which the young fledge (in terms of food resources, predators, etc.) that may have occurred post population decline. Approximately 40% of first and second brood fledglings at UF and SF had died by age of independence in period two (Appendix 8.1). No data on post-fledging survival in period one is available for comparison.

8.5.4 Possible demographic mechanisms

Population size at UF has declined by almost 80% between periods one and two, a decline mirrored in other areas of Oxfordshire (Easterbrook 1999) and in Britain as a whole (Gregory *et al.* 2001 Chapter

3). However, no significant between-period difference could be detected in overall annual productivity, or in the majority of the specific breeding success and nestling quality parameters investigated. What role therefore, if any, could a change in breeding performance have played in the decline?

There are three possible scenarios: (1) A temporary reduction in breeding performance may have been a proximate cause of the decline in the UF population between periods one and two. However, the population stabilised around a new, lower carrying capacity, resulting in a density-dependent return to its pre-decline rate before the repeat census in period two (Green 1999). (2) Breeding adults may be working harder during the breeding season in response to a reduction in resource availability between periods one and two life history theory predicts that highly fecund, short-lived species are expected to place greater value in current offspring, when the probability of surviving to breed in the future is low – e.g. Roff (1992), Ghalambor and Martin (2000). Thus, birds maintain their breeding performance, but possibly pay for this through reduced survival rates later in the year (Siriwardena *et al.* 2000a). (3) The decline has been caused by a demographic mechanism other than breeding performance. In this scenario a density-dependent increase in breeding performance would be expected, unless: (i) breeding performance is density-independent; (ii) there was a concurrent reduction in breeding season resources; or (iii) the population had stabilised around a new, lower carrying capacity before the repeat census in period two.

Analyses of long-term ring-recovery data from the BTO's National Ringing Scheme indicate that observed variations in survival are sufficient to have caused the recent changes in abundance in a number of species, including the House Sparrow (Siriwardena *et al.* 1999, see Chapter 10). Such changes are likely to occur during the non-breeding season when mortality is at its highest (Payne and Wilson 1999; Siriwardena *et al.* 2000a). Whilst a relationship between abundance and survival does not preclude an important additional influence of breeding success, a reduction in survival rate is consistent with scenario's 2 and 3 above. Clearly the carrying capacity at UF has been dramatically reduced between periods one and two. Fewer seed rich stubbles over the autumn and winter (Fuller *et al.* 1995), a reduction in spilt grain (Summers-Smith 1988) and a general increase in the tidiness and storage standards of farms as a result of European Union (EU) hygiene regulations, could all be causal factors resulting in lower overwinter survival rates in the House Sparrow.

8.6 CONCLUSION

Whilst scenario 1 above cannot be ruled out, the available evidence suggests that a reduction in survival, probably during the non-breeding season, is the proximate demographic mechanism driving the decline of the House Sparrow at UF. A reduction in the availability of key invertebrate and seed foods during the breeding season, may also suggest an additive role for 2 above. In this scenario House Sparrows could be trading survival for productivity in order to maximise lifetime reproductive success in a deteriorating environment.

Appendix 8.1 Post-fledging survival in the House Sparrow *Passer domesticus*

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A8.1.1 SUMMARY

1. Information on post-fledging survival rates are not available from the BTO's National Ringing Scheme because information on the numbers of birds ringed in different age-classes have not been computerised.
2. The collection of data from the intensive local study undertaken in Oxfordshire provided an opportunity to measure this important demographic parameter using capture-mark-resighting methodologies.
3. The most parsimonious model that fitted the data was one in which survival increased linearly through the post-fledging period, from fledging to independence from their parents, ten days later. The survival rate over the ten-day post-fledging period was 0.62 (s.e. = 0.054).

A8.1.2 METHODS

A8.1.2.1 Study populations

Thirty wooden boxes (h=29cms, w=13cms, d=19cms) were erected in 1998 at each of two farm sites; University Farm at Wytham (SP4709) and Step Farm near Faringdon (SU2695) in Oxfordshire, UK. Data for the present study were collected in June and July 2000.

House Sparrows lay one egg per day (Summers-Smith 1988), with a modal clutch size in Oxfordshire of four (Seel 1968). The young usually fledge between 13 and 16 days after hatching (Seel 1970; Summers-Smith 1988; Hole unpubl.) and the adults continue to feed them for 10-14 days after fledging (Summers-Smith 1988). In Oxfordshire, a pair may have up to three successful breeding attempts in a season, occasionally more (Seel 1968; Hole unpubl.).

A8.1.2.2 Field methods

In 2000, boxes were checked every other day to determine onset of laying and every day towards the end of the incubation period to determine hatch date. Nestlings were banded with a numbered aluminium ring and a unique combination of three coloured plastic rings on day 13 after hatching (hatch day = day '0'), the last day prior to fledging that House Sparrow nestlings could be safely handled. Nests were then checked four days later to determine fledging success.

Ten first broods (i.e. broods initiated around the median date for first attempts) were monitored at University Farm and twenty-three at Step Farm. In addition, a further ten second broods (determined by detailed observations of marked females and whose broods were initiated around the median date for second attempts) were monitored at University Farm. The ten first broods at University Farm (the 'UF' cohort) fledged within a period of 12 days (6 June – 18 June) and the twenty-three first broods at Step Farm (the 'SF' cohort) within a period of ten days (29 May – 8 June). The ten second broods at University Farm (the 'US' cohort) fledged within a period of 14 days (12 July – 26 July), approximately one month later than the first broods.

8.1.2.3 Resighting of marked juveniles

A resighting period constituted a thorough search of the farmyard and immediate surroundings (hedges, trees and buildings) for three hours, by two researchers at University Farm (six observer hours in total) and for five hours at Step Farm (ten observer hours in total). A longer resighting period at Step Farm was used to allow for the larger number of broods being followed and the greater area being covered. Resighting began two days after nestling day 13 of the earliest brood in each cohort and was repeated every other day until 16 days after nestling day 13 of the latest brood in that cohort. An encounter history ('1' for seen, '0' for not seen during each resighting period) was then created for each individual within a brood, covering a period of 16 days from nestling day 13 to day 29 for that brood. Thus, each encounter history is unique to each individual fledgling, comprising a '1' to signify 'seen on nestling day 13,' followed by eight resighting occasions. The Program MARK (White and Burnham 1999) was then used to generate a population level estimate of survival rate from nestling day 13 to independence at day 23, using the Cormack-Jolly-Seber (CJS) model of survival measured by resighting notes (Cormack 1964; Jolly 1965; Seber 1965).

A major source of error in many survival studies occurs when dispersal of individuals from the study area cannot be distinguished from mortality (Clobert and Lebreton 1990; Martin *et al.* 1995). In this study it is unlikely that any dispersal occurred however, as a result of the dependent young remaining in or around the farmyard for the entire post-fledging period (Hole, unpubl.).

A8.1.2.4 MARK analyses

Goodness of fit (GOF) tests conducted in the program U-CARE were used to assess whether there was significant variation in either resighting or survival probabilities that was not accounted for in the underlying model. These GOF tests are the same as tests 2 (2.CT and 2.CM) and 3 (3.SR and 3.SM) in programme RELEASE (Burnham *et al.* 1987), their combined result indicating the overall goodness of fit of the data to the fully parameterised CJS model. Modelling was a straightforward application of the principle of parsimony, i.e. the gradual reduction of the number of parameters whilst ensuring that the model remains a reliable representation of the data (Lebreton *et al.* 1992). Following the notation of Lebreton *et al.* (1992), the symbol ϕ is used for survival rate and P for resighting rate. Resighting rate was modelled first, followed by survival rate.

Model selection was undertaken on the basis of Akaike's information criterion (AIC) (Lebreton *et al.* 1992), where the AIC is equal to the deviance from the model plus two times the number of estimable parameters (i.e. degrees of freedom) and where the model with the lowest AIC is considered to be the most parsimonious. A difference in AIC of two or more units is generally accepted to indicate a significant difference in model fit (Lebreton *et al.* 1992). Likelihood-ratio tests (LRT) between nested models were also used as formal tests of significance for individual terms in the model (LRTs are better suited to the testing of specific hypotheses than an AIC framework and provide formal test statistics). Models including full time-dependence in survival rate were tested against two *a priori* alternatives, to account for a possible change in survival probability through the post-fledging period (i.e. as fledglings become more experienced): (1) constant survival; (2) survival constrained to be a linear function of time from fledging (ϕ_{lin}).

Parameter estimates from the most parsimonious model overall were then used to calculate a population-level estimate of post-fledging survival probability (from fledging on nestling day 13, to independence at day 23).

A8.1.3 RESULTS

A8.1.3.1 Goodness of fit tests

Only test 2.CT was significant ($\chi^2=45.776$, d.f.=15, $P<0.001$), indicating ‘sighting-dependence’ in some individuals (i.e. fledglings that were seen more often, or less often than would be expected by chance) and thus a violation of one of the CJS model assumptions (i.e. that every marked individual present in the population at time t has the same probability of resighting at time $t+1$). The encounter history for each individual was therefore split in U-CARE, according to Pradel (1993), allowing such trap-dependence to be accounted for using dummy age-class variables and treated as a form of age dependence in the new data-set (signified by the subscript ‘m’).

A8.1.3.2 Survival and resighting rates

The starting model ($\phi_t P_{m+t}$) contained fully time-dependent survival rate and additive time-dependent and trap-effect terms for resighting rate (Pradel 1993). Removal of the time-dependence term in resighting rate was not supported by AIC or LRT (Table A8.1.3.2.1). Further models were specified with time-dependence in survival rate altered according to the two *a priori* alternatives. AIC and LRT favoured only the model $\phi_{lin} P_{m+t}$ over the starting model (Table A8.3.2.1).

The most parsimonious model $\phi_{lin} P_{m+t}$ gave a survival rate from fledging (day 13) to independence (day 23) of 0.619 (SE=0.054). Standard error was calculated using a Taylor Series Expansion to account for propagation of error (White, pers. comm.).

Table A8.1.3.2.1 Resighting rate (P) and post-fledging survival (ϕ) as a function of time (t) and dummy age class (m ; see text). NP = number of identifiable parameters; DEV = deviance; AIC = Akaike’s information criterion; LRT = Likelihood ratio test. LRT comparisons are based on differences in deviance between two nested models. A non-significant result indicates that the model with the lower number of identifiable parameters adequately fits the data. *Subscripts*: m = age-dependence (to account for sighting dependence); t = time (48 hour period); *Special case*: lin = survival constrained to be a linear function of time (see text).

Model	NP	DEV	AIC	LRT comparison	Result of LRT for individual model terms
<i>Modelling resighting rate</i>					
$\phi_t P_{m+t}$	16	482.40	1197.81		
$\phi_t P_m$	10	544.90	1247.64	$\phi_t P_{m+t}$	$\chi^2=62.50$, d.f.=6, $P=0.000$
<i>Modelling survival rate</i>					
$\phi_t P_{m+t}$	16	482.40	1197.81		
$\phi_{lin} P_{m+t}$	11	487.50	1192.33	$\phi_t P_{m+t}$	$\chi^2=5.101$, d.f.=5, $P=0.404$
ϕP_{m+t}	10	494.05	1196.79	$\phi_t P_{m+t}$	$\chi^2=11.650$, d.f.=6, $P=0.070$

Appendix 8.2 Adult and first-year survival in the House Sparrow *Passer domesticus*

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A8.2.1 SUMMARY

1. Few estimates of adult and first-year survival rates from localised intensive studies are available in the literature.
2. Collection of data from the intensive local study undertaken in Oxfordshire provided an opportunity to measure these demographic parameters using capture-mark-resighting methodologies.
3. The most parsimonious models that accomplished the *a priori* requirements of the study gave an adult annual survival rate of 0.47 (SE=0.05) and a first-year annual survival rate of 0.34 (SE=0.04).

A8.2.2 METHODS

A8.2.2.1 Estimation of adult and first-year apparent annual survival

A8.2.2.2 Study populations

House Sparrow survival rates were investigated between November 1998 and November 2000 at four farm sites in Oxfordshire, UK: University Farm (henceforth referred to as UF), Wytham (SP4709); Step Farm (SF), Faringdon (SU2695); Chilswell Farm (CF), Boars Hill (SP4903); and Kingston Hill Farm (KF), Kingston Bagpuize (SU4100). Average breeding season population sizes over the two years of the study were approximately 35, 170, 40 and 50 individuals respectively.

A8.2.2.3 Marking procedure

Individuals on all four farm sites were caught during intensive mist-netting sessions throughout the months of May-November 1998, to provide an initial cohort of marked birds. Birds were ringed with an aluminium ring and a unique combination of three coloured plastic rings. Where possible, individuals were aged as adult or first-year using feather condition and stage of moult in relation to season (Svensson 1992). Both adults and first-years undergo a complete moult in late summer/autumn (Svensson 1992), after which it is usually impossible to determine the age-class of a bird. However, only data from birds of known age were used in this study. Adult birds were sexed according to plumage characteristics (Svensson 1992). First-years were sexed according to plumage characteristics where possible (dependent on the state of moult) or when they were first re-sighted (i.e. when they entered the data-set).

Mist-netting continued throughout the course of the three-year study at all four farm sites. Additionally, at UF and SF, the majority of first-year birds were ringed as nestlings during the 1998 and 1999 breeding seasons.

A8.2.2.4 Resighting methodology

A resighting period constituted six observer hours a day over a three day period at UF, KF and CF (18 hours in total) and ten observer hours a day over a three day period at SF (30 hours in total – to account for the considerably larger population size). Resighting was carried out at the start of each month, from November through to May of winters 1998/1999 (seven occasions) and 1999/2000 (seven occasions), with a final resighting occasion at the start of November 2000, giving a total of 15 resighting occasions.

A8.2.2.5 Treatment of data-sets

Two data-sets were compiled: adult and first-year. The adult data-set comprised all 15 encounter periods (as above) since an adult bird in the first winter was still an adult in the second. However, only data from winter 1998/1999 OR winter 1999/2000 was used in the first-year data-set (a first-year appearing in the first winter would, by definition, be an adult in the second winter). The first-year data-set therefore comprised 8 encounter periods – monthly from November to May of either winter 1998/1999 OR 1999/2000 (seven occasions) with a final encounter period the following November (1999 or 2000).

In order to estimate apparent adult and first-year annual survival rates (i.e. the *a priori* requirement of this study), data from each of the four farms were combined for each age-class and analysed in two separate data-sets, with the adult data-set grouped by sex and the first-year data-set grouped by sex and year (year was modelled as a subset of time in the adult data-set). Ideally, both data-sets would also have been grouped by farm. However, the data were too sparse to support this level of complexity in subsequent analyses (a significant proportion of model parameters in the initial saturated model were non-estimable).

Note that the annual survival estimates produced from these data-sets are *apparent* estimates. They contain an unknown component of emigration – a source of error inherent to all mark-resighting studies (Lebreton *et al.* 1992) and are consequently likely to underestimate the time survival rate..

A8.2.2.6 Survival analysis

Estimation of survival rates was carried out in programme MARK (White and Burnham 1999). This programme allows both resighting probabilities and survival rates to vary over time and between groups of individuals, based on the Cormack-Jolly-Seber (CJS) model (Cormack 1964; Jolly 1965; Seber 1965). The CJS model has four basic assumptions: (1) Every marked individual present in the population at time t has the same probability of recapture (P_{t+1}); (2) Immediately after time t every marked animal in the population has the same probability of surviving to time $t + 1$; (3) Leg rings are not lost or missed; and (4) The capture recapture/resighting data are collected during a short period relative to the interval between occasion t and $t + 1$ (Lebreton *et al.* 1992; Lebreton *et al.* 1993). Tests 2 and 3 in programme RELEASE (Burnham *et al.* 1987) were used to test whether the data met assumptions 1 & 2 (Cooch *et al.* 1997). These tests are computed as numerous component chi-squared tests, each being independent, so the component chi-squares within are additive. However, in order to avoid the problem of small sample sizes when performing these goodness of fit (GOF) tests, the two sexes were pooled within the adult data-set. Similarly, both sexes and both winters were pooled within the first-year data-set.

Analyses were begun from a saturated model (i.e. a model containing all variables of interest in both survival and resighting probabilities). The resighting component was modelled first, using the principle of parsimony (i.e. by gradually reducing the number of parameters in such a way that the model still provided a good representation of the data (Lebreton *et al.* 1992)). Model selection was undertaken on the basis of Akaike's information criterion (AIC), calculated as the deviance of the model plus twice the number of parameters, to limit the number of formal tests. When AIC of two models differed by less than two, the model with the lowest number of parameters was chosen (Lebreton *et al.* 1992). Likelihood ratio tests (LRT) were also performed on nested models (one including and one omitting the variable of interest) to test for effects of different variables on resighting rate. Once the most parsimonious model for resighting rate was established, in order to fulfil the *a priori* requirement of estimating adult and juvenile apparent annual survival, a further model was specified with constant survival probability, regardless of its support via model selection. Use of this constant survival model was required to avoid the problem of incorporating boundary estimates (resulting from lack of data) from time-dependent models, in the generation of apparent annual survival estimates.

Standard errors of survival estimates from the constant models were calculated using the following equation (G. White pers comm):

$$SE(\psi) = \sqrt{(\theta \cdot \phi^\lambda)^2 \cdot SE(\phi)^2} \quad (\text{A1})$$

where ψ = annual survival; θ = number of periods comprising annual survival; ϕ = survival rate over period; $\lambda = 1 - \theta$.

A8.2.2.7 Estimation of adult and first-year apparent annual survival

A8.2.2.8 Adult model: Goodness of fit tests

Both Test 3 and Test 2 were significant for the adult data-set ($\chi^2 = 151.57$, d.f. = 22, $P < 0.001$; and $\chi^2 = 86.77$, d.f. = 16, $P < 0.001$; respectively), indicating a significant violation of CJS assumptions 1 and 2 above. A significant result for Test 3 can indicate the presence of ‘transients’ – individuals recaptured/seen on one occasion only after initial release and that have undertaken temporary or permanent emigration, or were only ‘passing through.’ In order to correct for this, the first capture in each encounter history was suppressed (i.e. the first ‘1’ changed to a ‘0’) (W.J. Peach pers comm). The GOF tests were then re-run since this procedure may influence the result obtained for Test 2. A significant result however, was still obtained for Test 2 ($\chi^2 = 53.15$, d.f. = 12, $P < 0.001$), indicating heterogeneous resighting probability (most likely a result of individuals displaying ‘trap-shy’ or ‘trap happy’ behaviour). In order to account for this violation, a two-level dummy age-class structure was introduced into resighting probability, according to Pradel (1993).

A8.2.2.9 Adult model: Resighting rate

To obtain the most parsimonious model for resighting rate, modelling was begun from the saturated model ($\phi_{s,t,s*t} p_{m,s,t,s*t,m*s}$) (model (1) in Table A8.2.2.9.1), including variation between sexes (s) and time (t), in addition to the two-way interaction term ($s*t$), in both survival rate (ϕ) and resighting rate (P). Resighting rate also included a two-level dummy age-class term (m) and the two-way interaction between dummy age-class and sex ($m*s$) following Pradel (1993).

There was no significant effect of excluding the interactions between dummy age-class and sex, or sex and time (models 2 & 3). Sex could also be excluded without any increase in AIC, indicating better parsimony and statistical relevance (4). Removal of separate resighting rates between years (i.e. reduction to a model with time-dependent resighting probability within, but no difference between years) resulted in a substantially lower AIC (5). Complete exclusion of time-dependency, however, (i.e. constant resighting rate within and between years) was rejected by both AIC and LRT (6). Model (5) therefore described the data in the most parsimonious manner and was used in subsequent analyses of survival probability. (Note: dummy age-class (m) cannot be dropped from resighting probability since it represents a structural change to the data-set to account for lack of fit of the model assumptions).

Table A8.2.2.9.1 Modelling adult resighting rate (P) and survival rate (ϕ) of House Sparrows as a function of sex (s), time (t) and age-class (m) and the interaction terms $s*t$ and $m*s$. Model ($\phi_{s, t, s*t} P_{m, s, t, s*t, m*s}$) was used as the initial model (1). NP = number of parameters, DEV = deviance, AIC = Akaike's information criterion. Resighting rate (P) is shown in models 1-6. The most parsimonious model is shown in bold. Model 7 represents the *a priori* requirement for the calculation of annual juvenile survival rate, using the most parsimonious P component. (Note: (y) denotes constant P between years, as opposed to full time dependency (t)).

Model	NP	DEV	AIC	Tests between models
<i>Resighting component</i>				
(1) $P_{m, s, t, s*t, m*s}$	46	739.39	1408.62	(Saturated model)
(2) $P_{m, s, t, s*t}$	45	740.73	1407.72	Removing $m*t$: $\chi^2 = 1.35$, d.f. = 1, $P = 0.246$
(3) $P_{m, s, t}$	34	757.93	1400.56	Removing $s*t$: $\chi^2 = 17.20$, d.f. = 11, $P = 0.102$
(4) $P_{m, t}$	33	758.82	1399.27	Removing s : $\chi^2 = 0.888$, d.f. = 1, $P = 0.346$
(5) $P_{m, y}$	25	765.69	1388.89	Removing t : $\chi^2 = 6.866$, d.f. = 8, $P = 0.551$
(6) P_m	21	784.16	1398.88	Removing y : $\chi^2 = 18.475$, d.f. = 4, $P = 0.001$
<i>A priori survival requirement</i>				
(7) $\phi P_{m, y}$	3	815.20	1404.96	

A8.2.2.10 Adult model: Survival rate

Model (7) was specified with constant survival probability, in order to satisfy the *a priori* requirement of estimating apparent annual adult survival rate (given in Table A8.2.2.10.1).

Table A8.2.2.10.1 Annual survival rates of adult and first-year House Sparrows. Adult rate is derived from model (7), Table A8.2.2.9.1; first-year rate from model (10), Table A8.2.2.12.1.

Model rate derived from:	Apparent annual survival rate	SE
<i>Adult</i> $\phi p_{m, y}$	0.466	0.050
<i>First-year</i> ϕP_m	0.340	0.042

A8.2.2.11 First-year model: Goodness of fit tests

Both Test 3 and Test 2 were highly significant for the first-year data-set ($\chi^2 = 168.86$, d.f. = 10, $P < 0.001$; and $\chi^2 = 84.68$, d.f. = 7, $P < 0.001$; respectively), again indicating a significant violation of CJS assumptions 1 and 2. The first capture in each encounter history was therefore suppressed and the GOF tests re-run. A significant result however, was still obtained for Test 2 ($\chi^2 = 23.33$, d.f. = 4, $P < 0.001$). A two-level dummy age-class structure was therefore introduced into resighting probability, according to Pradel (1993), as before.

A8.2.2.12 First-year model: Resighting rate

To obtain the most parsimonious model for resighting rate, modelling was begun from the saturated model ($\phi_{s, t, y, s^*t, s^*y, y^*t} P_{m, s, t, y, s^*t, s^*y, y^*t, m^*y, m^*s}$) (Table A8.2.2.12.1), including variation between sexes (s), year (y) and time (t) in addition to the two-way interaction terms in both survival rate (ϕ) and resighting rate (P). Resighting rate also included a dummy age-class term (m) and the two-way interactions between dummy age-class and sex (m^*s) and dummy age-class and year (m^*y).

There was no significant effect of excluding the interaction between dummy age-class and sex from model (2) (Table A8.2.2.12.1). Exclusion of the interaction between dummy age-class and year was supported by LRT but resulted in a slight increase in AIC. However, since this increase was <1 and in order to increase the statistical power and improve the parsimony, we continued with the model with fewest parameters (3) (Lebreton *et al.* 1992). The interactions between year and time; sex and time; and sex and year could all be sequentially excluded (models 4-6). Year, sex and time could also all be sequentially removed without significantly effecting the overall fit (models 7-9). The least parameterised model (9) therefore described the data in the most parsimonious manner and was used in subsequent analyses of survival probability.

Table A8.2.2.12.1 Modelling first-year resighting rate (P) and survival rate (ϕ) of House Sparrows as a function of sex (s), time (t), year (y) and age-class (m) and the interaction terms s^*t , s^*y , y^*t , m^*y and m^*s . Model ($\phi_{s, t, w, s^*t, s^*w, w^*t} P_{m, s, t, y, s^*t, s^*y, y^*t, m^*y, m^*s}$) was used as the initial model (1). NP = number of parameters, DEV = deviance, AIC = Akaike's information criterion. Resighting rate (P) is shown in models 1-9. The most parsimonious model is shown in bold. Model 10 represents the *a priori* requirement for the calculation of annual juvenile survival rate, using the most parsimonious P component.

Model	NP	DEV	AIC	Tests between models
Resighting component				
(1) $P_{m, s, t, y, s^*t, s^*y, y^*t, m^*y, m^*s}$	39	955.81	1598.44	(Saturated model)
(2) $P_{m, s, t, y, s^*t, s^*y, y^*t, m^*y}$	38	955.72	1596.20	Removing m^*s : $\chi^2 = 0.09$, d.f. = 1, $P = 0.764$
(3) $P_{m, s, t, y, s^*t, s^*y, y^*t}$	37	958.40	1596.72	Removing m^*y : $\chi^2 = 2.675$, d.f. = 1, $P = 0.102$
(4) $P_{m, s, t, y, s^*t, s^*y}$	32	966.16	1593.79	Removing y^*t : $\chi^2 = 7.760$, d.f. = 5, $P = 0.170$
(5) P_{m, s, t, y, s^*y}	28	971.05	1590.20	Removing s^*t : $\chi^2 = 4.889$, d.f. = 4, $P = 0.299$
(6) $P_{m, s, t, y}$	27	971.10	1588.14	Removing s^*y : $\chi^2 = 0.054$, d.f. = 1, $P = 0.816$
(7) $P_{m, s, t}$	26	971.11	1586.05	Removing y : $\chi^2 = 0.015$, d.f. = 1, $P = 0.903$
(8) $P_{m, t}$	25	973.82	1586.65	Removing s : $\chi^2 = 2.703$, d.f. = 1, $P = 0.100$
(9) P_m	21	977.83	1582.30	Removing t : $\chi^2 = 4.008$, d.f. = 4, $P = 0.405$
A priori survival requirement				
(10) ϕP_m	3	1020.70	1588.31	

A8.2.2.13 First-year model: Survival rate

Model (10) was specified with constant survival probability, in order to satisfy the *a priori* requirement of estimating apparent annual first-year survival rate (given in Table A8.2.2.10.1).

9 NATIONAL TRENDS IN THE BREEDING PERFORMANCE OF HOUSE SPARROWS *Passer domesticus*

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9.1 CHAPTER SUMMARY

1. This study reports the first detailed statistical analysis of the national Nest Record Scheme archive for House Sparrow. Its aim is to investigate temporal and spatial patterns in the breeding performance and to investigate whether changes in any aspect of breeding performance might have helped to drive population change.
2. Breeding performance per nesting attempt has tended to improve over the past 40 years although average brood size has fallen slightly.
3. We analysed breeding performance with respect to blocks of years in which population monitoring schemes (Common Birds Census (CBC) and Garden Bird Feeding Survey (GBFS)) show consistent patterns of stability, increase or decrease.
4. Breeding performance was positively correlated with population growth rate measured on all CBC monitoring sites but was negatively correlated with population growth rates in suburban GBFS gardens. These results suggest that changes in breeding performance may have had a role in determining population changes in the wider countryside, but not in suburban gardens.
5. Breeding performance was highest and has improved most rapidly in the North and West of Britain, where populations have also increased in recent years. Breeding performance was lowest and has improved least rapidly in the South East and South West, where densities are currently greatest but population declines have been steepest, both historically and currently.
6. Although there was little difference in breeding performance between birds nesting on arable, pastoral or mixed farming systems, it was better on farmland than in urban areas and poorest in suburban areas where population densities are greatest but declining most rapidly. In addition, the breeding performance of House Sparrows has improved in mixed farming areas, but declined in arable areas where populations are currently low and have fallen.
7. House Sparrow nesting success was lower in counties with greater livestock levels but brood sizes were longer. The possible influences of the intensity of pastoral land management and livestock husbandry practices on resource availability for nesting House Sparrows is discussed.

9.2 INTRODUCTION

One of the key hypotheses put forward to explain the rapid population declines of House Sparrows is with regard to possible declines in the availability of invertebrate food used to feed chicks in the nest (Summers-Smith 1999; Bower 1999). In the first few days after hatching, chicks are fed

almost exclusively on a protein-rich diet of invertebrates, but this is then supplemented increasingly with vegetable food as the chicks get older (Summers-Smith 1988). Key prey types fed to chicks are aphids (Aphidoidea), weevils (Curculionidae), grasshoppers (Orthoptera) and caterpillars (Lepidoptera). The proportions vary between habitats, with urban House Sparrows feeding more vegetable food and caterpillars to their chicks than birds in more rural situations. Changes and intensification of agricultural practices since the 1970s have resulted in reductions in invertebrate and seed availability on farmland with consequences for bird populations living in farmland (Robinson & Sutherland 2002; Vickery *et al.* 2001; Chamberlain *et al.* 2000; Benton *et al.* in press; Wilson *et al.* 1999).

Chicks are fed approximately equally by male and female parents, although the male decreases his provisioning rate two to three days before the chicks fledge (Summers-Smith 1988). In the event of death of one parent, the other parent may successfully rear a brood, although it may be stimulated to abandon the brood and seek a replacement clutch (Summers-Smith 1963). The chance of a lone parent succeeding to rear a brood is higher if the death of the other parent occurs later in the breeding cycle (Summers-Smith 1988). Evidence from a number of sources suggests that adult mortality rates are highest in the breeding season (Summers-Smith & Thomas in press; Summers-Smith 1988; Heij & Moeliker 1990). Higher adult mortality and the decrease in chance of nesting success with the death of one parent, suggests that the breeding season is a time of stress for House Sparrows.

Here we analyse the BTO's Nest Record Scheme (NRS) archive for House Sparrow to investigate temporal and spatial patterns in the breeding performance and to investigate whether changes in any aspect of breeding performance might have helped to drive population change. The dataset was computerized as a part of this project, so the work described here represents the first study using modern statistical techniques, since the analysis of Summers-Smith (1963). It should be noted that data from the NRS can only provide information per nesting attempt. Information on the numbers of broods raised by a pair per year are not obtainable for the dataset. Thus this analysis is able to report on average laying dates, clutch sizes, hatching success, brood sizes and nest failure rates at egg and chick stages. These variables can be combined to produce a measure of the number of fledglings raised per nesting attempt.

Periods of population increase, decline and stability were identified in Chapter 3 from significant changes in the direction of population trend measured in different habitats by the Common Birds Census (CBC) or the Garden Bird Feeding Survey (GBFS). If breeding performance is higher during population increases and lower during population declines, this would be consistent with the possibility that changes in breeding performance had helped to drive population changes. If a converse pattern occurs, this would suggest that breeding performance changes as a result of a density-dependent response to population change after a change in another demographic factor.

In addition, we analyse differences in breeding performance between different broad regions and habitats to investigate how breeding performance relates to differences in population density and trajectory as measured by CBC, GBFS and the BTO/JNCC/RSPB Breeding Bird Survey (Chapter 3). Finally, we undertake some specific tests of how breeding performance varies in relation to spatial differences in various key agricultural variables. In particular, a seed-eating species, such as the House Sparrow, might be expected to benefit from increased levels of livestock in a county, if livestock feeding stations are readily available, and might benefit where spring-sowing and stubbles are more prevalent, both of which might provide more food resources in winter and when birds are preparing for breeding.

9.3 METHODS

The NRS (reviewed in detail by Crick & Baillie 1996) comprises a national network of volunteer observers who submit standardized records of nest contents, location, habitat and evidence of success or failure, derived from one or more visits to a nest site. Some or all of first egg date, clutch and brood size, chick:egg ratio (a measure of hatching success) and daily nest failure rates can be

estimated for each nest record card (NRC), depending on the information provided. NRCs also contain habitat data recorded using a hierarchical scheme in which a nest is assigned first to a general category (woodland, grassland, farmland, etc.) and then to a combination of three further levels of habitat detail (Crick 1992; Crick, Dudley & Glue 1994). Prior to 1990, habitat data were recorded differently (using a single code representing one of around 100 habitat types, together with additional information about key components of the habitat).

We have analysed House Sparrow nest record data from 1960 to 2000 to investigate temporal variations in breeding success and the influences of habitat. The latter made use of the habitat data on NRCs as described below. Temporal changes in breeding performance were assessed by means of both categorical and continuous time variables (blocks of years and linear/quadratic trends, respectively), while variations with habitat were investigated using categorical variables defining groups of NRCs from similar habitats.

The variation in breeding performance per breeding attempt was investigated using the following nest record-derived variables:

- First egg date (the date on which the first egg in the clutch is likely to have been laid, excluding cases where the date is not known within \pm five days; day 1 = 1 January).
- Clutch size (the maximum number of eggs found in a nest). Clutch size data were rejected if egg laying could have continued after the last visit of the recorder.
- Brood size (the maximum number of young found in a nest). This is likely to overestimate the brood size at fledging, but will approach it if mortality early in nestling life (when chicks are most vulnerable) is the most significant form of partial brood loss.
- Chick:egg ratio (the ratio of brood size to clutch size where the whole nest did not fail). This incorporates early losses of chicks, as well as hatching success (the proportion of the eggs in the clutch that hatch successfully).
- Daily nest failure rates before and after hatching (see below).

The number and timing of the visits (relative to nest progress) recorded on each NRC determines which of the above variables can be calculated, so the sample sizes for our analyses differed between variables and are given in Appendix 9.1.

The variation in each nest record variable was investigated using generalised linear models in the GENMOD procedure of SAS (SAS Institute, Inc. 1996). Daily nest failure rates were estimated using a formulation of Mayfield's (1961, 1975) method as a logistic model with a binomial error term, in which success or failure over a given number of days (as a binary variable) was modelled with the number of days over which the nest was exposed during the egg, nestling and whole nest (egg and nestling combined) periods as the binomial denominator (Crawley 1993; Etheridge, Summers & Green 1997; Aebischer 1999). The numbers of exposure days during the egg, nestling and whole nest (egg and nestling) periods were calculated as the mid-points between the maxima and minima possible, given the timing of nest visits recorded on each NRC (note that exposure days refer only to the timespan for which data were recorded for each nest and do not represent the full length of the egg and/or nestling periods). Chick:egg ratio was also modelled using a logit link and binomial errors, brood size forming the numerator and clutch size the binomial denominator. Individually, clutch and brood sizes were modelled with identity links and normal errors, as were first egg dates.

Because the NRS is unstructured, the acquisition of data from different parts of Britain has never been controlled and it is possible, therefore, that apparent changes in breeding performance parameters could merely reflect geographical variation and changes in the sample over time. To account for this, we added, as controls, continuous terms for latitude, longitude and the interaction between them to each of our models that investigated temporal variation in breeding performance (see below). Latitude and longitude were assigned to NRCs at the county level (values for the centre of each county) because finer-scale information on location was not recorded on most NRCs prior to 1985.

The significance of the variation with respect to the continuous or categorical predictors of interest was then assessed by comparing the fit of a model incorporating the predictor(s) of interest with a simplified model that omitted it, using a likelihood-ratio test (SAS Institute, Inc. 1996).

In order to reveal the net effects of the variation in each variable, we combined the category-specific estimates of clutch size, chick:egg ratio and daily nest failure rates from each comparison of temporal or habitat classifications to estimate the number of fledglings produced per breeding attempt. This was done according to the following formula (after Hensler 1985; Siriwardena *et al.* 2000a):

$$FPA_i = CS \times HS \times (1 - EFR)^{EP} \times (1 - NFR)^{NP},$$

where FPA_i is the number of fledglings produced per breeding attempt, CS is clutch size, HS is hatching success (chick:egg ratio), EFR and NFR are the egg and nestling period daily nest failure rates, respectively, and EP and NP are the lengths of the egg and nestling periods in days. EP and NP were taken to be the midpoints of the ranges given in Cramp & Perrins (1994) for populations in or near the British Isles as follows: 15 and 14 days, (N.B. egg periods include three days to allow for egg-laying). Confidence intervals for the FPA_i values were calculated following the methods used in Siriwardena *et al.* (2000).

9.3.1 Descriptive Comparisons and Hypothesis Tests

Variation in breeding performance with respect to time was investigated using both categorical and continuous variables. Annual samples were combined into blocks of years using two blocking regimes. First, years were combined in simple five-year blocks from 1960-1964 to 1995-1999. Second, blocks were defined using periods of consistent population trend direction, as delimited by the significant turning points in each species' CBC or GBFS trends (see Chapter 3). The year-blocks defined by each population trend are shown in Table 9.3.1.1; each analysis using these blocks made use of the appropriate set of NRCs, for example farmland CBC blocks were used to classify cards from farmland. We also investigated whether significant trends have occurred in each variable over time by fitting simple linear functions to the data. These simple functions are the most efficient and easily interpreted way to summarize long-term trends (especially when data are sparse), although they may over-simplify the variation. Block analyses allow more complex variation with time: five-year blocks allow considerable flexibility in the temporal pattern that is produced, while blocks based on population trends have an objective demographic basis because demographic rates can reasonably be assumed to have been constant within periods of consistent trend direction.

Table 9.3.1.1 Blocks of years used for analyses of House Sparrow nest record data with respect to time

Source of blocking information	Blocks used	NRC sample used
Five-year blocks	Pre-1965, 1965-69, 1970-1974, ... 1995-99	All
All Plots CBC	1976-78, 1979-82, 1983-93, 1994-99	All
Farmland CBC	1976-82, 1983-90, 1991-93, 1994-00	Farmland
All Gardens GBFS	1970-72, 1973-76, 1977-79, 1980-83, 1984-95, 1996-99	All
Rural GBFS	1970-72, 1973-83, 1984-99	Farmland
Suburban GBFS	1970-72, 1973-76, 1977-83, 1984-93, 1994-99	Human

The potential for variation in block-specific breeding performance parameters and FPA_t to have driven long-term population trends was assessed both graphically and by calculating correlation coefficients between the variables in question and block-specific CBC or GBFS trend slopes. The latter were estimated as the block-specific mean values of the first derivative of each species' long-term CBC or GBFS trend (see Siriwardena *et al.* 2000a for further details): a positive correlation with breeding performance (i.e. a negative correlation with a failure rate) would show that the variation in the parameter concerned is consistent with it having played a role in driving the observed population trend. It should be borne in mind that this approach does not allow for different demographic mechanisms at different times. Statistical significance is not provided because sample sizes of blocks are all small ($n \leq 8$), thus the correlations are only illustrative.

9.3.2 Variation in breeding performance with respect to habitat

Habitat information on NRCs is now coded according to the scheme of Crick (1992), but for data from 1989 and earlier, translations from the preceding, less systematic scheme must be used (see, e.g., Siriwardena *et al.* 2000a,d). These habitat codes were used to classify NRCs into the categories described in Table 9.3.2.1 and breeding performance was then compared between the categories described. Tests were then conducted using models similar to those described for the temporal analyses above, with each of first egg date, clutch size, brood size, chick:egg ratio and the daily nest failure rates in the egg, nestling and whole nest periods being modelled (individually) as a function of each (categorical) habitat variable. Likelihood ratio tests against a constant model were used to identify significant habitat-specific effects and habitat-specific estimates of FPA were calculated. To control for possible temporal biases in the NRC samples (a possible consequence of the unstructured nature of the scheme), for example if farmland cards tended to be older than suburban cards, we repeated these analyses with the addition of a continuous time trend variable (a linear year effect).

To test for differences in the pattern of temporal change between habitat categories, we fitted further models of each component of breeding performance incorporating habitat \times linear time trend interaction terms. Because significant results from these tests could actually reflect geographical changes in the nest record sample rather than true differences in time trends, we repeated the tests with controls for interactions between trends and latitude, longitude and the interaction between them.

Table 9.3.2.1 Nest record habitat divisions used to investigate variations in breeding performance

Test	Categories compared
Broad habitat	Farmland, Suburban/urban
Farm type	Arable, Grazing, Mixed
Human site type	Urban, Suburban, Rural

9.3.3 Variation in breeding performance between regions

NRCs were grouped into the regions defined for our analyses of CBC data (see Chapter 3) in order to investigate large-scale spatial variation in breeding success. Simple tests using region as a categorical variable were used to identify average regional values, as described for other categorical variables above. Further analyses controlling for possible temporal biases in the sample using a linear time trend were also conducted. We then examined the data for differences between the regions in temporal trends using models in which different linear time-trends were allowed for each region.

9.3.4 Variation in breeding performance with respect to agriculture

The June Agricultural Census conducted annually in England and Wales by DEFRA provides data on various features of agriculture that could affect House Sparrow breeding performance. The data are most easily accessed as county-level summaries and we have used these data as covariates in analyses of breeding performance, using models similar to those described above. Specifically, we tested whether breeding performance was affected by (i) the proportion of farmland under arable (as opposed to pastoral) management, (ii) the proportion of barley that is sown in spring (no other cereals are split by sowing time in the June Census data), (iii) grazing intensity, measured in terms of the number of cows, the number of sheep and a combined grazing index (assuming one cow=three sheep). The latter was also tested using data only from NRCs from pastoral habitats, in order to isolate direct effects of livestock densities from broader geographical patterns. The tests conducted are summarized in Table 9.3.4.1.

Table 9.3.4.1 Agricultural Census variables used to investigate variation in breeding performance.

Variable	Variable name	Years Data Available
Proportion of Arable	GRABRAT	1963-2000
Proportion of Barley Sown in Spring	BARLRAT	1978-2000
Number of Cows	COWS	1977-2000
Number of Sheep	SHEEP	1970, 1977-2000
Grazing Intensity	GRAZIND	1977-2000
Number of Cows (Pastoral Habitats)	COWS2	1977-2000
Number of Sheep (Pastoral Habitats)	SHEEP2	1970, 1977-2000
Grazing Intensity (Pastoral Habitats)	GRAZIND2	1977-2000

9.4 RESULTS

9.4.1 Long-term trends

Long-term trends in the various aspects of breeding performance are shown in Figures 9.4.1.1 and 9.4.1.2 and tests of linear trends over time are explored in Table 9.4.1.1. It can be seen that there is a significant but shallow long-term trend towards smaller brood sizes over time. Clutch size and chick:egg ratio show no trend over time, but both egg- and chick-stage failure rates have fallen. Chick-stage failure rates are the most variable, with particularly high levels measured in 1983, 1984 and 1985, although it should be noted that sample sizes for these years were relatively small ($n = 27, 36, 45$ respectively). In some years no failures were detected in the annual sample which probably reflects the generally low rate of nest failure experienced by House Sparrows contained with insufficient annual samples of nests to detect failures, although sample sizes were usually greater than 50 (see Appendix 10.1) which are considered generally sufficient for the estimation of nest failure rates (Johnson 1982, Beintema 1992). Finally, House Sparrows show a significant trend towards earlier laying over the years, amounting to an average advancement of about five days over the past 25 years.

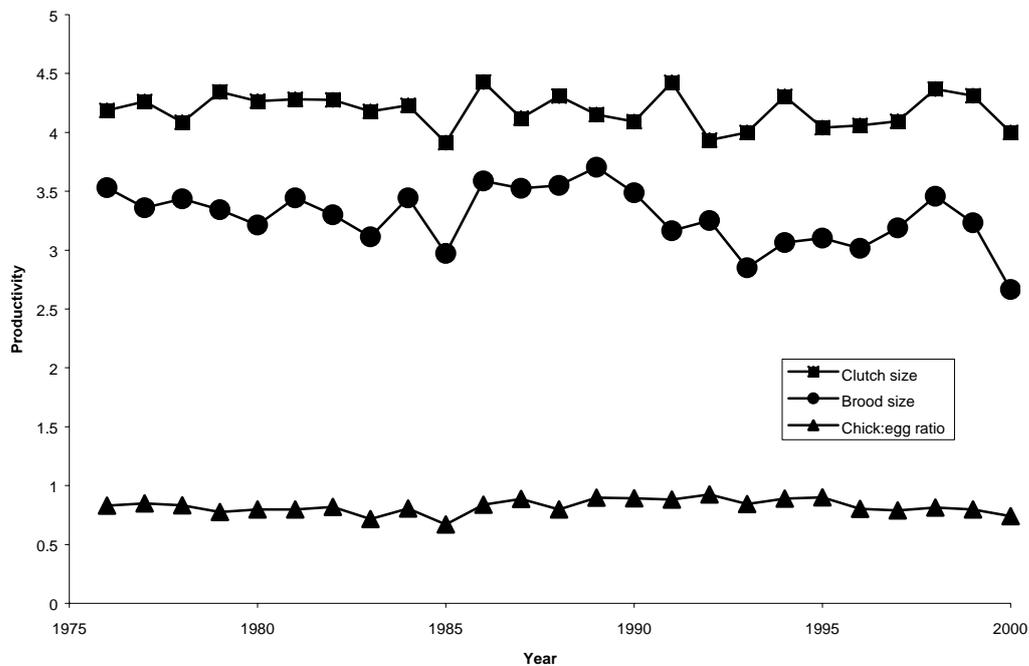


Figure 9.4.1.1 Mean annual estimates of clutch and brood size and chick:egg ratio for House Sparrow.

House Sparrow breeding performance

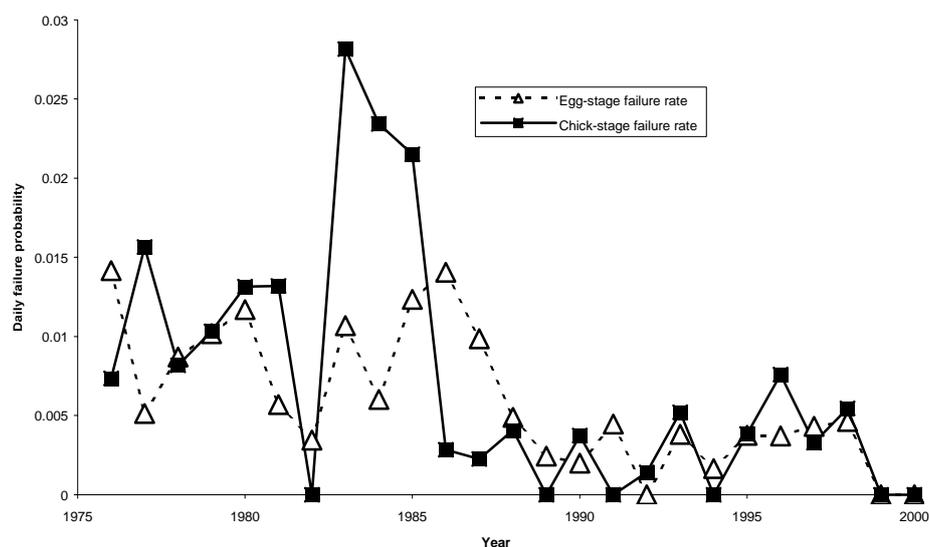


Figure 9.4.1.2 Annual estimates of the failure rates of nests at egg and chick stages for House Sparrow.

Table 9.4.1.1 Tests for linear trends in all NRCs for House Sparrow (controlling for changes in latitude and longitude). LRT is the Likelihood Ratio Test for the significance of the slope.

Breeding performance parameter	Slope (SE)	LRT		
		χ^2_1	<i>P</i>	
First Egg Date	-0.192 (0.50)	14.61	<0.001	
Clutch Size	0.002 (0.001)	2.50	0.114	
Brood Size	-0.004 (0.002)	6.28	0.012	
Chick:egg Ratio	0.001 (0.002)	0.06	0.801	
Daily Nest Failure Rate	Egg Period	-0.029 (0.005)	31.32	<0.001
	Nestling Period	-0.039 (0.006)	56.69	<0.001
	Whole Nest Period	-0.031 (0.003)	102.15	<0.001

9.4.2 Analysis of block-specific breeding performance in relation to abundance trends

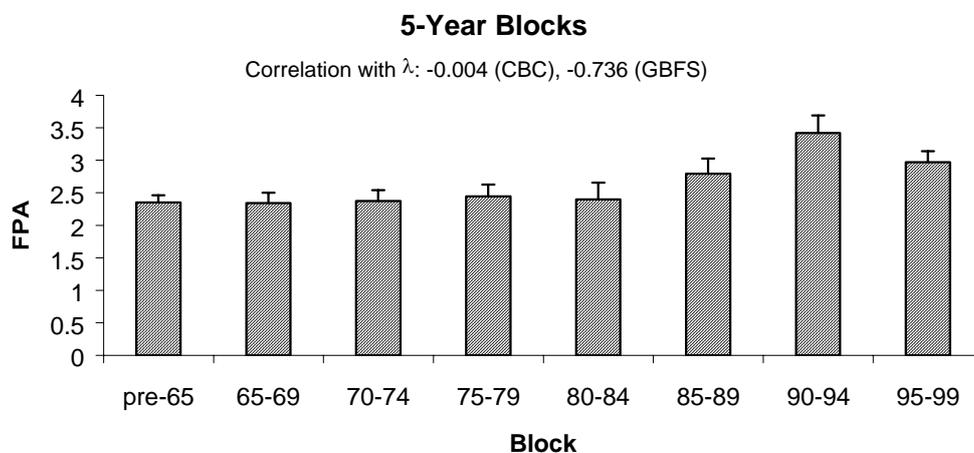
Six different sets of year-blocks were investigated (Table 9.3.1.1), five were related to periods of decline, stability and increase determined from CBC and GBFS trends and one was based on five-year periods. Sample sizes are provided in Appendix 9.1.

9.4.2.1 Five-year blocks

When nest record data were divided up into five-year blocks, significant differences between blocks were found for all variables except clutch size (Table 9.4.2.1.1). Correlations with block-specific population growth rates (λ) for CBC showed conflicting results: brood size and chick:egg ratio tended to be larger when populations are declining most, but failure rates rose. The latter result would be consistent with the idea that changes in nest failure rates had helped to drive population changes. Correlations with population growth rates measured by the GBFS also showed conflicting results. Thus, brood size was higher when growth rates were higher but chick:egg ratio was lower and failure rates were worse. Overall, there was no clear relationship between FPA and CBC trend but there was a strongly negative one with GBFS trend (breeding performance was worse when population changes were bigger (more positive); Figure 9.4.2.1.1).

Table 9.4.2.1.1 Tests for heterogeneity between five-year blocks (controlling for changes in latitude and longitude) and correlations with block-specific population growth rates (λ).

Breeding performance parameter		LRT		Correlations with λ	
		χ^2_7	<i>P</i>	CBC	GFBS
First Egg Date		52.38	<0.001	0.123	0.536
Clutch Size		9.85	0.197	-	-
Brood Size		50.61	<0.001	-0.172	0.478
Chick:egg Ratio		29.14	<0.001	-0.315	-0.170
Daily Nest Failure Rate	Egg Period	49.57	<0.001	-0.049	0.805
	Nestling Period	78.44	<0.001	-0.276	0.834
	Whole Nest Period	162.35	<0.001	-0.186	0.878

**Figure 9.4.2.1.1** Block-specific estimates of fledgings per breeding attempt (FPA) in five-year blocks.

9.4.2.2 CBC blocks: all plots

When breeding performance was related to the periods of differing population change, as measured on all CBC plots, breeding performance (as measured by nest failure rates) tended to be better when population changes were more positive (Table 9.4.2.2.1) although brood sizes were smaller. The influence of nest failure rates prevailed when population growth rates were correlated against estimates of FPA (Figure 9.4.2.2.1), such that population growth rates were higher when more fledglings were produced per nesting attempt.

Table 9.4.2.2.1 Likelihood Ratio Tests (LRT) for differences in breeding performance between blocks of population stability or decline on all CBC plots (controlling for changes in latitude and longitude) and correlations with block-specific population growth rates (λ).

Breeding performance parameter		LRT		Correlation with λ
		χ^2_3	<i>P</i>	
First Egg Date		13.16	0.004	-0.203
Clutch Size		4.29	0.232	-
Brood Size		32.90	<0.001	-0.475
Chick:egg Ratio		2.09	0.555	-
Daily Nest Failure Rate	Egg Period	12.64	0.006	-0.450
	Nestling Period	19.07	<0.001	-0.415
	Whole Nest Period	66.38	<0.001	-0.448

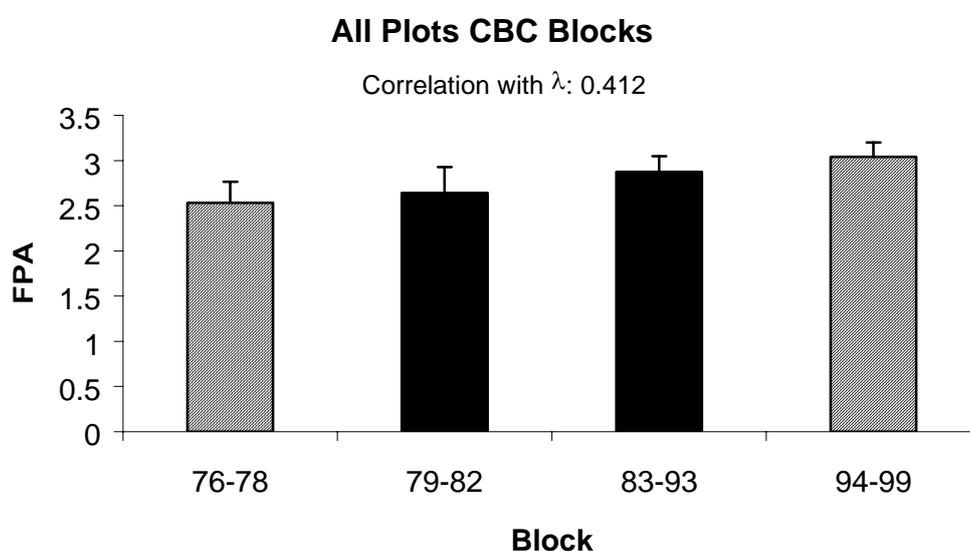


Figure 9.4.2.2.1 Block-specific estimates of fledglings per nesting attempt (FPA) in blocks of population stability (hatching) or decline (black), as measured from all CBC plots.

9.4.2.3 CBC blocks: farmland plots

The analysis of block-specific breeding performance for farmland nests, in relation to population trends on CBC farmland plots showed that brood size tended to be slightly larger when population growth rates were more positive, but that weak correlations between failure rates at the egg- and chick- stage tended to cancel each other out (Table 9.4.2.3.1). The overall effect on breeding performance, in terms of fledglings raised per nesting attempt, was a weakly negative correlation (i.e. it tends to be marginally higher when population growth rates are lower (Figure 9.4.2.3.1)).

Table 9.4.2.3.1 Likelihood Ratio Tests (LRT) for differences in breeding performance between blocks of population stability or decline on farmland CBC plots (controlling for changes in latitude and longitude) and correlations with block-specific population growth rates (λ).

Breeding performance parameter		LRT		Correlation with λ
		χ^2	<i>P</i>	
First Egg Date		13.38	0.004	0.380
Clutch Size		1.82	0.610	-
Brood Size		31.59	<0.001	0.276
Chick:egg Ratio		2.22	0.527	-
Daily Nest Failure Rate	Egg Period	6.73	0.081	0.189
	Nestling Period	7.12	0.068	-0.106
	Whole Nest Period	26.95	<0.001	-0.060

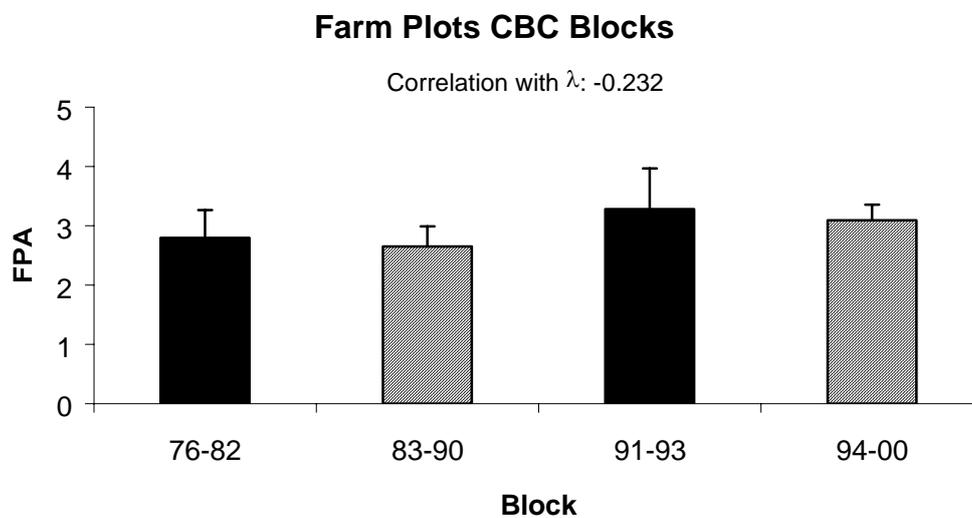


Figure 9.4.2.3.1 Block-specific estimates of fledglings per nesting attempt (FPA) in blocks of population stability (hatching) or decline (black), as measured from farmland CBC plots.

9.4.2.4 GBFS blocks

Failure rates of nests tended to be higher when GBFS population changes were more positive, whether considering all GBFS gardens (Table 9.4.2.4.1), or when considering rural (Table 9.4.2.4.2) and suburban/urban (Table 9.4.2.4.3) GBFS gardens separately. These patterns tended to have the predominant effect on correlations between population growth rate and the number of fledglings produced per nesting attempt (Figures 9.4.2.4.1, 9.4.2.4.2 & 9.4.2.4.3 respectively). This was despite brood size tending to be consistently bigger when population growth rates were more positive for all GBFS gardens, as was clutch size for rural gardens. Chick:egg ratio was lower when population growth rates were higher on suburban/urban gardens, adding to the impact of nest failure rates on the correlation between overall breeding performance, in terms of the number of fledglings raised per nesting attempt, and population growth rate (Table 9.4.2.4.3).

Table 9.4.2.4.1 Likelihood Ratio Tests (LRT) for differences in breeding performance between blocks of population stability or decline on all GBFS gardens (controlling for changes in latitude & longitude) and correlations with block-specific population growth rates (λ).

Breeding performance parameter		LRT		Correlation with λ
		χ^2_5	<i>P</i>	
First Egg Date		40.21	<0.001	0.366
Clutch Size		8.61	0.126	-
Brood Size		22.20	<0.001	0.809
Chick:egg Ratio		15.05	0.010	0.102
Daily Nest Failure Rate	Egg Period	35.92	<0.001	0.638
	Nestling Period	35.86	<0.001	0.811
	Whole Nest Period	106.37	<0.001	0.823

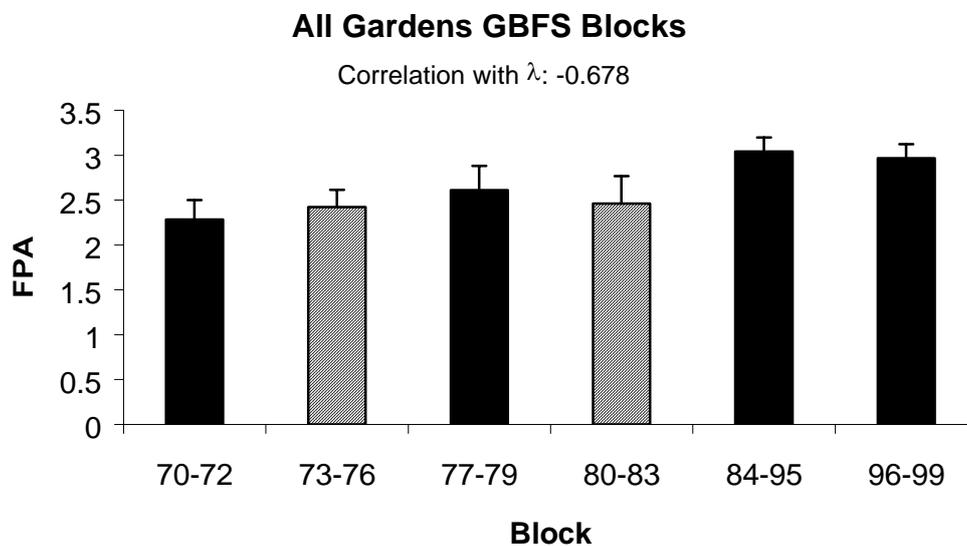


Figure 9.4.2.4.1 Block-specific estimates of fledglings per nesting attempt (FPA) in blocks of population stability (hatching) or decline (black), as measured from all GBFS gardens.

Table 9.4.2.4.2 Likelihood Ratio Tests (LRT) for differences in breeding performance between blocks of population stability or decline on rural GBFS gardens (controlling for changes in latitude and longitude) and correlations with block-specific population growth rates (λ).

Breeding performance parameter		LRT		Correlation with λ
		χ^2_2	<i>P</i>	
First Egg Date		1.17	0.558	-
Clutch Size		7.34	0.026	0.283
Brood Size		1.42	0.492	-
Chick:egg Ratio		2.11	0.349	-
Daily Nest Failure Rate	Egg Period	11.69	0.003	0.060
	Nestling Period	14.67	<0.001	0.567
	Whole Nest Period	52.94	<0.001	0.249

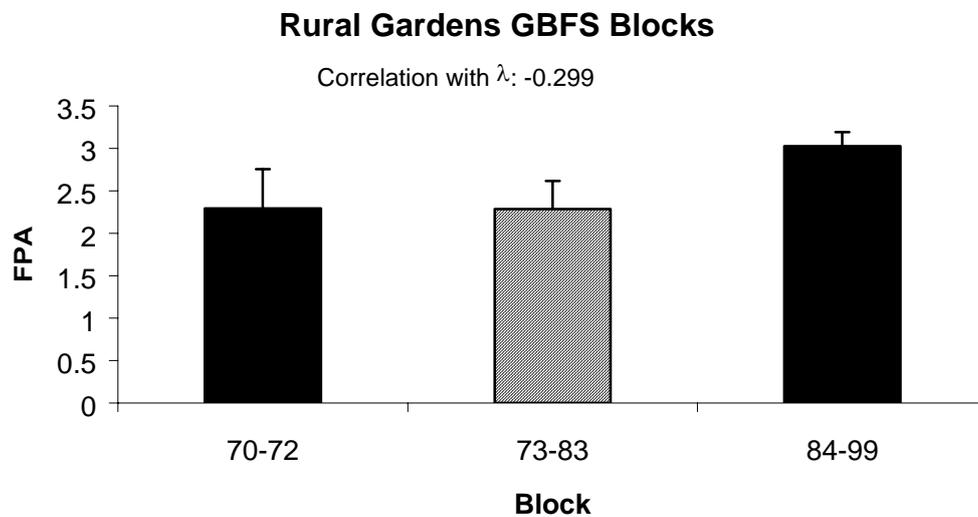


Figure 9.4.2.4.2 Block-specific estimates of fledglings per nesting attempt (FPA) in blocks of population stability (hatching) or decline (black), as measured from all GBFS gardens.

Table 9.4.2.4.3 Likelihood Ratio Tests (LRT) for differences in breeding performance between blocks of population increase, stability or decline on suburban/urban GBFS gardens (controlling for changes in latitude and longitude) and correlations with block-specific population growth rates (λ).

Breeding performance parameter		LRT		Correlation with λ
		χ^2_4	<i>P</i>	
First Egg Date		66.42	<0.001	0.911
Clutch Size		5.27	0.261	-
Brood Size		2.92	0.571	-
Chick:egg Ratio		8.71	0.069	-0.805
Daily Nest Failure Rate	Egg Period	23.22	<0.001	0.757
	Nestling Period	24.54	<0.001	0.828
	Whole Nest Period	57.51	<0.001	0.859

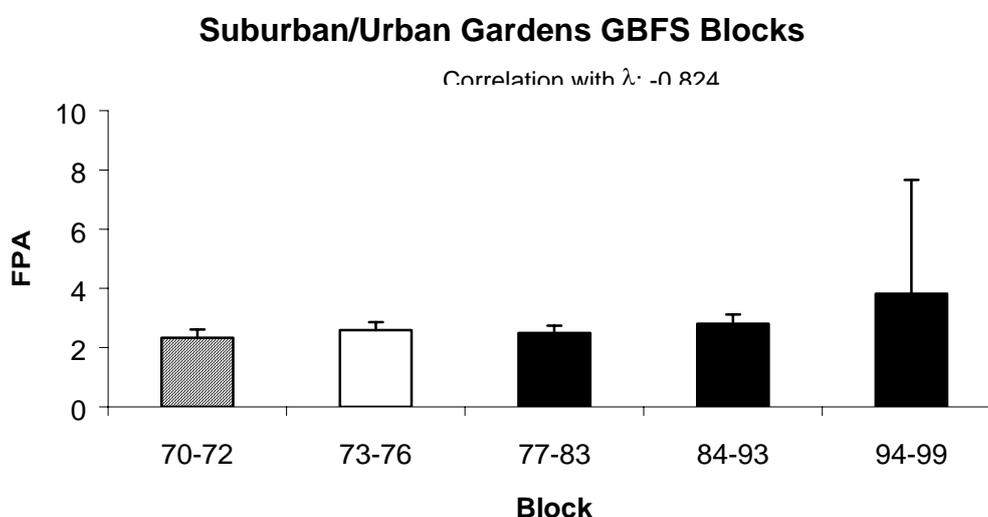


Figure 9.4.2.4.3 Block-specific estimates of fledglings per nesting attempt (FPA) in blocks of population increase (white), stability (hatching) or decline (black), as measured from suburban/urban GBFS gardens.

9.4.3 Variation in breeding performance with respect to habitat

Sample sizes are provided in Appendix 9.1.

9.4.3.1 Comparison of House Sparrows in farmland and suburban/urban habitats

Although the results tended to be confounded by trends through time, all failure rates were higher in suburban/urban areas than on farmland. Average clutch size was lower in suburban/urban areas (mean \pm 95% confidence limits. = 4.07 ± 0.055) than on farmland (4.15 ± 0.058) but chick:egg ratio and brood size were slightly higher there than on farmland (Table 9.4.3.1.1). Overall, breeding performance tended to be better on farms, in terms of fledglings per nesting attempt (Figure 9.4.3.1.1). In addition, House Sparrows tend to lay *c.* five days earlier in suburban/urban areas than farmland areas ($19 \text{ May} \pm 2.0 \text{ days}$ vs. $23 \text{ May} \pm 2.3 \text{ days}$).

Table 9.4.3.1.1 Likelihood Ratio Tests (LRT) for differences in breeding performance between House Sparrows nesting on farmland and those in suburban/urban habitats (with and without controls for linear trends through time).

Breeding performance parameter		Basic LRT		Control for linear year LRT	
		χ^2_1	<i>P</i>	χ^2_1	<i>P</i>
First Egg Date		8.52	0.004	19.00	<0.001
Clutch Size		5.71	0.017	1.51	0.219
Brood Size		2.98	0.084	3.12	0.077
Chick:egg Ratio		6.16	0.013	8.71	0.003
Daily Nest Failure Rate	Egg Period	4.07	0.044	0.07	0.794
	Nestling Period	16.54	<0.001	4.01	0.045
	Whole Nest Period	13.28	<0.001	1.11	0.293

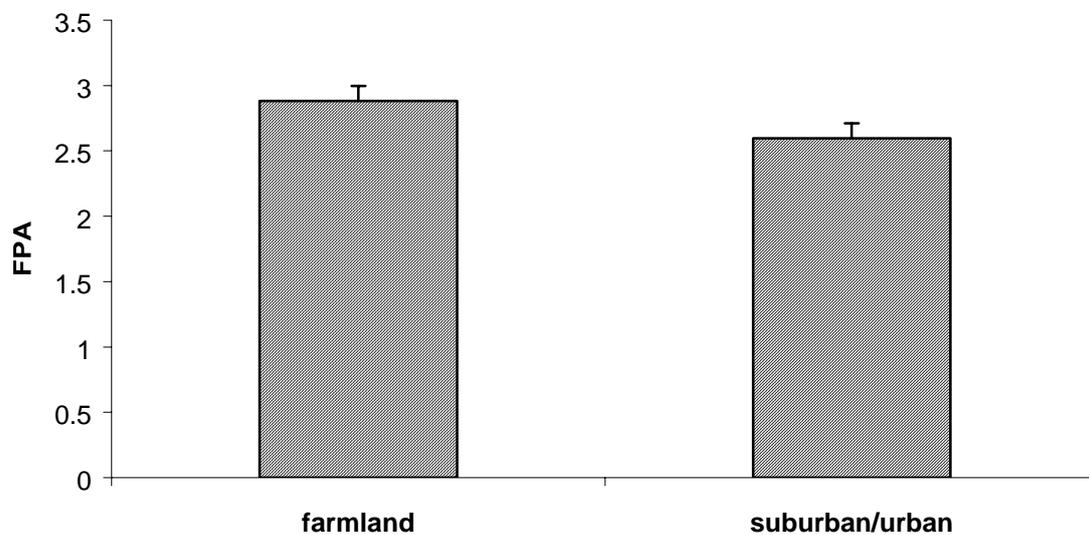


Figure 9.4.3.1.1 Estimates of fledglings per nesting attempt (FPA) for House Sparrows nesting in farmland and suburban/urban habitats.

Comparison of differences in trends in breeding performance between House Sparrows nesting in farmland and suburban/urban habitats (Table 9.4.3.1.2) showed that there was little difference between the two habitats, except that brood size has fallen slightly on farmland but risen slightly in suburban/urban habitats. Both habitats showed trends for earlier laying, but the trend was much more pronounced in suburban/urban habitats than rural habitats.

Table 9.4.3.1.2 Comparison of linear trends in breeding performance between House Sparrows nesting on farmland and those in suburban/urban habitats (with and without controls for changes in the geographical distribution of samples through time). Where the Likelihood Ratio Test (LRT) indicates a significant difference in trends, the slopes of the trends are provided.

Breeding performance parameter		Basic LRT		Slope Estimates (SE)
		χ^2_1	<i>P</i>	Farms, Suburban/Urban
First Egg Date		15.00	<0.001	-0.055 (0.081), -0.537 (0.094)
Clutch Size		0.18	0.674	-
Brood Size		3.24	0.072	-0.002 (0.002), 0.005 (0.003)
Chick:egg Ratio		0.72	0.396	-
Daily Nest Failure Rate	Egg Period	0.29	0.590	-
	Nestling Period	0.86	0.354	-
	Whole Nest Period	0.20	0.655	-
<i>Controlling for geographical changes in the sample</i>				
First Egg Date		22.36	<0.001	-0.069 (0.084), -0.657 (0.099)
Clutch Size		0.09	0.767	-
Brood Size		8.13	0.004	-0.004 (0.003), 0.007 (0.003)
Chick:egg Ratio		0.90	0.344	-
Daily Nest Failure Rate	Egg Period	0.81	0.368	-
	Nestling Period	1.17	0.280	-
	Whole Nest Period	0.58	0.446	-

9.4.3.2 Comparison of House Sparrows in different farmland types

We looked at arable, pastoral and mixed farm types and found that average clutch sizes tended to be lowest for House Sparrows nesting in pastoral farmland, while nest failure rate at the nestling stage (and overall) tended to be highest in arable areas (Table 9.4.3.2.1). These patterns were not confounded by temporal trends, but the overall effect on productivity (FPA) was to cancel each other out (Figure 9.4.3.2.1). In addition, House Sparrows nesting in pastoral habitats tended to lay earlier, on average, than in other habitats (mean \pm 95% confidence limits: pastoral = 15 May \pm 5.0 days ; mixed = 29 May \pm 5.4 days; arable = 4 June \pm 9.4 days).

Table 9.4.3.2.1 Likelihood Ratio Tests (LRT) for differences in breeding performance between House Sparrows nesting in arable, mixed or pastoral farmland habitats (with and without controls for linear trends through time).

Breeding performance parameter		Basic LRT		Control for linear year LRT	
		χ^2_2	<i>P</i>	χ^2_2	<i>P</i>
First Egg Date		18.45	<0.001	18.40	<0.001
Clutch Size		7.98	0.019	7.30	0.026
Brood Size		22.53	<0.001	25.90	<0.001
Chick:egg Ratio		0.56	0.758	0.16	0.922
Daily Nest Failure Rate	Egg Period	0.24	0.887	3.92	0.141
	Nestling Period	10.12	0.006	11.67	0.003
	Whole Nest Period	7.40	0.025	5.97	0.051

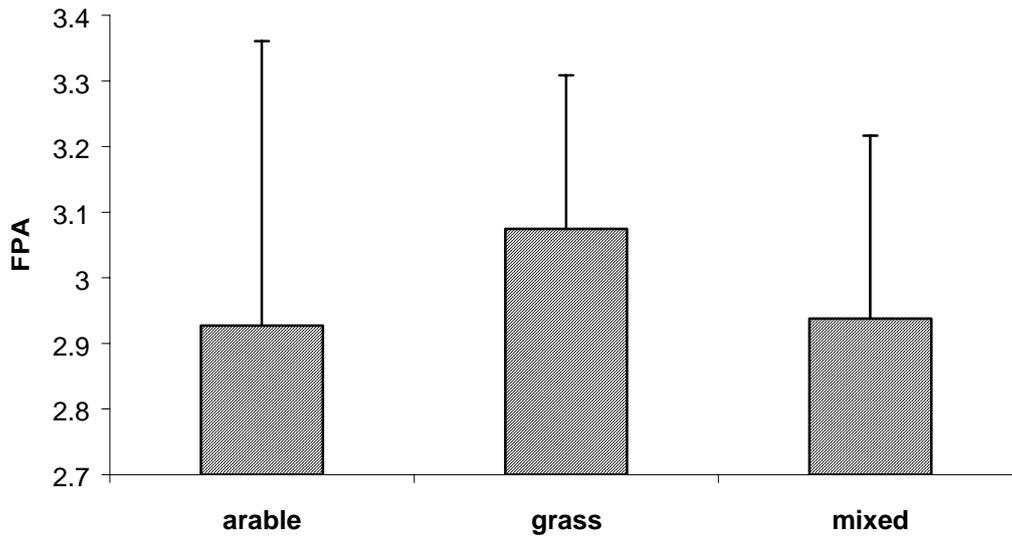


Figure 9.4.3.2.1 Estimates of fledglings per nesting attempt (FPA) for House Sparrows nesting in three broad farmland habitat types.

Table 9.4.3.2.2 shows differences in linear trends in breeding performance in the three farming habitats. There was a difference in long-term trends in clutch size between the habitats, with clutch size having increased in arable and mixed farming habitats, but having remained relatively stable or declined in pastoral habitats. The failure-rate of nests at the egg-stage has tended to increase on arable farmland, but has declined on the other farm types. Overall, the different aspects of breeding performance show conflicting trends in arable and pastoral habitats, it is only in the mixed farming habitats that breeding performance shows consistent improvements. However, since changes in nest success tends to have the most influence on productivity per nest, it is likely that productivity has declined in arable habitats but improved in pastoral. Finally, as might be expected from Table 9.4.3.2.1, birds nesting in grazing habitats show trends toward earlier laying, whereas those in other habitats have tended to lay later, on average.

Table 9.4.3.2.2 Comparison of linear trends in breeding performance between House Sparrows nesting in arable, mixed or pastoral farmland habitats (with and without controls for changes in the geographical distribution of samples through time). Where the Likelihood Ratio Test (LRT) indicates significant differences in trends, the slopes of the trends are provided.

Breeding performance parameter		Basic LRT		Slope Estimates (SE)
		χ^2_2	<i>P</i>	Arable, Grazing, Mixed
First Egg Date		10.97	0.004	0.328 (0.510), -0.486 (0.208), 0.619 (0.266)
Clutch Size		18.40	<0.001	0.020 (0.011), -0.008 (0.006), 0.027 (0.006)
Brood Size		6.31	0.043	-0.035 (0.012), -0.008 (0.007), 0.002 (0.009)
Chick:egg Ratio		2.85	0.241	-
Daily Nest Failure Rate	Egg Period	6.85	0.033	0.049 (0.050), -0.055 (0.020), -0.086 (0.021)
	Nestling Period	0.85	0.653	-
	Whole Nest Period	2.20	0.333	-
<i>Controlling for geographical changes in the sample</i>				
First Egg Date		9.35	0.009	0.345 (0.510), -0.454 (0.218), 0.572 (0.265)
Clutch Size		18.18	<0.001	0.018 (0.010), -0.009 (0.006), 0.027 (0.006)
Brood Size		2.58	0.275	-
Chick:egg Ratio		2.67	0.263	-
Daily Nest Failure Rate	Egg Period	7.74	0.021	0.054 (0.049), -0.068 (0.022), -0.092 (0.021)
	Nestling Period	1.37	0.503	-
	Whole Nest Period	2.71	0.258	-

9.4.3.3 Comparison of House Sparrows nesting near human habitation in rural, suburban and urban situations

Although nest failure rates tended to be highest at the egg-stage in rural habitats, they were highest at the chick-stage and overall in urban habitats (Table 9.4.3.3.1). (Failure rate over the whole nest period were 32% for suburban House Sparrows, compared with 15% in the other two habitats. In contrast brood sizes and chick:egg ratios were greatest in suburban habitats. These patterns were not confounded by temporal patterns and thus, overall breeding performance was lower in suburban habitats than in rural or urban (Figure 9.4.3.3.1). Average laying dates did not differ between the habitats.

Table 9.4.3.3.1 Likelihood Ratio Tests (LRT) for differences in breeding performance between House Sparrows nesting in or near human habitation in rural, suburban and urban situations (with and without controls for linear trends through time).

Breeding performance parameter		Basic LRT		Control for linear year LRT	
		χ^2_2	<i>P</i>	χ^2_2	<i>P</i>
First Egg Date		4.86	0.088	0.85	0.653
Clutch Size		3.23	0.199	2.09	0.352
Brood Size		14.46	<0.001	13.03	0.002
Chick:egg Ratio		14.07	0.001	13.29	0.001
Daily Nest Failure Rate	Egg Period	7.10	0.029	4.94	0.085
	Nestling Period	27.77	<0.001	11.36	0.003
	Whole Nest Period	26.54	<0.001	7.94	0.019

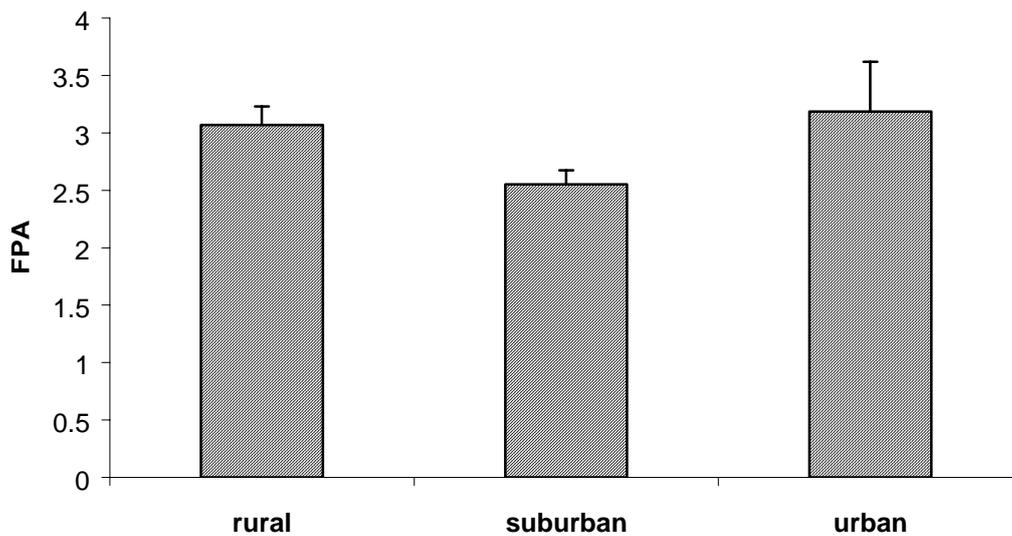


Figure 9.4.3.3.1 Estimates of fledglings per nesting attempt (FPA) for House Sparrows nesting near human habitation.

Analysis of trends over time (Table 9.4.3.3.2), after allowing for the confounding effects of geographical changes in the samples through time, showed that clutch and brood size had increased in suburban areas compared with the other two habitats, and that brood size had decreased in rural situations. The tendency for laying to have become earlier was most pronounced in urban situations and least so in rural habitats.

Table 9.4.3.3.2 Comparison of linear trends in breeding performance between House Sparrows nesting near rural, suburban and urban human habitation (with and without controls for changes in the geographical distribution of samples through time). Where the Likelihood Ratio Test (LRT) indicates significant differences in trends, the slopes of the trends are provided.

Breeding performance parameter		Basic LRT		Slope Estimates (SE) Rural, Suburban, Urban
		χ^2_2	<i>P</i>	
First Egg Date		3.76	0.152	-
Clutch Size		2.05	0.359	-
Brood Size		8.37	0.015	-0.011 (0.003), 0.001 (0.003), 0.008 (0.010)
Chick:egg Ratio		1.57	0.457	-
Daily Nest Failure Rate	Egg Period	3.22	0.200	-
	Nestling Period	0.74	0.690	-
	Whole Nest Period	2.87	0.239	-
<i>Controlling for geographical changes in the sample</i>				
First Egg Date		6.93	0.031	-0.290 (0.114), -0.598 (0.110), -0.990 (0.305)
Clutch Size		5.26	0.072	-0.003 (0.003), 0.006 (0.003), 0.005 (0.009)
Brood Size		14.55	<0.001	-0.011 (0.004), 0.005 (0.003), 0.004 (0.010)
Chick:egg Ratio		2.24	0.326	-
Daily Nest Failure Rate	Egg Period	3.43	0.180	-
	Nestling Period	0.65	0.721	-
	Whole Nest Period	2.91	0.234	-

9.4.4 Variation in breeding performance between regions

There were significant differences between the regions in all aspects of breeding performance apart from clutch size (Table 9.4.4.1). Overall breeding performance was highest in the North and West, followed by the East, and although it was variable in the South West, breeding performance was lowest in the South East (Figure 9.4.4.1). There was no evidence that the results were confounded by temporal biases in the sample. Sample sizes are provided in Appendix 9.1.

Table 9.4.4.1 Likelihood Ratio Tests (LRT) for differences in breeding performance between House Sparrows nesting in five geographical regions (with and without controls for linear trends through time).

Breeding performance parameter		Basic LRT		Control for linear year LRT	
		χ^2_4	<i>P</i>	χ^2_4	<i>P</i>
First Egg Date		33.14	<0.001	34.85	<0.001
Clutch Size		4.86	0.302	4.40	0.355
Brood Size		36.30	<0.001	36.80	<0.001
Chick:egg Ratio		29.25	<0.001	29.22	<0.001
Daily Nest Failure Rate	Egg Period	8.97	0.062	10.04	0.040
	Nestling Period	23.06	<0.001	18.78	<0.001
	Whole Nest Period	11.54	0.021	11.17	0.025

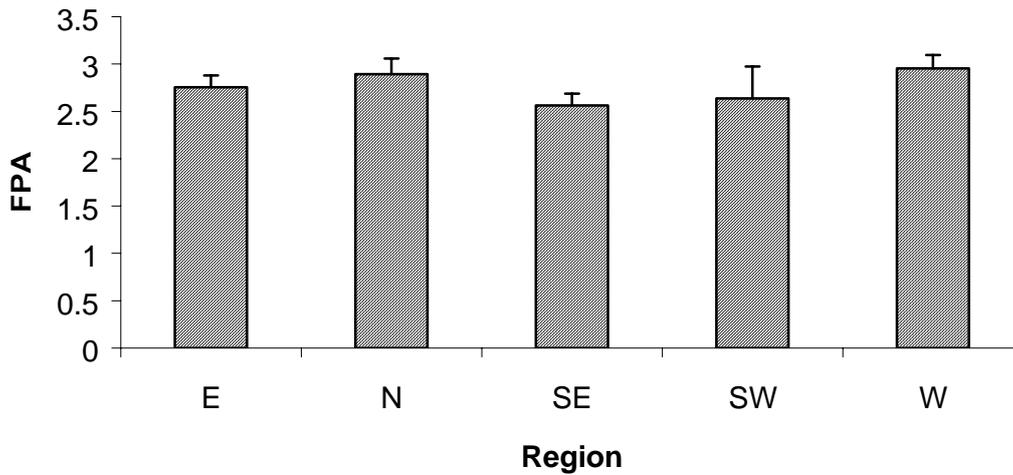


Figure 9.4.4.1 Estimates of fledglings per nesting attempt (FPA) for House Sparrows nesting in five broad geographical regions.

There were significant differences in trends in all aspects of breeding performance except for brood size and failure rate of nests at the egg-stage (Table 9.4.4.2). Clutch size has increased most in the North, increased marginally in the East, South West and South East, but decreased in the West. Chick:egg ratio has increased most in the East, less so in the South East and North, remained approximately level in the West, but declined in the South West. Chick-stage failure rate has declined most in the East, then decreasingly so in the West, South West and South East, and least in the North. The pattern was slightly changed when considering failure rate over the whole nest cycle, with rates of decline becoming shallower in the order: East > North & West > South East & South West.

Table 9.4.4.2 Comparison of linear trends in breeding performance between House Sparrows nesting in five main regions of Britain: East, North, South East, South West and West.

Breeding performance parameter		LRT		Slope Estimates (SE)
		χ^2_4	<i>P</i>	E, N, SE, SW, W
First Egg Date		31.44	<0.001	-0.766 (0.123), -0.265 (0.118), 0.050 (0.081), -0.048 (0.209), -0.159 (0.106)
Clutch Size		26.92	<0.001	0.007 (0.004), 0.014 (0.003), 0.003 (0.002), 0.009 (0.007), -0.007 (0.003)
Brood Size		5.97	0.202	-
Chick:egg Ratio		37.62	<0.001	0.033 (0.005), 0.007 (0.004), 0.011 (0.002), -0.011 (0.008), 0.002 (0.004)
Daily Nest Failure Rate	Egg Period	5.58	0.233	-
	Nestling Period	11.25	0.024	-0.075 (0.014), -0.019 (0.014), -0.027 (0.008), -0.030 (0.019), -0.037 (0.013)
	Whole Nest Period	15.97	0.003	-0.053 (0.007), -0.025 (0.008), -0.020 (0.005), -0.019 (0.014), -0.024 (0.007)

9.4.5 Variation in breeding performance with respect to agriculture

Table 9.4.5.1 provides the results of the various tests undertaken to investigate whether House Sparrow breeding performance varies with respect to key agricultural variables (listed in Table 9.3.4.1).

The first test investigated whether the proportion of arable habitat in a county (GRABRAT) influences breeding performance. Clutch size tended to be larger in counties containing more arable habitat, but other aspects of breeding performance were unrelated to this ratio. In contrast, most aspects of breeding performance tended to be poorer as the proportion of spring-sown barley (BARLRAT) (in relation to autumn-sown barley) increased in a county: brood size, chick:egg ratio and nest failure rates were all worse in counties containing a greater proportion of spring-sown barley.

The relationships between breeding performance and livestock levels in counties were investigated with respect to just Britain as a whole (COWS, SHEEP, GRAZIND) as well as with respect to NRCs from pastoral habitats (COWS2, SHEEP2, GRAZIND2). The general pattern in Britain as a whole, was one in which breeding performance tended to be worse in counties containing greater numbers of livestock. However, this was reversed for House Sparrows nesting in pastoral habitats because House Sparrow brood size tended to be larger in counties with more sheep or cows (or overall grazing index). Although failure rate over the whole nest period tended to increase with grazing index for birds nesting in pastoral habitat.

Table 9.4.5.1 Tests for trends in House Sparrow breeding performance with respect to gradients in key agricultural variables. Where significant results were obtained in relation to livestock, the slopes were often extremely small (as measured on a per-animal basis), thus the direction of the relationship is provided.

Breeding performance parameter		GRABRAT			COWS			COWS2		
		χ^2_1	<i>P</i>	Slope (SE)	χ^2_1	<i>P</i>	Slope (SE)	χ^2_1	<i>P</i>	Slope (SE)
First Egg Date		34.35	<0.001	20.6 (3.50)	2.75	0.097	-	0.21	0.644	-
Clutch Size		5.50	0.019	0.225 (0.096)	9.71	0.002	Negative	0.03	0.856	-
Brood Size		2.62	0.106	-	0.10	0.756	-	8.16	0.004	Positive
Chick:egg Ratio		1.27	0.260	-	0.05	0.826	-	0.12	0.730	-
Daily Nest	Egg Period	0.14	0.707	-	0.15	0.703	-	0.70	0.403	-
Failure Rate	Nestling Period	1.28	0.258	-	4.60	0.032	Negative	0.76	0.383	-
	Whole Nest Period	0.02	0.877	-	4.63	0.031	Negative	2.96	0.085	-

Breeding performance parameter		SHEEP			SHEEP2			BARLRAT		
		χ^2_1	<i>P</i>	Slope (SE)	χ^2_1	<i>P</i>	Slope (SE)	χ^2_1	<i>P</i>	Slope (SE)
First Egg Date		4.32	0.038	Negative	0.32	0.572	-	0.14	0.712	-
Clutch Size		14.40	<0.001	Negative	0.28	0.600	-	1.70	0.192	-
Brood Size		4.81	0.028	Negative	7.22	0.007	Positive	3.79	0.052	-0.266 (0.137)
Chick:egg Ratio		1.05	0.306	-	0.31	0.581	-	9.55	0.002	-0.682 (0.220)
Daily Nest	Egg Period	0.03	0.856	-	0.18	0.674	-	7.74	0.005	1.491 (0.530)
Failure Rate	Nestling Period	0.02	0.877	-	1.46	0.226	-	6.94	0.008	1.329 (0.495)
	Whole Nest Period	0.17	0.677	-	2.96	0.085	-	25.05	<0.001	1.579 (0.310)

Breeding performance parameter		GRAZIND			GRAZIND2		
		χ^2_1	<i>P</i>	Slope (SE)	χ^2_1	<i>P</i>	Slope (SE)
First Egg Date		3.99	0.046	-0.012 (0.006)	0.84	0.359	-
Clutch Size		13.59	<0.001	-0.0006 (0.0002)	0.00	0.990	-
Brood Size		4.23	0.040	-0.0003 (0.0001)	7.81	0.005	0.0008 (0.0003)
Chick:egg Ratio		0.94	0.333	-	0.01	0.942	-
Daily Nest	Egg Period	0.22	0.638	-	0.70	0.402	-
Failure Rate	Nestling Period	0.01	0.934	-	1.37	0.242	-
	Whole Nest Period	0.00	0.952	-	5.15	0.023	0.003 (0.001)

9.5 DISCUSSION

The long-term NRS data for House Sparrow provide a unique insight into the changes and trends in breeding performance that have occurred nationally and regionally over the past 40 years. While the geographical spread of records and occurrence of volunteer observers who have specialised on House Sparrows may vary over time, this can be controlled for statistically in the analyses. The potentially confounding influence of underlying trends can also be statistically controlled in the comparison of records from different habitats. The only aspect that cannot be investigated with Nest Record data is that of the number of broods attempted per pair per season. Thus the discussion that follows must be considered to refer to breeding performance per nesting attempt, not that of a pair over the course of the nesting season.

9.5.1 Trends in breeding performance

Overall, the analysis of NRCs show that House Sparrow breeding performance has tended to increase over time and that this has occurred in all regions. However, the increases appeared to be least rapid in the parts of the country (South East and South West) where population declines have been the most rapid in the long-term (as measured by the CBC and where declines are still the most rapid in the short-term (as measured by the BBS Chapter 3).

In Chapter 3, we determined turning points in the trajectories of population abundance measured by the CBC and GBFS. These were used to define blocks of time when House Sparrow populations were statistically stable, increasing or decreasing. This allowed us to analyse how breeding performance varied in relation to population growth rate. Although different aspects of breeding performance might show positive and negative correlations with population growth rate, in general the key variables for determining the correlation with overall productivity were the nest failure rates.

An important finding was that, for the blocks defined by turning points in the population trajectory for all CBC plots, FPA was positively correlated with block-specific population growth rates. Both egg-stage and chick-stage failure rates were inversely related to population growth rates, i.e. failure rates were lowest when population growth was most positive. This suggests that breeding performance could have an explanatory role with respect to the population changes measured by the CBC.

The analysis of year-blocks determined from the farmland CBC also showed that chick-stage nest failure rates were lower, and brood size was larger, when population growth rates were higher. However, egg-stage failure rates tended to be higher in periods when population growth was higher and these failure rates appeared to predominate in the analysis of FPA.

Contradictory results were also found in the analysis of GBFS-determined blocks of years. Thus, although both brood size and chick:egg ratio were higher when population growth rates on all GBFS gardens were higher, egg- and chick-stage failure rates were too, leading to lower estimates of FPA. The correlation between FPA and block-specific population growth rates on Rural GBFS gardens was very weak because of contradictory results for clutch size and chick-stage failure rates. However, there was a strongly negative relationship between breeding performance and population growth rate as measured for suburban GBFS gardens, which was due to the combined effects of chick:egg ratio and egg- and chick-stage failure rates. This suggests that a factor other than breeding performance per nesting attempt has driven population changes in suburban gardens.

9.5.2 Breeding performance in different habitats and regions

The comparison of breeding performance between different habitats is likely to reflect broad differences that exist between large regions of Britain. There is a general east-west gradient, with pastoral farming occurring more to the west and arable farming predominating in the east, with mixed farming occurring in central Britain (Chamberlain *et al.* 2000, Robinson *et al.* 2001). Arable farming benefits from the better soil quality and drier weather found in the East, whereas conditions for pastoral farming are enhanced by the wetter conditions found in the West. Over the past 20 to 30 years regional farming practices have become more specialised and farms have tended to lose livestock in the east and lose arable cropping in the west. Furthermore, there are large-scale spatial patterns of agricultural practice in Britain (Siriwardena *et al.* 2000b) that mean that regional and habitat differences will often be inter-correlated.

The regional analysis showed that breeding performance was highest in the North and West regions, intermediate in the East and lowest in South East and South West. Furthermore, breeding performance has tended to increase in all regions, although the improvements are most rapid in the North & West. This may be a factor influencing the population increases in Scotland and Wales, as measured by the BBS (Chapter 3). The relatively poor breeding performance in the South East, combined with evidence for the lowest rate of improvement in breeding performance of all the regions, might be a factor helping to drive the population declines in this region measured by CBC and BBS. Samples of nest records were insufficient to investigate this further but comparative studies of breeding success in areas of population increase and decrease would be valuable in helping to understand the mechanisms behind differences in breeding performance.

Breeding performance was greater on farmland than in towns and villages, and urban sparrows enjoy a better output of fledglings per nesting attempt than sparrows in suburban habitats. Such a pattern may be related to population density breeding, as the estimates from the BBS reveals that densities are highest in suburban areas (c. 320km⁻²), intermediate in urban areas (c. 220km⁻²) and lowest in farmland (c. 25km⁻² in arable areas and c. 45km⁻² in pastoral areas). However, this would require an inverse pattern of some other aspect of demography, for example, higher over-winter survival rates in suburbia, if populations were at equilibrium. On the other hand, populations have declined most steeply in suburban areas (Chapter 3) and poor nesting success may be a contributory factor, although not determining the pattern of population change. The size of the difference in failure rates of nests (32% suburban; 15% urban and rural) is substantial and warrants further detailed study.

Interestingly, there was little overall difference between farms of different type, although productivity appeared to be generally improving for birds living on mixed farms, but declining on arable farms. House Sparrow populations not only occur at their lowest densities on arable land, but have shown consistent patterns of decline on CBC and BBS (Chapter 3), and declining nest success may be a contributory factor. Siriwardena *et al.* (2000d) found that breeding performance for a number of granivorous species is better on mixed farming systems, which they suggested might be due to the availability of a greater range of foraging opportunities within a local area. Mixed farming systems are also associated with more extensive intensive farming practices (Siriwardena *et al.* 2001a) that appear to benefit a range of species (Chamberlain & Fuller 2001). However, the lack of a response of House Sparrow abundance to the addition of small areas of arable land within pastoral landscapes (Robinson *et al.* 2001) fits with a pattern of little difference in nesting success between the two systems.

Although House Sparrows live at higher densities in pastoral areas than arable areas, their breeding performance is lower in counties with greater populations of livestock. However, when considering just those birds nesting in pastoral habitats, brood sizes tended to increase with greater numbers of cows and sheep but failure rates appeared to increase too. Areas where high stocking rates occur may be indicative of more intensive pasture management and more intensive livestock husbandry practices. There have been widespread changes in grassland management in Britain in recent decades (Vickery *et al.* 1999). These have resulted in considerable uniformity of management to increase

yields, with the replacement of hay with silage, and increased fertiliser treatments that have negative impacts on invertebrate abundance (Wilson *et al.* 1999). Silage, with its earlier and more frequent cuts will provide less seed for granivores, such as sparrows. The declines in invertebrate numbers would be detrimental for sparrows at the chick-feeding stage and may limit their productivity. Although greater livestock numbers might increase the availability of spilt grain and livestock feed, intensive livestock husbandry might be associated with more careful control of livestock food provisioning to avoid spoiling and hence loss to House Sparrows and other animals (see Chapter 11). This would decrease food supplies available during breeding and thereby tend to limit breeding success. The influence of pastoral land management and livestock husbandry on food availability for nesting House Sparrows is an area which requires more intensive research.

The negative response of House Sparrows to increased levels of spring barley within a county was unexpected and difficult to account for, except as a potentially spurious correlation arising as a result of a correlation between spring barley and another factor that affects House Sparrows. Spring barley is associated with later harvests and the increased likelihood of over-wintering stubbles (Siriwardena *et al.* 2001a). Both practices should make more food available over the winter, when sparrows are setting up and defending their nesting sites and preparing for the nesting season (Summers-Smith 1988). However, this result is consistent with the finding of Robinson *et al.* (2001) that the addition of areas of spring cereal or stubbles in farmland areas has no influence on the abundance of House Sparrows. It suggests that these agricultural factors are likely to be unimportant in the decline of House Sparrows, despite their key role for other species (e.g. Wilson *et al.* 1996).

Appendix 9.1 Sample sizes of House Sparrow Nest Record Cards used in the analyses in Chapter 9.**Table A9.1.1** Sample sizes of House Sparrow Nest Record Cards used in the analysis of five-year blocks (Table A9.4.2.1.1).

Years	First Egg Date	Clutch Size	Brood Size	Chick:egg Ratio	Egg-stage Failure Rates	Chick-stage Failure Rates	WholeNest Failure Rates
Pre-65	841	1016	1487	798	1292	991	1709
65-69	390	501	695	405	633	471	778
70-74	341	418	614	342	522	432	657
75-79	264	314	564	254	423	390	523
80-84	129	177	282	149	216	176	228
85-89	156	218	450	177	282	293	411
90-94	146	161	458	139	266	358	420
95-99	315	398	851	351	562	625	775
Total	2582	3203	5401	2615	4196	3736	5501

Table A9.1.2 Sample sizes of House Sparrow Nest Record Cards used in the analysis of year blocks for All CBC Plots (Table A9.4.2.2.1).

Years	First Egg Date	Clutch Size	Brood Size	Chick:egg Ratio	Egg-stage Failure Rates	Chick-stage Failure Rates	Whole Nest Failure Rates
76-78	167	206	348	168	277	233	325
79-82	118	145	276	118	186	179	211
83-93	316	410	912	342	572	647	830
94-99	347	434	943	384	619	692	855
Total	948	1195	2479	1012	1654	1751	2221

Table A9.1.3 Sample sizes of House Sparrow Nest Record Cards used in the analysis of year blocks for Farmland CBC Plots (Table A9.4.2.3.1).

Years	First Egg Date	Clutch Size	Brood Size	Chick:egg Ratio	Egg-stage Failure Rates	Chick-stage Failure Rates	Whole Nest Failure Rates
76-82	57	83	170	62	111	99	145
83-90	64	131	250	108	155	154	219
91-93	32	37	153	34	70	123	139
94-00	219	272	550	242	371	398	497
Total	372	523	1123	446	707	774	1000

House Sparrow breeding performance

Table A9.1.4 Sample sizes of House Sparrow Nest Record Cards used in the analysis of year blocks for All GBFS Plots (Table A9.4.2.4.1).

Years	First Egg Date	Clutch Size	Brood Size	Chick:egg Ratio	Egg-stage Failure Rates	Chick-stage Failure Rates	Whole Nest Failure Rates
70-72	201	257	373	206	323	262	399
73-76	276	325	497	270	411	362	529
77-79	128	150	308	120	211	198	252
80-83	107	138	230	113	171	140	186
84-95	354	443	1058	374	644	767	966
96-99	285	373	753	329	511	545	682
Total	1351	1686	3219	1412	2271	2274	3014

Table A9.1.5 Sample sizes of House Sparrow Nest Record Cards used in the analysis of year blocks for Rural GBFS Plots (Table A9.4.2.4.2).

Years	First Egg Date	Clutch Size	Brood Size	Chick:egg Ratio	Egg-stage Failure Rates	Chick-stage Failure Rates	Whole Nest Failure Rates
70-72	44	69	97	53	81	66	109
73-83	96	134	267	102	180	145	239
84-99	309	427	933	375	583	664	840
Total	449	630	1297	530	844	875	1188

Table A9.1.6 Sample sizes of House Sparrow Nest Record Cards used in the analysis of year blocks for Suburban/Urban GBFS Plots (Table A9.4.2.3.3).

Years	First Egg Date	Clutch Size	Brood Size	Chick:egg Ratio	Egg-stage Failure Rates	Chick-stage Failure Rates	Whole Nest Failure Rates
70-72	132	149	217	122	193	157	229
73-76	169	197	273	165	240	207	289
77-83	149	160	257	131	216	173	227
84-93	134	149	300	119	204	226	293
94-99	39	46	167	43	87	128	152
Total	623	701	1214	580	940	891	1190

Table A9.1.7 Sample sizes of House Sparrow Nest Record Cards used in the comparison of Farmland vs. Suburban/Urban habitats (Table A9.4.3.1.1).

Years	First Egg Date	Clutch Size	Brood Size	Chick:egg Ratio	Egg-stage Failure Rates	Chick-stage Failure Rates	Whole Nest Failure Rates
Farm	566	785	1320	608	1042	1014	1442
Suburban/urban	724	866	1277	655	1183	1056	1520
Total	1290	1651	2597	1263	2225	2070	2962

Table A9.1.8 Sample sizes of House Sparrow Nest Record Cards used in the comparison of Arable, Mixed and Pastoral farmland habitats (Table A9.4.3.2.1).

Years	First Egg Date	Clutch Size	Brood Size	Chick:egg Ratio	Egg-stage Failure Rates	Chick-stage Failure Rates	Whole Nest Failure Rates
Arable	35	66	80	48	79	73	114
Pastoral	123	131	274	103	203	243	326
Mixed	106	141	195	119	179	158	207
Total	264	338	549	270	461	474	647

Table A9.1.9 Sample sizes of House Sparrow Nest Record Cards used in the comparison of nests near human habitation in Rural, Suburban and Urban habitats (Table A9.4.3.3.1).

Years	First Egg Date	Clutch Size	Brood Size	Chick:egg Ratio	Egg-stage Failure Rates	Chick-stage Failure Rates	Whole Nest Failure Rates
Rural	235	325	615	249	465	541	717
Suburban	682	817	1173	622	1102	970	1403
Urban	42	50	105	34	81	86	118
Total	905	1648	1597	2238	147	139	376

Table A9.1.10 Sample sizes of House Sparrow Nest Record Cards used in the comparison of British regions: East, North, South East, South West and West (Table A9.4.4.1).

Years	First Egg Date	Clutch Size	Brood Size	Chick:egg Ratio	Egg-stage Failure Rates	Chick-stage Failure Rates	Whole Nest Failure Rates
East	592	755	1120	575	966	967	1335
North	344	451	682	339	605	483	757
South East	651	762	1066	580	1009	832	1198
South West	86	100	191	79	143	139	201
West	399	531	891	409	686	690	967
Total	2072	2599	3950	1982	3409	3111	4458

10 POPULATION DYNAMICS OF HOUSE SPARROWS *Passer domesticus* BREEDING IN BRITAIN: AN INTEGRATED ANALYSIS

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10.1 CHAPTER SUMMARY

1. Data on the abundance of House Sparrows on Common Birds Census (CBC) plots are modelled here in relation to changes in breeding performance, measured using Nest Record Scheme data, and changes in adult and first-year survival, measured from ringing recoveries.
2. Adult survival rates tended to rise to a peak in the early 1980s then fall in the 1980s and early 1990s before showing some signs of improvement again. The survival rates of House Sparrows in their first year of life showed a general trend of improvement from the mid-1970s to early 1990s, before falling back again in the latter half of the 1990s.
3. Population models in which either productivity or survival rates were kept constant, showed that the latter matched the observed CBC trend better, indicating that changes in productivity were likely to have driven the population changes of House Sparrow since 1975.
4. The best fit to the data was found when egg-stage failure rates alone were permitted to vary. Varying failure at the chick stage most accurately reproduced the full extent of the population decline in the early 1980s. However, reasonable approximations to the decline were obtained whether egg- or chick-stage failure rates or hatching success were allowed to vary in the model.
5. In order to model the relatively sparse ringing recovery data for House Sparrows, we calculated survival rates for adult and first-year birds for four blocks of years, determined by the turning points found in the CBC population trajectory. The model in which adult survival was permitted to vary provided a poor fit to the CBC trend, but variation in first-year survival provided a model that showed a reasonable match to the changes in abundance measured by the CBC.
6. The modelling exercise suggested that changes in clutch size, post-fledging survival and numbers of broods per pair per year are unlikely to have played an important role in driving changes in the abundance of House Sparrows since 1975.
7. Analysis of demographic data prior to 1975 suggests that declines in survival rates of first-year birds caused the population decline, but that improvements in breeding performance and possibly first-year survival have halted the population decline.

10.2 INTRODUCTION

Populations of birds change as a result of changes in the rates of births, deaths, immigration and emigration. For a bird such as the House Sparrow *Passer domesticus*, which is highly sedentary (Summers-Smith & Thomas in press), emigration and immigration will not be significant when considering changes in its national population abundance. The national declines in population size

demonstrated in Chapter 3 can thus be examined with respect to changes in breeding performance (Chapter 9) and survival rates (this chapter) measured from national monitoring schemes.

Various hypotheses have been put forward to explain the declines of House Sparrows (e.g. Summers-Smith 1999). Some relate to changes in aspects of breeding performance, such as declines in the availability of food fed to chicks, due to pollution (Bower 1999) or changes in agricultural practice. Either could lead to reductions in chick survival rates. Others relate to factors that might affect survival rates of adult and birds in their first year of life, for example due to the impacts of predation (Churcher & Lawton 1987), disease transmission (Prowse 2002) or the availability of adequate food supplies in winter (Siriwardena *et al.* 1999; Ringsby *et al.* 1996). While the results of Chapter 9 suggested that changes in breeding performance, as measured by the Nest Record Scheme (NRS), are consistent with the possibility that they might have driven population changes measured by the Common Birds Census (CBC), the relative importance of this compared to changes in survival were not assessed. Here we use an Integrated Population Modelling approach (Baillie 1990; Greenwood *et al.* 1993), to combine measures of breeding performance and survival in a single population dynamics model, to assess the relative importance of the different demographic factors in determining House Sparrow population change.

Previous analyses, used to identify stages of the life cycle at which crucial changes have taken place, have been carried out for Spotted Flycatcher (Freeman and Crick 2002), Bullfinch (Siriwardena *et al.* 2001b), Song Thrush (Thomson *et al.* 1997), and Reed Bunting (Peach *et al.* 1999). These analyses fitted population models, derived from estimates of the demographic variables, to the estimated abundance indices. This approach, however, ignores sampling covariances between the abundance indices. A preferable approach is to fit demographic population models directly to the individual bird counts from a census scheme, such as the CBC, and here we introduce a new method for doing this. The method is based on maximum likelihood; hence standard comparative measures of goodness of fit, such as maximised log-likelihood values and the Pearson Chi-Square statistic can be calculated for any fitted model. This provides an efficient means of comparing alternative models, in order to identify the significant demographic changes for the species of interest, here the House Sparrow.

10.3 METHODS

10.3.1 Nest Record data

We derived annual estimates of productivity per breeding attempt from data gathered under the BTO's Nest Record Scheme (Crick and Baillie 1996; Chapter 9). Nest Record Cards are completed by volunteer observers who record the contents of the nest on each visit and information about its location (including nest sites and surrounding habitat). These allow the calculation of clutch and brood sizes, hatching success (the proportion of eggs in a clutch that hatch), the period under observation and the status (successful, failed or ultimate outcome unknown) when the nest was last surveyed.

The nest status and the length of the observation period can be used to obtain estimates of nest survival via the method of Mayfield (1961, 1975) and standard errors via those of Johnson (1979). Such estimates were calculated separately for the days when the birds were incubating ('egg stage') or feeding chicks ('nestling stage'), since different ecological factors may influence changes in each. The method assumes that the daily failure probabilities are constant within the period in question. Violation of this assumption may bias the estimated probability of ultimate nest success, but any bias is unlikely to vary from year to year and annual comparisons and temporal trends should not be affected (Crick and Baillie 1996). Full methods and a detailed analysis can be found in Chapter 9.

10.3.2 Ring-Recovery data

In Britain, the great majority of House Sparrows ringed have been as fully grown birds, with a more-or-less uniform seasonal distribution, apart from a slight peak in the breeding season (Summers-Smith

& Thomas in press). Although the House Sparrow is one of the commonest breeding birds in Britain & Ireland, comparatively small numbers have been ringed and recovered. This is largely because, from 1970, ringers were actively discouraged from ringing a species that was considered to be largely sedentary and of little conservation interest. This was at a time when bird ringing was used mainly to investigate movements rather than to estimate survival (Baillie *et al.* 1996). The restriction on ringing was relaxed and then removed in 1993. In total, 411,478 House Sparrows have been ringed in Britain & Ireland, and the total number of recoveries is 6,019, although only c. 125,000 birds have been ringed and c. 1000 have been recovered since the 1970s, when population monitoring was instigated.

Recoveries of birds up to 31 May 2001 are included in the analyses. We employed only records of birds ringed between April and October, which restricts the data to the British breeding population. Data were split into two classes according to age at ringing (birds in their first year of life and adults). Adults are defined as birds aged one year or greater; ages of these birds cannot be more accurately identified in the hand. Birds caught as adults (between April and October) and recovered before 31 May the following year were classed as having been recovered in the year of ringing. Subsequent recovery periods ran from 1 June to the following 31 May, reflecting median ringing date of adult birds. Birds ringed as independent juveniles were considered as first-year birds until 31 May in the year following hatching, after which they were classed as adults.

Survival rates of first-year and adult birds were calculated using a range of ring-recovery models for birds of two age classes (see Brownie *et al.* 1985), with likelihood maximisation by the package MARK of White and Burnham (1999). As the numbers of birds ringed in each age class was not known, models were adopted that were conditional upon the numbers of birds recovered.

Data analysed comprised birds ringed since 1965, although estimates for the early years were not included in subsequent population models. Recoveries of House Sparrows are rather few, and we aimed to increase the precision of estimates in the 1970s by including these earlier cohorts in the analysis, and taking advantage of the fact that some birds will have survived, in unknown numbers, into the period of interest.

10.3.3 Common Birds Census data

Populations of House Sparrows in the wider countryside of Britain have been monitored by the CBC (Marchant *et al.* 1990). Each year between 200 and 300 survey plots were visited 10 to 12 times a year by volunteer observers and the territories present mapped. The number of territories on each plot can then be modelled using a generalized linear model as a log-linear function of plot and year with a Poisson error term, to provide an annual index of numbers in a given habitat (e.g. ter Braak *et al.* 1994; Peach *et al.* 1998). Full details of the methods used to calculate the population trends can be found in Chapter 3.

In this chapter, population models based on demographic parameters estimated from ring-recovery and nest record data were fitted to these territory counts from 1976 to 2000. Limited data from earlier years were excluded. CBC sites tend to be associated with the more populated areas of the country and, as they are selected by the observers, tend not to be fully representative, being dominated by certain habitat types. Indices derived from them are however considered typical of lowland Southern Britain (Fuller *et al.* 1985).

10.3.4 Population models

Our population models combine information on survival and productivity to predict inter-annual population changes. We begin with a base-line model of the population changes measured by the CBC, which is independent of any demographic (i.e. productivity or survival) data. The base-line model is calculated as follows: we assume the territory count c_{ij} at CBC site i in year j has a Poisson distribution and is given, in expectation, by

$$c_{ij} = S_i N_j \quad (1)$$

where S_i and N_j are respectively factors specific to site and year. The model therefore assumes that the population numbers fluctuate proportionately at all sites, though naturally some sites generally contain more birds than others. This geographical variability is accounted for by the S_i . Alternatively

$$\ln(c_{ij}) = \ln(S_i) + \ln(N_j) = s_i + n_j \quad (2)$$

and annual indices \hat{N}_j can readily be calculated by maximum likelihood; this is a Generalised Linear Model (GLM) based on a logarithmic link function (McCullagh & Nelder 1990). Such indices are routinely calculated from CBC data and adopted as annual estimates of abundance. These estimates are clearly independent of any demographic information available, as each annual index value is a free parameter. This model we denote $\{S_i, N_j\}$; it is the most general time-varying model that can be fitted, without expanding upon the simple assumption that the site and year effects are additive on the log scale and is equivalent to the standard CBC index. The GLM is readily modified to impose simple trends upon the estimates N_j . We show here that it is also possible to fit a population model within this framework and, hence, model the relationship between counts and the demographic parameters, effectively by imposing alternative constraints on the N_j . This is preferable to estimating the year effects under model (2) and undertaking a separate modelling exercise, since only by incorporating the population model directly into the GLM are sampling covariances of these parameters accounted for.

We then establish a deterministic population model:

$$N_{j+1} = N_j (\phi_{aj} + \phi_{1j} p FPA_j) \quad (3a)$$

$$FPA_j = CS_j \times HS_j \times (1 - EFR_j)^{EP} \times (1 - NFR_j)^{NP} \quad (3b)$$

where N_j is an index proportional to the species' abundance in year j , ϕ_{aj} , ϕ_{1j} and FPA_j are respectively adult and first-year survival probabilities and productivity (fledglings) per breeding attempt in year j . FPA_j is further broken down into demographic variables calculable from NRS data: clutch size (CS), hatching success (HS , the ratio of brood size to clutch size, or chick:egg ratio) and daily nest failure rate at the egg (EFR) and nestling (NFR) stages (Chapter 9). The exponents EP and NP are the lengths of the incubation and nestling periods, here taken to be 15 and 14 days respectively (Cramp & Perrins 1994). Total productivity in a season differs from that per breeding attempt, as the latter does not include repeat broods and mortality immediately after fledging. These are difficult to quantify in the field and their contribution is represented in (3a) by a parameter p , assumed constant across years. Given that FPA_j is productivity per nesting attempt (rather than per bird), and assuming an equal sex ratio, if model assumptions hold p is one half of the product of post-fledging survival and the average number of broods per pair (see Freeman & Crick in press). Note, however, that any consistent bias in measured productivity parameters or first-year survival becomes confounded also with p .

The various population models in this chapter consider demographic parameters either in their time-varying forms as above, or replaced by average values over the period modelled (i.e. 1976 to 2000). We denote these constant average values by dropping the subscript j in the above definitions.

Applying (3) recursively over T years we have

$$N_j = N_1 k_j \quad j = 2,3,4,\dots,T \quad (4a)$$

$$k_j = \prod_{i=1}^{j-1} (\phi_{ai} + p FPA_i \phi_{li}) \quad j = 2,3,4,\dots,T \quad (4b)$$

hence

$$\ln(N_j) = \ln(N_1) + k'_j \quad (5a)$$

$$k'_j = \sum_{i=1}^{j-1} \ln(\phi_{ai} + p FPA_i \phi_{li}) \quad (5b)$$

Substituting (5) into (2) gives

$$\ln(c_{ij}) = s_i + \ln(N_1) + k'_j \quad (6)$$

If survival probabilities and productivity per breeding attempt are regarded as known (in practice, replaced by their estimates from ringing and nest record data), the only unknown parameters in (6) are the site effects s_i , the population N_1 in year 1 and p , the unknown component of productivity. The various demographic models fitted in this chapter differ in the sets of values used for survival and productivity per breeding attempt, according to which variables are assigned constant and time-dependent values; that is, each model employs different explanatory variables k'_j .

For fixed p , equation (6) therefore retains a GLM form, and an estimate \tilde{N}_1 of N_1 conditional on p is readily evaluated via equation (6) and any GLM software, since k'_j becomes an offset variable and \tilde{N}_1 is calculated via the model intercept. An iterative search over p provides unconditional maximum likelihood estimates \hat{N}_1 and \hat{p} .

10.4 RESULTS

10.4.1 Demographic parameters

For completeness, annual estimates of the components of productivity obtained from national Nest Record data are given in Figures 10.4.1.1 and 10.4.1.2 (see Chapter 9 for a full discussion of these results). Annual sample sizes of nest record cards used to calculate nest survival rates are in Appendix 10.1. This shows that the unusually high chick-stage failure rates in 1983, 84 and 85 are not due to unreasonably small samples.

Estimated survival rates of first-year and adult birds are shown in Figure 10.4.1.3. Precise, separate, annual rates for each year of the data cannot be independently estimated due to problems of model convergence, and some form of additional constraint is necessary. Those shown are derived by constraining the two survival rates for 2000 to be equal to the comparable rates in 1999. The rates for 2000 are not themselves required in the population model, and their uncertainty is of no further concern; however, we need to ascertain that the constraints imposed on this parameter do not unduly influence those in earlier years. This we did by fitting two additional models. In these, the survival rates in 2000 were constrained to be equal to the highest, and then the lowest of the estimates for earlier years in the series. The effects of these constraints on trends in survival for 1976-1999 were minor (Figure 10.4.1.4) and restricted only to the final years, long after any major changes in population had taken place. We therefore use the estimates of Figure 10.4.1.3 as fully annual age- and time-specific survival rates where these are required in subsequent population models.

House Sparrow population dynamics

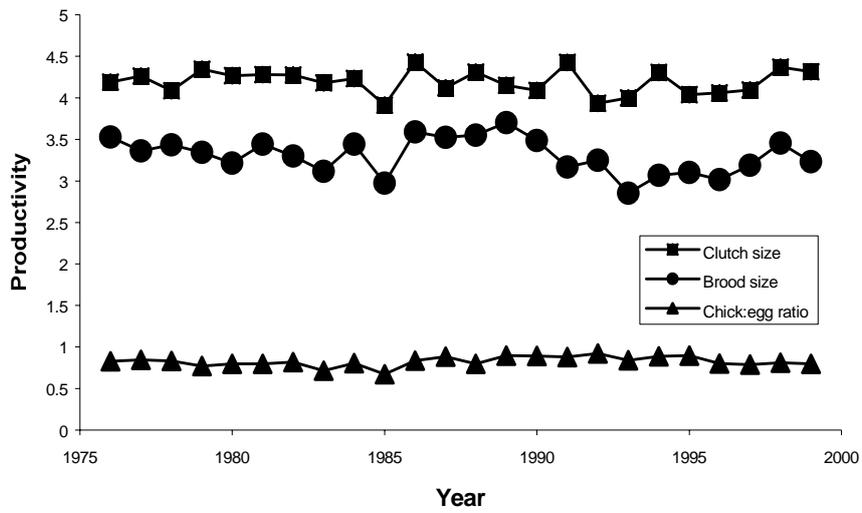


Figure 10.4.1.1 Annual estimates of clutch size, brood size and hatching success (chick:egg ratio) for House Sparrow.

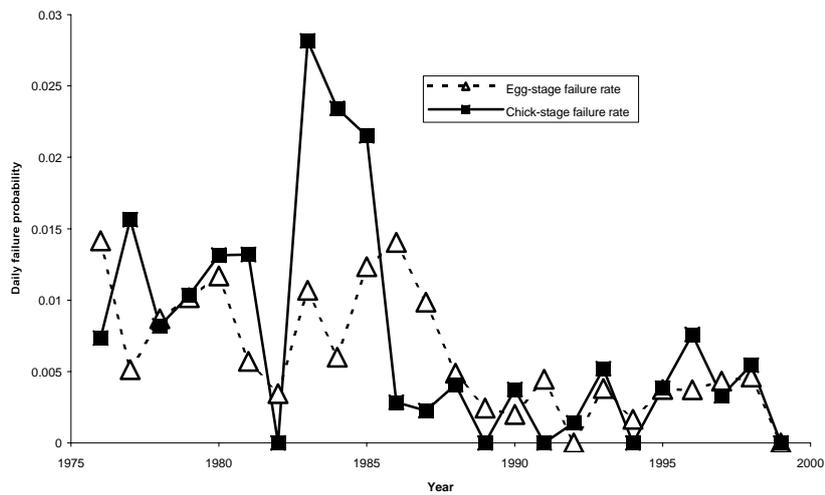


Figure 10.4.1.2 Annual estimates of failure rates of nests at egg and chick stages for House Sparrow.

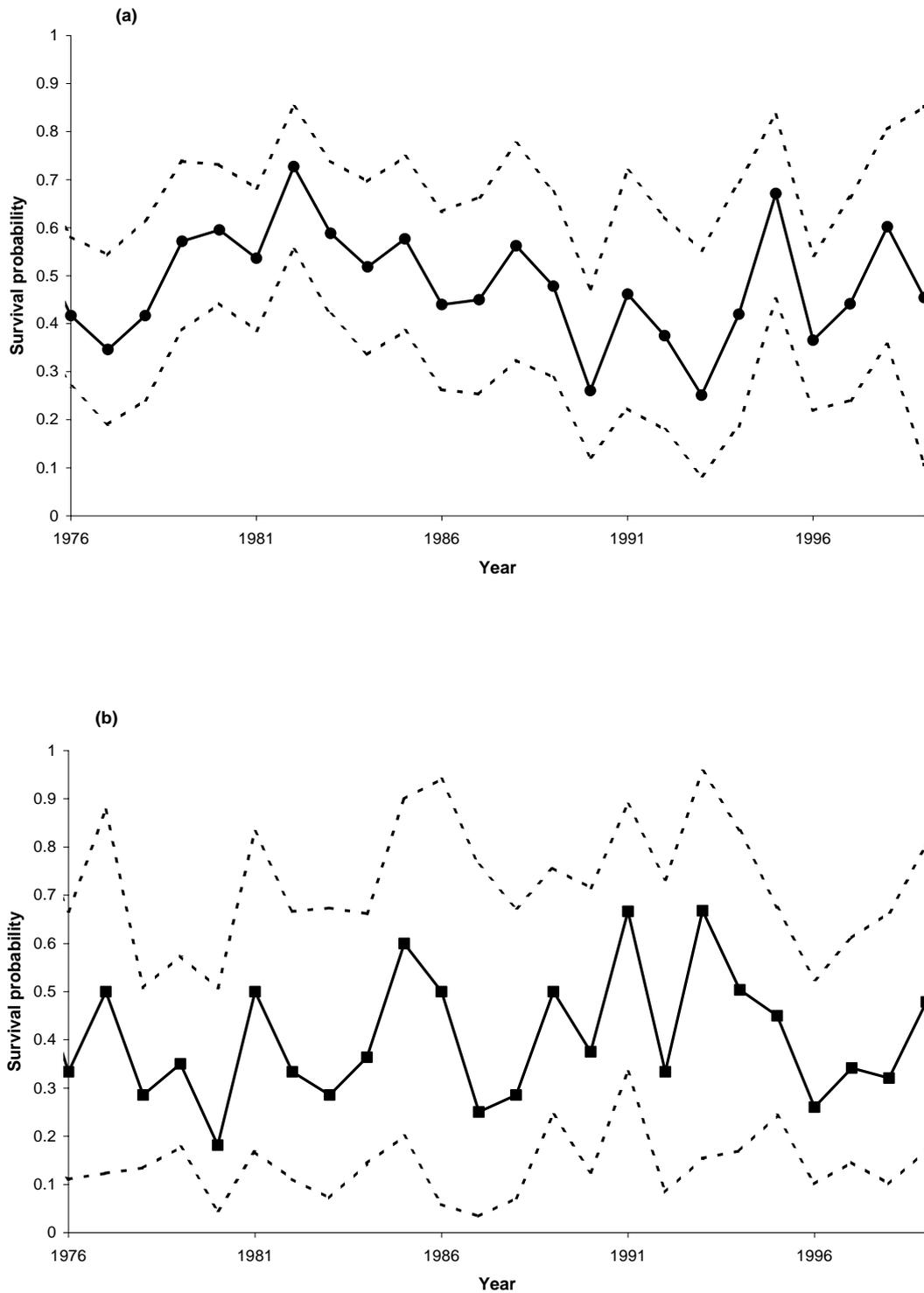


Figure 10.4.1.3 Annual estimates of survival rates of House Sparrow for (a) Adult, and (b) First-year birds. Dashed lines represent 95% confidence limits.

House Sparrow population dynamics

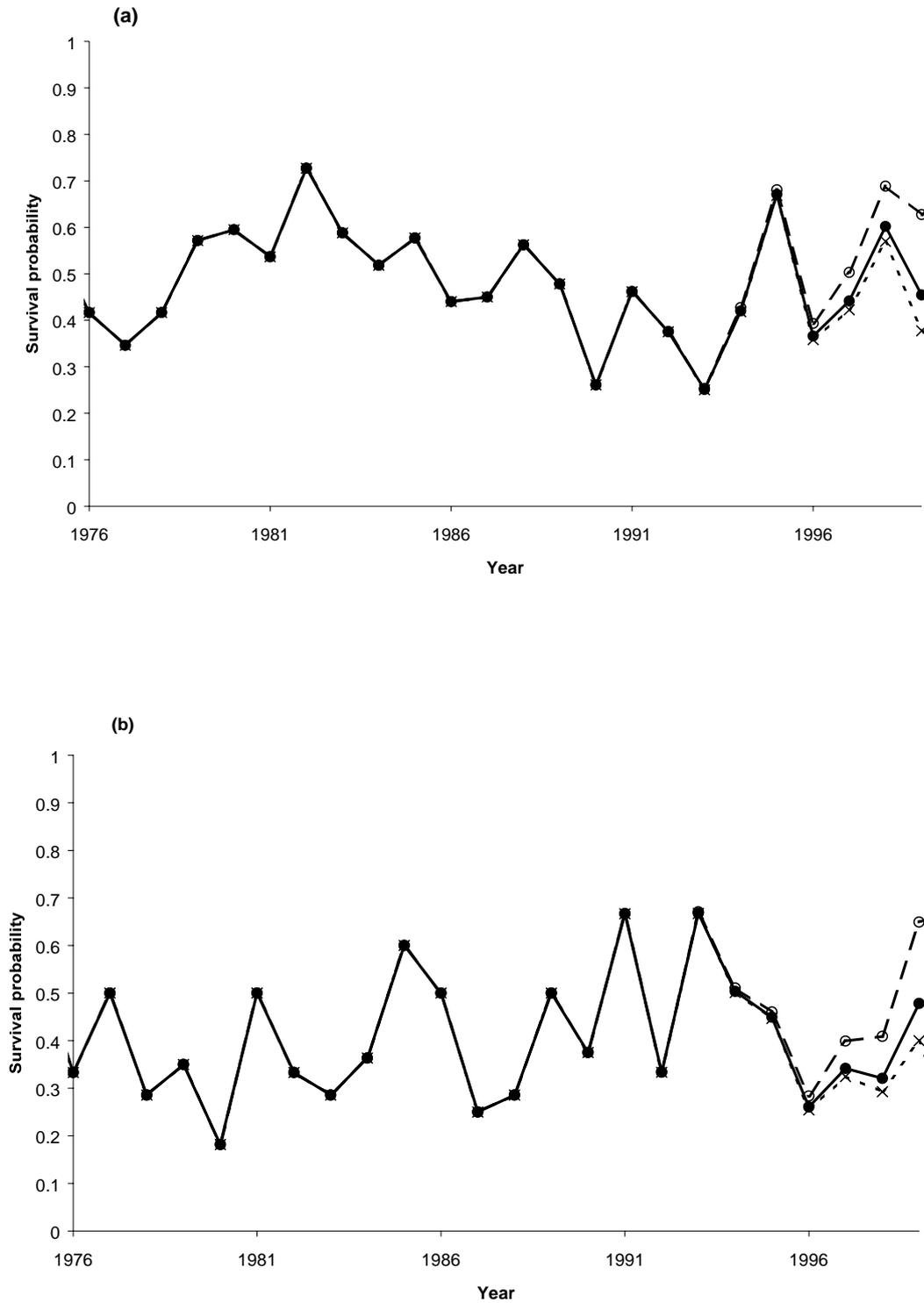


Figure 10.4.1.4 Sensitivity of (a) Adult and (b) First-year House Sparrow survival rates to the treatment of the final year. The solid lines (with filled circles) show the pattern of survival rates when the survival rates for 2000 were constrained to be equal to that for 1999. This is compared with survival rates when the survival in 2000 was constrained to be equal to the highest estimated value in the time series (dashed lines with open circles), or equal to those of the lowest estimated value (dotted lines with crosses).

Both sets of annual rates were highly variable and, especially for first year birds, imprecisely estimated. This reflects the paucity of the ring-recovery data for this species, and such highly variable estimates can be expected to produce highly variable trajectories in a population model. We, therefore, also consider a reduced parameter model for the survival analysis. We constrain the survival rates to be equal within four 'blocks' of consecutive years: 1976-79, 1980-83, 1984-94 and 1995-2000, these blocks being determined by the statistically significant turning points in the smoothed CBC index (Chapter 3). The resulting estimates of adult survival differ significantly between blocks ($\chi^2_3 = 11.00, P=0.01$). However, this model is not significantly better than one with first-year survival set constant over the duration 1976-2000 ($\chi^2_3 = 2.97, P=0.40$). What is very notable from these estimates (see Figure 10.4.1.5) is that, from one block to the next, increases (decreases) in estimated first-year survival accompany decreases (increases) in adult survival.

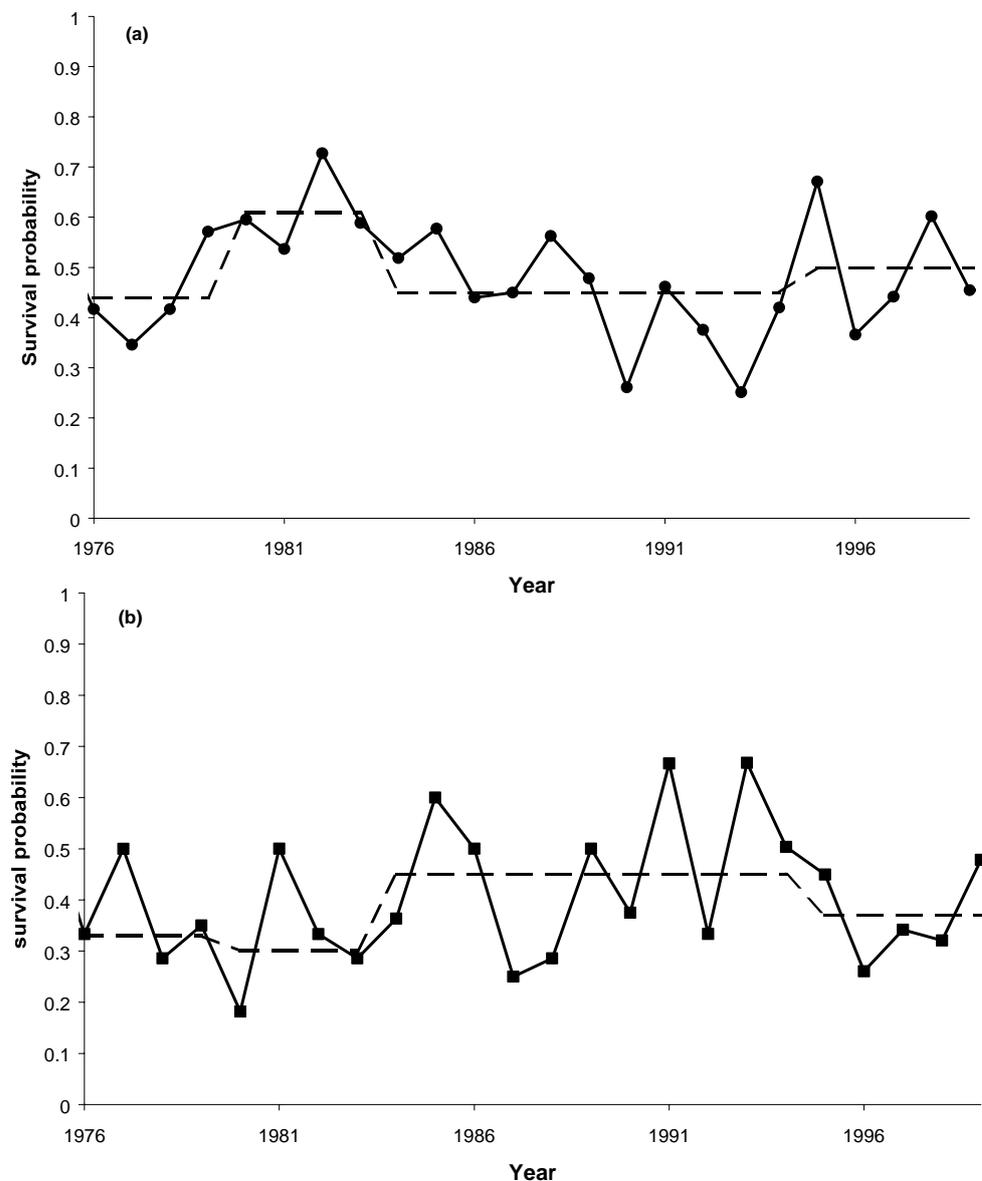


Figure 10.4.1.5 Block estimates of House Sparrow survival rates for (a) Adult and (b) First-year birds.

10.4.2 Population models

House Sparrows were recorded on a total of 241 CBC plots at least once during the period 1976-2000. Annual population indices estimated across all these sites, derived from the model $\{S_i, N_j\}$, are shown in Figure 10.4.2.1 (this is equivalent to the annual GAM models fitted in Chapter 3 in Figure 3.4.2.2). The most striking feature is the pronounced decline between 1979 and 1983, with a subsequent further fall to 1987, both of which are preceded and followed by periods of approximate stability. Imposing a constant annual rate of decline in abundance (on the log scale) significantly worsens the fit ($\chi^2_{23} = 99.16$, $P < 0.01$), which confirms that the population trends change significantly with time. This analysis is a more general method than that used to define significant turning points (Chapter 3) and allows explicit comparison with other models below.

We initially fitted a population model in which all demographic parameters took their most general, fully time-dependent form to the CBC data. The resulting model (Figure 10.4.2.1) shows an unrealistic approximate halving to 1979 (although within the confidence intervals of the $\{S_i, N_j\}$ model), but some resemblance to the indices estimated under the $\{S_i, N_j\}$ model thereafter. We emphasise that the population model is not *fitted* to these indices – rather both sets of annual estimates plotted are obtained from models fitted separately to the individual CBC territory counts. Despite the initial steep decline, the indices under the most general model provide a helpful visual assessment of the quality of each of the demographic models that follow.

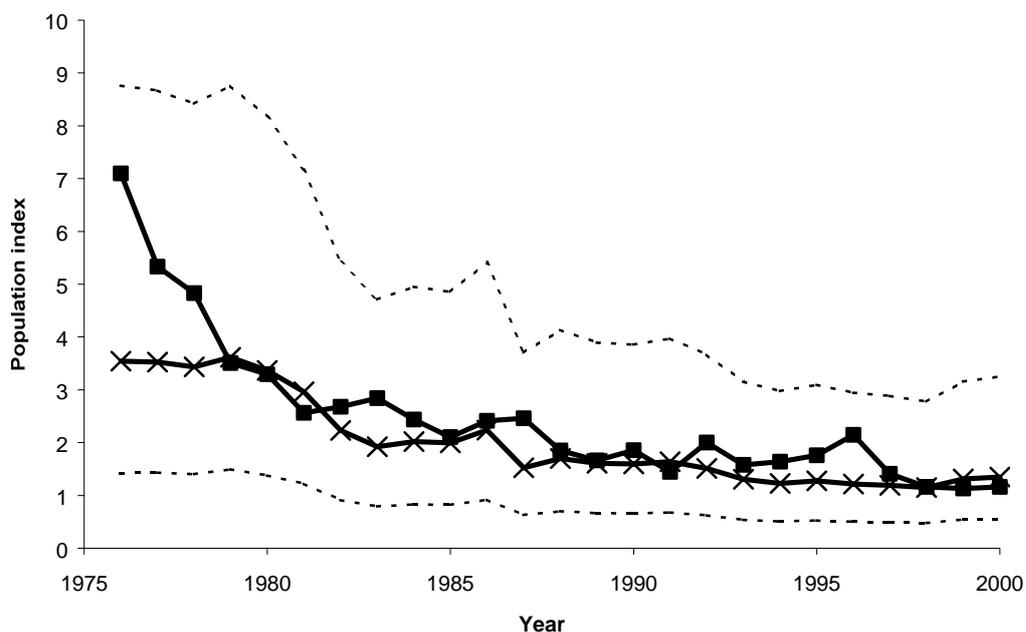


Figure 10.4.2.1 Comparison of a population model (solid line with closed squares) in which all demographic parameters are fully time-dependent, with the general model $\{S_i, N_j\}$ of annual changes in House Sparrow abundance measured by the CBC (solid line with crosses) and its confidence limits (dotted lines).

We then fitted two alternative models (two alternative sets of demographic variables), as follows:

- i) employing single constant values for each of the two survival parameters ϕ_a and ϕ_l , with fully time-dependent productivity rates and
- ii), the converse, in which the nest record variables, alone, were assigned their constant, average values CS , HS , EFR and NFR (Figure 10.4.2.2).

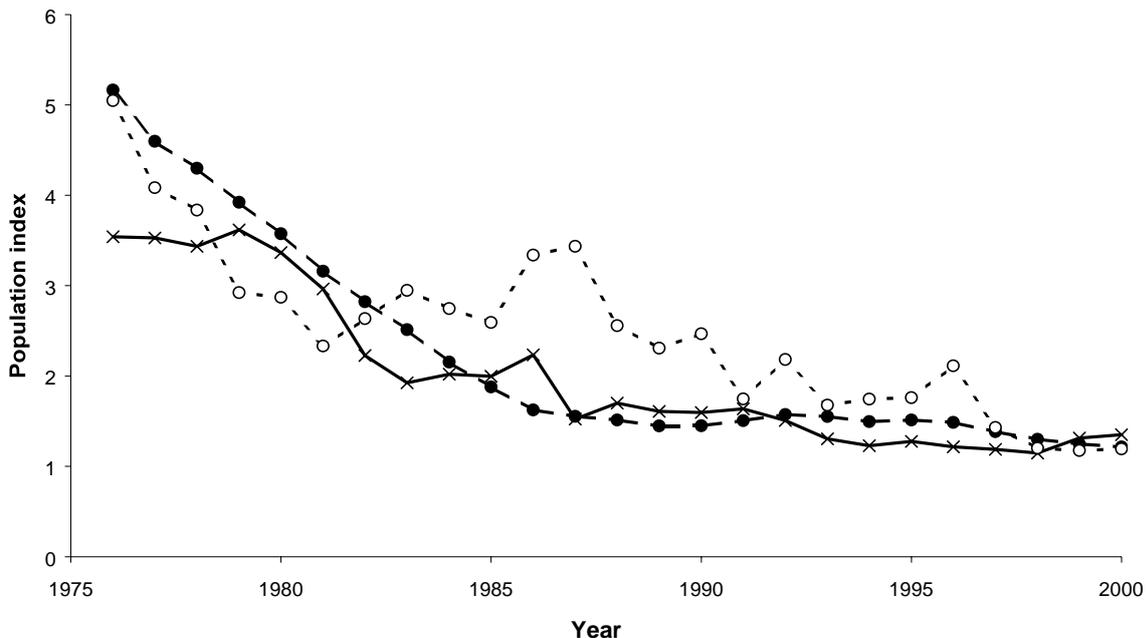


Figure 10.4.2.2 Population models for House Sparrow in which either survival rates (dashed line, filled circles) or productivity (dotted line, open circles) are held constant, in relation to the general $\{S_i, N_j\}$ model of CBC population changes (solid line, crosses).

Setting survival constant substantially reduces the extent of the predicted initial decline but maintains a similar shape, inevitably smoother, thereafter. In particular, it adequately reproduces the period of steep decline after 1979 and subsequent stabilisation. Setting the nest record parameters constant, however, produces a very different shape, with an increase in the early 1980s and a pronounced decline thereafter. This shape is very different to that of the $\{S_i, N_j\}$ model. Log-likelihood values l for the forms with (i) constant survival ($l = 9670.68$) and (ii) constant productivity ($l = 9619.97$) indicate the extent to which the latter provides a considerably worse fit to the CBC data. It follows from (3) that setting both sets of parameters constant simultaneously reduces the model to the simple log-linear time trend model fitted earlier (Figure 10.4.2.3); this model ($l = 9752.07$) fits the data better than either (i) or (ii).

The better fit of the constant survival model, (i) above, than the constant productivity model (ii), implies that changes in survival are not required in the model to produce the observed fluctuations. Productivity per nesting attempt varied in a manner broadly consistent with the fluctuations in the abundance index. Under model (i), the product of the number of breeding attempts and post-fledging survival is estimated to be 0.792, which appears reasonable for a multi-brooded species

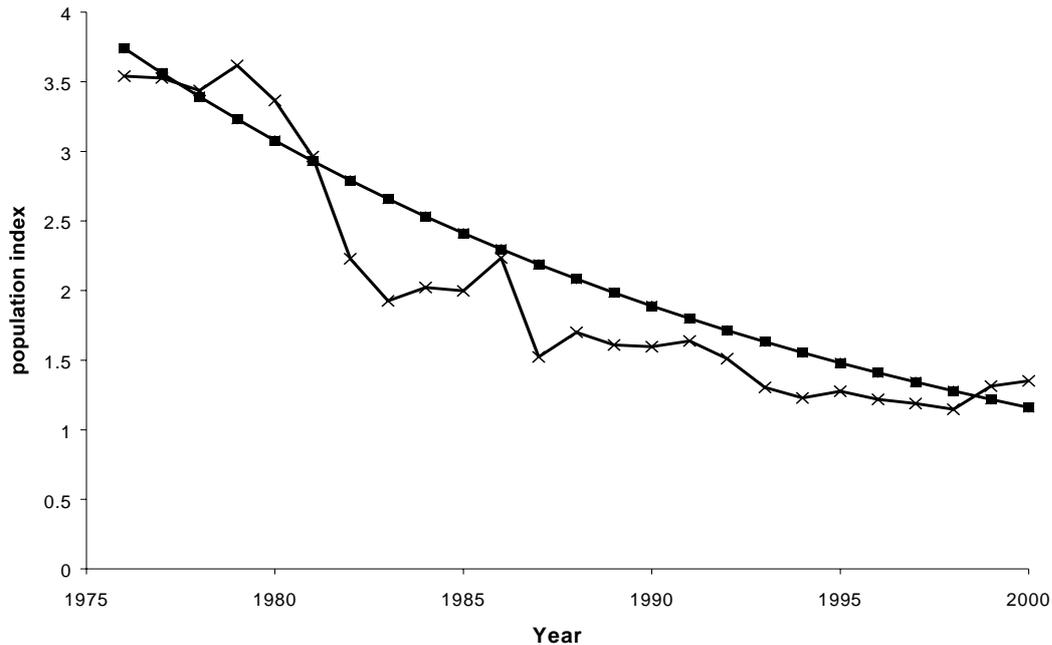


Figure 10.4.2.3 Population model for House Sparrow in which both survival rates and productivity are held constant (solid line, filled squares) in relation to the general $\{S_i, N_j\}$ model of CBC population changes (solid line, crosses).

that can be expected to suffer high post-fledging mortality (see Chapter 8). We therefore assume constant survival in future models, unless otherwise stated.

To investigate which of the various productivity parameters is most influential upon the shape of the model, and the extent to which it changes the goodness of fit to the CBC data, we set each one of the four nest record parameters to be constant in turn, while the remaining three retained their annual variability. Should the good fit be lost on removing variability in one parameter, that is the stage of the breeding cycle most likely to have influenced fluctuations in the population index.

Setting clutch size constant had the least effect, relative to model (i) above ($l = 9659.45$), and, of the four, the best fit was that of the model with nestling stage failure rate (NFR) set constant ($l = 9743.22$). However, examination of the resulting population trajectories (Figure 10.4.2.4) shows that this latter model produces the shallowest decline of all during the early 1980s. The remaining models all contain temporal variation in NFR, and all show a greater decline in the early 1980s and a subsequent levelling. The improvement in fit when NFR is set constant appears to be largely on account of the years at the start of the series, poorly estimated by the alternative models. Thus, although apparently fitting less well than the other models, we conclude that factors affecting the birds at the nestling stage of the reproduction cycle are more likely to have been responsible for the population changes of the species in the 1980s than the other factors. The decline in abundance has since almost abated, but there is as yet no sign of House Sparrow returning to its former numbers, which we estimate were approximately twice as high in the late 1970s as they are today.

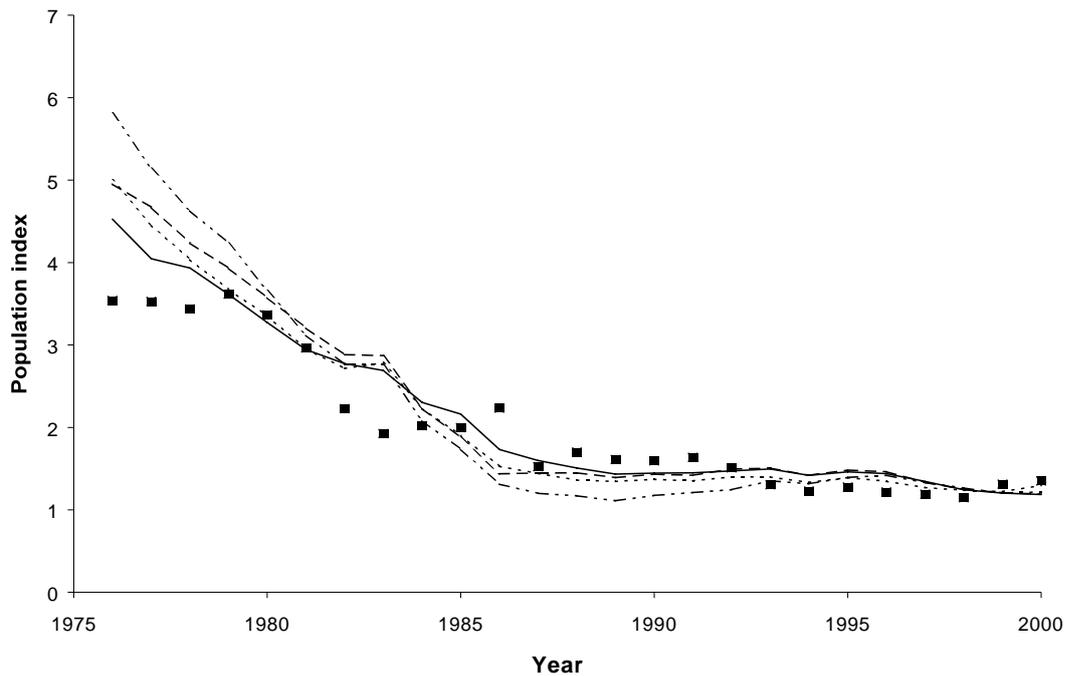


Figure 10.4.2.4 Population models for House Sparrow in which each element of breeding performance is held constant in turn, in relation to the general $\{S_i, N_j\}$ model of CBC population changes (filled squares). The models are: (i) constant nestling-stage failure rate (thin solid line); (ii) constant egg-stage failure rate (dashed line); (iii) constant clutch size (dot-dash line); (iv) constant hatching success (dotted line).

We also considered a suite of models in which each demographic parameter in turn was permitted, in isolation, to change over time while the others were kept constant. Given the sparseness of the ringing data, for this part of the study we used the 'block' survival model estimates, partitioning the time series into four periods determined by turning points in the population abundance trajectory. Under population models based on these block rates, the fitted population is forced to change direction at the same time that the CBC index undergoes significant change, by virtue of the way the blocks are defined and, without variation in productivity, it cannot change direction elsewhere; the direction of this change, however, is determined entirely by the ring recoveries. The resulting population model log-likelihood values are shown in Table 10.4.2.1.

Much the best fit to the CBC data, among those models with varying productivity, was obtained by changing egg-stage failure rates (EFR). However, varying NFR most adequately reproduced the period of steepest decline, and the better fit (in terms of higher maximised log-likelihood values l) of some of the alternative models largely depended on their yielding lower values early in the series (Figure 10.4.2.5). The period of greatest decline under this model, 1983-86, is slightly later than that implied by the $\{S_i, N_j\}$ model, fitted independently of demographic data. However, the model with varying NFR almost exactly matched the scale of the loss, 50%, between 1979 (the highest level in the period) and 1987 (the end of the period of most rapid change). Nonetheless, although permitting clutch size to vary produced little change from the straight-line model, variation in either EFR or hatching success did also produce, to a lesser extent, a steeper decline in the 1980s than subsequently.

Table 10.4.2.1 Maximised log-likelihoods and Pearson Chi-squared goodness of fit statistics for a range of models fitted to British House Sparrow data, in each of which one demographic parameter alone was permitted to vary (i.e. took time-dependent values). Also provided are estimates of \hat{p} , the parameter in the models which accounts for the product of post-fledging survival and the number of broods raised per year, which cannot be measured directly. Figures in parentheses give the difference between the log-likelihood value and that for the best-fitting model for the data, rounded to the nearest integer.

Parameter permitted to vary	\hat{p}	l (data 1976-2000)	Pearson χ^2 (df = 1625)	l (data 1980-2000)	Pearson χ^2 (df = 1459)
First-year survival	0.382	9707.13 (57)	2736.83	8150.74 (40)	2260.78
Adult survival	0.387	9662.70 (101)	2809.41	8133.54 (58)	2263.00
NFR (Chick stage failure rate)	0.381	9750.37 (14)	2609.84	8176.89 (14)	2184.03
EFR (Egg stage failure rate)	0.378	9764.01 (0)	2555.94	8191.07 (0)	2130.39
Clutch Size	0.385	9743.15 (21)	2603.96	8180.23 (11)	2150.65
Hatching Success	0.380	9754.49 (10)	2588.50	8179.66 (11)	2168.84

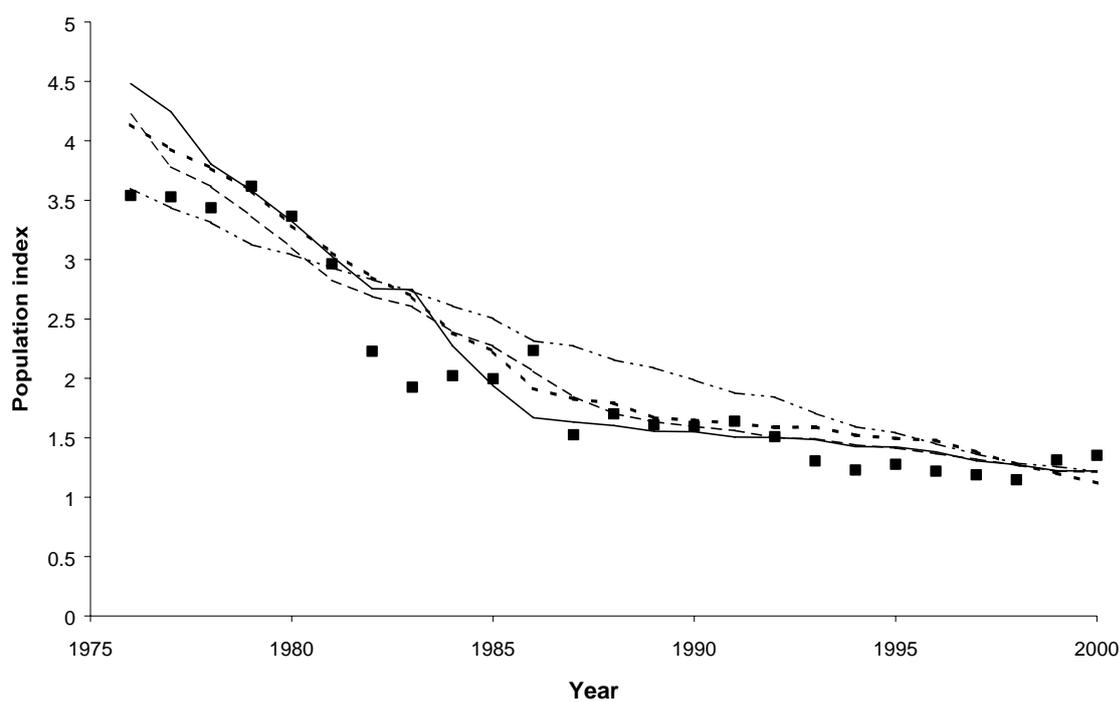


Figure 10.4.2.5 Population models for House Sparrow in which each element of breeding performance varies in turn while all other factors are held constant, in relation to the general $\{S_i, N_j\}$ model of CBC population changes (filled squares). The models are: (i) varying nestling-stage failure rate (thin solid line); (ii) varying egg-stage failure rate (dashed line); (iii) varying clutch size (dot-dash line); (iv) varying hatching success (dotted line).

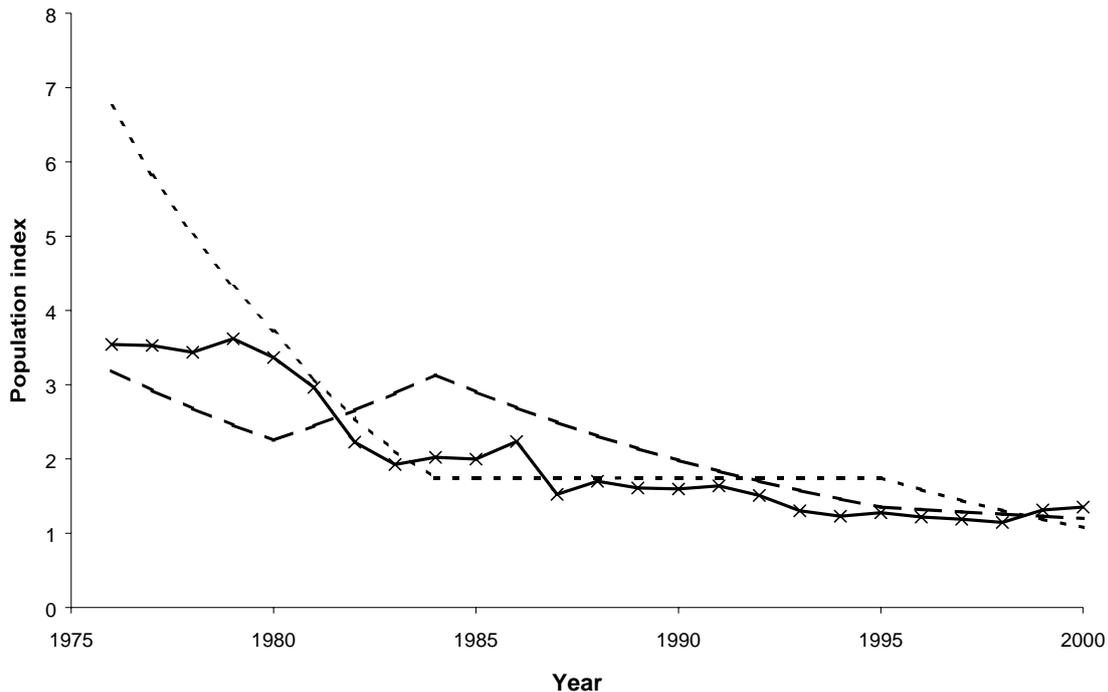


Figure 10.4.2.6 Population models for House Sparrow in which adult survival (dashed line) or first-year survival (dotted line) varies while all other factors are held constant, in relation to the general $\{S_i, N_j\}$ model of CBC population changes (solid line with crosses).

A very much worse fit results from permitting either first-year or adult survival rate to vary, even using the 'block' model, which smooths out some of the extreme annual survival estimates (Figure 10.4.2.6). Variable first-year rates however also produce a decline between 1979 and 1987, the overall quality of the fit deteriorating before and after this period. Even after omitting the years 1976-1979 and refitting the model, these models have considerably lower log-likelihood values than any of the analogous forms in which one of the nest record parameters is permitted to vary (Table 10.4.2.1).

We conclude this section with further consideration of the parameter p , the unmeasured component of our population models that includes post-fledging survival and the numbers of breeding attempts per pair per year. Up to now this has been taken as constant, but in reality it is likely to vary annually as much as any other demographic variable and thereby to affect population fluctuations.

We therefore consider a simple model in which we permit a degree of temporal variation in this parameter. Survival rates were set constant, but clutch size, hatching success, and egg- and chick-stage failure rates were permitted to vary. We fitted this model independently to two halves of the data, for periods 1976 to 87 and 1988 to 2000. The separation of these periods marks the onset of the period of relative stability. The model shows that in the early period, during strong population decline, the estimated value of p was almost 25% higher than in the later period, during population stability (0.456 as opposed to 0.370). This indicates that the period of decline was associated with a combination of higher post-fledging survival and/or larger numbers of breeding attempts per pair per year.

10.5 DISCUSSION

In this chapter, we have attempted to bring together changes in breeding performance and survival in order to illuminate the possible demographic mechanisms behind the population changes of House Sparrow since the mid-1970s. The numbers of nest records and ringing recoveries were sufficient to attempt this national analysis in relation to the CBC population trends, but sample sizes were insufficient to attempt any finer division of the data to investigate habitat- or region-specific population models for this species.

The general patterns of changes in breeding performance show trends towards decreased nest failure rates since the 1970s (Chapter 9). Here we show that adult survival rates tended to rise to a peak in the early 1980s, then fall in the 1980s and early 1990s, before showing some signs of improvement again. Although the survival rates of House Sparrows in their first year of life are measured relatively imprecisely, they show a general trend of improvement from the mid-1970s to early 1990s, before falling back again in the latter half of the 1990s. The analysis of survival rates over blocks of years determined by the turning points in the CBC population trajectory showed that, while there was sufficient precision to detect differences in adult survival between blocks of years, there were insufficient samples to permit this for first-year birds.

The key aim of this population modelling work was to identify a demographic factor that could account for the period of steep population decline observed between 1979 and 1987, preceded and followed by periods of relative stability. As an initial step, it was shown that a model that permitted survival rates to vary while holding breeding performance constant, performed less well than one in which survival was held constant but breeding performance was allowed to vary. This suggested that changes in survival rates are *less* likely to be the demographic mechanism behind the changes in House Sparrow abundance over this period than changes in breeding performance. Although Siriwardena *et al.* (1999) observed that changes in adult survival over this period seemed consistent with a role in driving the population changes, the modelling framework developed here allows a formal comparison of the relative goodness of fit of competing models, which was not available in the former work. It should be noted also that Siriwardena *et al.* (1999) found no correlation between inter-annual changes in survival and changes in abundance on CBC plots, but this might have been due to the relative imprecision with which survival can be estimated (see Figure 10.4.1.3), given the samples sizes available.

Our population models then explored which aspect of breeding performance might be most influential in determining the pattern of population changes observed in the CBC indices. Although variations in hatching success, egg-stage nest failure rates and chick-stage failure rates all produced reasonably close fits to the data, changes in chick-stage failure rates provided a pattern that most closely resembled the steep decline between 1979 and 1987, followed by a levelling off.

Analogous models in which average survival rates, calculated over blocks of years determined by turning points in population trajectory, were allowed to vary showed that adult survival rates produced a relatively poorly performing model (although it is similar in general pattern to the annually varying model of Siriwardena *et al.* 1999). In contrast, the model in which first-year survival was allowed to vary produced a pattern that mimicked the rapid decline in the early 1980s, followed by some population stability, although only a limited resemblance to the measured population changes was apparent in the late 1970s. This should, however, be seen in the context of limited CBC data for those years. Thus, changes in first-year survival must remain a candidate for helping to drive the population changes of House Sparrow over the past 25 years.

While the current modelling framework is an improvement on previous methods, further work could usefully be directed towards improving the precision of the survival models. These could be adapted, for example, to relate survival functionally to weather covariates. If a significant relationship with a biologically reasonable weather factor could be identified, the resulting survival estimates could be

less prone to be extreme values and be more precise, due to the reduction in parameters. A population model based upon them may also then prove less erratic and fit the CBC data better. An advantage of the approach adopted here is that sampling covariances of annual indices are properly accounted for. However, as discussed above, survival rates (and also productivity parameters) are treated in the population models as known constants, rather than as estimates with an associated degree of error. Besbeas *et al.* (2002) combine population data and ringing data into a single, integrated model, thus both accommodating sampling error in the survival parameters and, via the Kalman Filter, permitting a stochastic component the annual abundance indices. A natural extension, to incorporate the raw nest record data too, rather than a set of fixed productivity parameters, into a fully integrated population model is an area of current research.

Finally, the modelling framework was used to investigate whether changes in P , the unmeasured component of demography (i.e. survival immediately following fledging and numbers of breeding attempts per pair), might have been influential in driving population changes for the House Sparrow. The modelling showed that the estimated value of P was higher during the period of population decline (in 1976 to 1987) than in the period of relative stability (1988-1999). This would suggest that either or both of post-fledging survival or numbers of breeding attempts per pair were larger during the declining phase of the population than during the period of subsequent stability. Thus it is unlikely that changes in either of these factors have contributed to the population decline.

We can conclude, therefore, that changes in breeding performance, particularly due to nestling-stage failure rates, are likely to have been influential in driving the observed population changes on CBC plots since the mid-1970s. This confirms the results found in Chapter 9 from the cruder analysis of Nest Record data in relation to block-specific population growth rates. The modelling exercise suggests that we can rule out changes in adult survival and in clutch size, but that changes in failure rates at the egg-stage, in hatching success and in first-year survival might have played a part too.

How can this result be squared with the results of Siriwardena *et al.* (1999), who suggested that changes in survival rates are likely to have driven the decline? The current analysis supersedes that of Siriwardena *et al.* over the period from 1975 to present, because breeding performance data were not available in the former analysis and the newer modelling framework allows formal comparison of the relative goodness-of-fit of competing models. However, Siriwardena *et al.* compared survival rates for two blocks of years covering a longer period: a period between 1962 and 1975, when House Sparrow populations were thought to be relatively stable, and a period between 1976 and 1994 when populations declined on CBC. Although they were able to show that there was a significant fall in survival rates between the two periods, they were constrained to make adult and first-year survival vary in parallel. We have produced separate survival estimates for the period 1965 to 1975. These show that annual first-year survival was 0.53 (s.e. 0.024), compared with 0.30 (s.e. 0.080) in the period of rapid decline from 1980-83; whereas the figures for adult survival were 0.58 (s.e. 0.012) and 0.61 (s.e. 0.040) respectively. Although Figure 10.4.1.5 shows that adult survival fell thereafter to 0.45 (s.e. 0.034), probably explaining the decline observed by Siriwardena *et al.* (1999) in his block model (see above), this fits poorly with the pattern of population change shown by the CBC. Thus, it appears that changes in first-year survival are most likely to have driven the population decline and to have helped partially to halt the decline by increasing in the mid-1980s.

The analysis of Nest Record data in Chapter 9 shows that breeding performance, in terms of fledglings produced per nesting attempt, remained constant through the 1960s and 1970s and only started to rise in the mid 1980s (Figure 9.4.2.1.1). Thus one can conclude that improvements in breeding performance have been important in helping to halt the decline, allowing the population to plateau out at a new lower level. The improvements in breeding performance (and first-year survival) could well be due to a density dependent response to falling House Sparrow numbers, but it is interesting to observe that adult survival rates show little sign of responding in a density dependent manner to declining abundance.

Detailed analysis of the demographic mechanisms behind the population declines of a number of passerines, particularly seed-eating species, in Britain have tended to suggest that changes in survival rates, rather than breeding performance, have driven population declines (reviewed by Siriwardena *et al.* 2000c). Population declines apparently driven by declining breeding performance are relatively uncommon, but have been found for Linnet, where increases in egg-stage failure rates are sufficient to account for its population decline between 1975-1986 (Siriwardena *et al.* 2000a). The existence of different demographic mechanisms affecting the changes in abundance of a species at different periods is an unusual finding, although it has been postulated to explain aspects of the population changes of a few species. Thus, for example, Peach *et al.* (1999) suggested that declines in breeding performance of Reed Buntings *Emberiza schoeniclus* may be holding back population recovery, after an initial decline caused by reduced survival rates.

There are a number of potential factors that might have affected survival rates and breeding performance of House Sparrows, both directly and indirectly. These are discussed more fully in Chapter 12, but briefly they are:

- Declines in invertebrate food for chicks (Summers-Smith 1988, 1999; Bower 1999)
- Declines in food for parents in summer or winter (Summers-Smith 1999; Easterbrook 1999)
- Increased predation of adults by Sparrowhawks (Sanderson 1996)
- Increased levels of pollution in towns (Dott & Brown 2000)
- Increased levels of cat predation (Churcher & Lawton 1987)

Given that first-year survival has not recovered to pre-1975 levels and that adult survival shows little sign of increasing in response to declining population levels, it is likely that the factor(s) that caused the decline in survival, and hence led to population decline, are still depressing House Sparrow population levels. The search for mechanisms to increase the abundance of House Sparrows needs to concentrate on factors affecting first-year and adult survival. In addition, the results of the modelling exercise that suggested that post-fledging survival and/or the numbers of broods (encapsulated by the parameter p in the population models) have declined in recent years, suggests that these, too, might be factors that could be altered to help effect population recovery.

Appendix 10.1 Annual sample sizes of House Sparrow Nest Record Cards contributing to the calculation of nest survival rates.

Year	Egg Stage	Chick Stage
1976	117	101
1977	76	71
1978	84	61
1979	51	66
1980	65	60
1981	37	32
1982	33	21
1983	36	27
1984	45	36
1985	63	45
1986	44	69
1987	37	52
1988	55	53
1989	83	74
1990	50	61
1991	66	65
1992	47	77
1993	46	88
1994	57	67
1995	51	80
1996	100	108
1997	128	141
1998	176	157
1999	43	59

11 NATIONAL SURVEYS OF FARMERS AND LOCAL AUTHORITIES

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Central Science Laboratory, Sand Hutton, York YO41 1LZ.

M^cKay, H., Langton, S., Garthwaite, D., Burnstone, J. & Bishop, J. (2002) National Surveys of Farmers and Local Authorities In H.Q.P. Crick, R.A. Robinson, G.F. Appleton, N.A. Clark & A.D. Rickard (eds) *Investigation into the causes of the decline of Starlings and House Sparrows in Great Britain*. BTO Research Report No 290, pp 213-262. DEFRA, Bristol.

11.1 CHAPTER SUMMARY

1. Questionnaire surveys of 3533 owner/occupiers of agricultural holdings in England, Wales and Scotland, stratified by region and farm type, were carried out in October and June 2001 respectively. The aim was to determine the numbers of Starlings and House Sparrows culled under general licence in the current year, one to five years ago, six to ten years ago and more than ten years ago. Additional information was gathered on the nature, seriousness and extent of perceived problems and the use and effectiveness of lethal and non-lethal control methods.
2. Final response rate was 28% for the owner/occupier survey. The Foot and Mouth outbreak earlier in the year probably reduced returns. Although response rates did not differ between regions and types of farming, large farms were more likely to respond. A sample of owner/occupier non-respondents was contacted to investigate the reasons for not replying.
3. The vast majority of owner/occupier respondents (97%) undertook no lethal control. If respondents are assumed to be representative of non-respondents, 271,000 (53,000–624,000) Starlings and 52,000 (5,000–132,000) House Sparrows are estimated to have been killed in the survey year.
4. Alternatively, if non-respondents are assumed to have killed no Starlings or House Sparrows, 74,000 (17,000–164,000) Starlings and 16,000 (1,000–45,000) House Sparrows are estimated to have been killed in the survey year. Contact with non-respondents supported this alternative assumption. Numbers estimated to have been killed were similar one to five years ago and six to ten years ago, but were higher in the period more than ten years ago.
5. Although culling occurred in all months of the year, control of Starlings was higher in the pre-breeding season and of House Sparrows during the breeding season.
6. In line with current population trends, most owner/occupiers thought Starling and House Sparrow populations had declined. However, there were regional differences; Welsh, and to a lesser extent Scottish, owner/occupiers perceived that the decline was less than respondents in other regions.
7. Neither species appears to be a widespread or serious problem; 3% of owner/occupiers reported Starling damage so severe that farm income was affected (0.5% for House Sparrows). Over ten years ago perceived problems were more widespread, with greater percentages of owner/occupiers reporting damage.

House Sparrow and Starling control

8. There were regional and farm-type differences in the perception of damage. While there was no change in perceived damage in Scotland and Wales, the largest decline in the proportion of farmers reporting damage occurred in the East (East Midlands and East Anglia) and damage rates appear to have declined less on dairy, and cattle and sheep farms, than on other types of farm.
9. Holdings with fodder beet/mangolds, livestock and reseeded grass were more likely to report Starling damage. Holdings with fodder beet/mangolds and sugar beet were more likely to report House Sparrow damage and holdings with spring oilseed rape less likely.
10. The most common problems with Starlings and House Sparrows as reported by owner/occupiers were contamination and consumption of livestock feed, followed by reduced crop yield. This damage was estimated by those reporting it to cost less than £1000 per annum per holding. The most costly damage, however, was consumption of food for human consumption, estimated at £2,100 per annum per holding reporting it.
11. Transmission of *Salmonella* and Foot and Mouth were the most common disease concerns reported by owner/occupiers, and pigs and cattle were considered to be the most threatened species.
12. Non-lethal control techniques were used by 20% of owner-occupiers. The most common methods used were netting of vent flaps, shooting, exclusion nets and auditory bird scarers. Of these, nets appeared to be the most effective and shooting and auditory scarers the least effective. Removal of spilt grain was also moderately effective against House Sparrows.
13. The majority of farms using lethal control also used non-lethal methods.
14. A survey form similar to the one sent to owner-occupiers was sent to all 410 Local Authorities in England, Wales, Scotland and Northern Ireland in June, 2001. The final response rate was 10%.
15. No Local Authorities undertook lethal control.
16. Most Local Authorities thought Starling and House Sparrow populations had declined.
17. Five percent of Local Authorities reported severe Starling problems (affecting budgets). No responding Local Authorities had problems with House Sparrows. Over ten years ago perceived problems were more widespread, with a greater percentage of Local Authorities reporting damage.
18. The most common Local Authority problems were fouling of public areas, concerns over public health and damage to property, estimated at £1000, £750 and £500 per annum per Authority reporting it, respectively. The total national cost of starling damage to Local Authorities was estimated at £159,000 per annum.
19. Non-lethal control techniques were used by 17% of Local Authorities. The most common method used was auditory scaring which was perceived to be partially effective.

11.2 INTRODUCTION

Since January 1993, the British government (DEFRA, formerly MAFF and DETR) have issued general licences under Section 16 of the Wildlife and Countryside Act (1981) for the killing or taking of Starlings *Sturnus vulgaris* and House Sparrows *Passer domesticus* for the purposes of: 'preventing the spread of disease and for preventing serious damage to livestock, foodstuffs for livestock, crops, vegetables, fruit, growing timber, fisheries or inland waters' or for 'protecting any collection of wild birds or preserving public health or public or air safety'. The licences allow any authorised person to kill or take listed species of birds for the above purposes using methods not prohibited by Section 5 of the 1981 Act. 'Killing or taking' includes taking, damaging or destruction of their nests or the taking or destruction of their eggs, where there is no other satisfactory solution. The Wildlife and Countryside Act (1981) defines 'authorised person' as the owner/occupier or any person authorised by the local authority or by listed official bodies. By their nature, general licences generate no data in the form of Licence Returns. Therefore, in order to understand the scale and potential impact of legal control activities on the population declines of Starlings and House Sparrows, a GB-wide questionnaire survey of owners/occupiers was carried out.

Although the primary objective was to estimate the numbers of birds culled under general licence, the opportunity was also taken to gather information on: (a) the seriousness and extent of damage and (b) the effectiveness of methods which have been used to control these species. These secondary objectives are in line with the government's policy on vertebrate control, which aims to develop or encourage the development of cost-effective, humane and environmentally acceptable methods of vertebrate control in order to help balance the concerns of animal welfare and conservation groups on the one hand, with those of farming, land-owning and fishing interests on the other (Policy Requirements Document for the 2001 Vertebrate Control R&D Review, MAFF Land Use Division/Chief Scientists' Group, December 2000).

11.3 OWNER-OCCUPIER SURVEY

11.3.1 Introduction and aim

To estimate the numbers of Starlings and House Sparrows culled over the last year, one to five years ago, six to ten years ago, and over ten years ago, and to collect additional information on: (a) the seriousness and extent of any problems and (b) the use and effectiveness of control techniques.

11.3.2 Methods

11.3.2.1 Pilot survey of land owners/occupiers

In order to pilot the survey a total of twelve farms were contacted, one conducted by face to face interview, the remainder over the telephone. Farms selected for the pilot survey were originally part of the CSL Pesticide Usage Survey Team's 'arable sample'. All holdings were in the Lincolnshire/East Yorkshire area and were those that had either been visited as part of the arable survey or had their visits cancelled because of Foot and Mouth restrictions. Most of the farms had some livestock.

All participants were sent a copy of the draft questionnaire by post after agreeing to take part in the survey. Participants were telephoned two to three days later and the surveyor then went through the questionnaire section by section. Farmers were regularly asked if they understood/were happy with the questions set out on the form.

The average length of time taken was 30-45 minutes, although some calls lasted longer. Few problems were identified with the forms, although additional questions were identified as being

necessary and were later incorporated into the form. The face-to-face interview was done from cold (i.e. the farmer had not previously seen a copy of the form) but no problems were encountered.

11.3.2.2 Full survey

The draft owner/occupier questionnaire form was amended accordingly (Appendix 11.1) and sent to each selected holding between 26 and 31 October, 2001 along with a covering letter explaining the purpose of the survey (Appendix 11.2). Ministerial approval was required prior to the survey being carried out and support was given by the Country Landowners and Business Association (CLA). The National Farmers' Union (NFU) was informed about the survey.

11.3.2.3 Questionnaire form

The questions included in the owner/occupier form (Appendix 11.1) were designed to obtain information on: (a) perceived changes in numbers of Starlings and House Sparrows (Question 6), (b) the seriousness and extent of any problem (Questions 4 and 5), (c) the numbers killed and time of year (Questions 8 and 9) and (d) control techniques used and whether they were thought to be effective (Question 7). In addition, questions were asked on farm type changes, crop areas and livestock type and numbers which were not available from the DEFRA June Census (Questions 1, 2 and 3). As far as possible, information was requested relating to four time periods: currently, one to five years ago, six to ten years ago and over ten years ago. Responses for 'over ten years ago' were assumed to include the period prior to population declines, as it was not considered reasonable to ask questions on the control of birds 25 years previously.

11.3.2.4 Sample

A sample of agricultural holdings was selected, stratified by seven regions (North, East/East Midlands, South East, South West, West Midlands/North West, Scotland and Wales) and eight farm types (cereals, general cropping, horticulture, pigs/poultry, dairy, cattle/sheep, mixed and other (a mixture of specialised farm sub-types)). With an estimated response rate of 30-50%, a sample size of 3,500 farms was thought to be required, based on a national survey of badger damage undertaken in 1997 (Moore *et al.* 1998).

11.3.2.5 Non-respondents

Approximately 3% (110) of the owner/occupier non-respondents were contacted from January 2002 onwards. Numbers contacted per region and farm type were calculated from the numbers of non-respondents for those categories. Individual names and addresses were then selected at random and telephone numbers found using BT's commercially available CD-ROM. Non-respondents were telephoned and asked a series of directed questions. The intention was to discover the reason for their lack of response and whether they had any problems with Starlings or House Sparrows. If they did report a problem they were then asked if they carried out any lethal control of these birds. Once this initial sample of non-respondents had been contacted, a separate sample consisting of all farms over 500 ha in size was selected (32 farms in total), as statistical analysis had revealed these holdings were most likely to have controlled Starlings or House Sparrows. We were able to contact 18 of these farms and ask similar questions.

11.3.2.6 DEFRA and Scottish Executive June census data

In order to examine relationships between bird problems and crop or livestock factors, additional data were obtained relating to the four time periods described above:

Time period	June Census data
Current	2000
1-5 years ago	1997
6-10 years ago	1992
over 10 years ago	1987 (1989 for Scotland)

The data for June 2000 were the most recent available at the time. The data categories relating to the period over ten years ago differed from recent years, and it was decided that 1987 (and 1989 for Scotland) were the most reliable and accessible data to use.

The data requested (on an individual farm basis, rather than summary statistics) were: farm area, main farming enterprise, crop areas (wheat, spring and winter barley, spring and winter rape, linseed and flax, root crops, maize, top fruit, soft fruit, field vegetables), grassland areas (permanent and re-seeded), woodland area, set-aside area, fallow area and livestock numbers (pigs, poultry, cattle and sheep).

11.3.2.7 Statistical analysis

The number of birds killed were initially estimated using the standard analysis for a stratified random sample (see for example, Cochran 1977), in order to produce a countrywide estimate, weighting for the different sampling and response rates in the different strata. However, due to the extremely skewed nature of the data, with many zeros and a few large values, it was suspected that the asymptotic standard errors from this analysis would not produce reliable confidence limits and so a bootstrapping approach (Manley 1991) was adopted. A further problem was that response rate was related to farm size, even within a stratum, and so the bootstrapped results were adjusted for this. This was done using π -estimators, adjusted by a non-response adjustment (Särndal *et al.* 1992) derived from a logistic regression model. Bootstrapping followed the method described in Särndal *et al.* (1992), resampling with replacement independently within each stratum.

All other tables of means and percentages are presented unweighted and so relate only to responding farms and not GB farms as a whole. In practice, since sampling was approximately in proportion to the stratum sizes, these results will not differ substantially from the results that would have been obtained from the stratified sampling analysis.

Relationships between the survey results and other variables were examined using a modelling approach, without adjustment for the finite nature of the population. Where data were essentially binary in nature (e.g. presence or absence of a problem) analysis was by logistic regression (Collett 1991). Where data were available for different time periods, mixed models (generalised linear mixed model or GLMM, Breslow and Clayton 1993) were used so that all years could be incorporated into a single model for each species, allowing for correlation of results between years. For the analysis relating the problem to crop and livestock factors, crop areas were found to be highly skewed (there were a large number of zeros), and so these data were fitted as the presence/absence of dummy variables.

The data on estimated declines in the numbers of Starlings and House Sparrows were converted to a numerical score and analysed by analysis of variance; whilst the normality assumption of ANOVA will not be exactly met by this approach, the large sample sizes should ensure that the F-statistics are approximately correct.

11.3.3 Results

11.3.3.1 Response rates

By 17 January, 2002, 984 owner/occupier forms had been returned and data checking completed. Further responses could not be included in the analyses, but were added to the record of non-respondents' comments. Finally, 980 forms were found to be usefully completed, giving an overall response rate of 28.0% (after 34 forms returned undelivered were taken into account). Response rates broken down by farm type and region are shown in Table 11.3.3.1.1.

Response rates did not vary significantly by region ($\chi^2 = 4.52$, 6 d.f., $P=0.61$) or by farm type ($\chi^2 = 7.73$ with 7 d.f., $P=0.36$), but total farm area did have an effect, with the relationship varying by farm type (type \times logarea interaction $\chi^2 = 33.68$, 7 d.f., $P<0.001$). This is illustrated in Table 11.3.3.1.2 which shows that larger farms tended to be more likely to respond in general (the usual pattern in agricultural surveys) but this trend is reversed in the 'pigs and poultry' and 'other' categories.

Table 11.3.3.1.1 Response rates by farm type and region.

a) percent response:

Farm type:	Cereals	General	Hort.	Pigs & Poultry	Dairy	Cattle & Sheep	Mixed	Other	All
Region:									
NE	26.8	30.0	32.5	23.0	30.0	25.0	25.0	20.0	26.3
East	33.1	34.2	24.2	31.6	30.4	23.8	31.9	30.4	31.0
SE	32.6	32.5	32.5	27.9	31.7	19.5	27.3	27.9	29.4
SW	37.0	35.0	38.4	35.3	24.5	31.3	23.2	20.5	29.6
NW	22.0	17.1	21.1	23.6	30.4	23.4	26.4	32.8	25.5
Wales	34.1	9.8	39.0	34.1	20.3	22.3	29.3	22.0	25.5
Scotland	25.9	24.7	41.0	25.8	30.0	20.6	24.3	24.2	25.6
All	30.8	28.2	31.1	28.7	27.7	23.5	26.5	25.3	27.7

b) standard errors:

Farm type:	Cereals	General	Hort.	Pigs & Poultry	Dairy	Cattle & Sheep	Mixed	Other	All
Region:									
NE	5.9	7.2	7.4	5.4	7.2	6.8	5.6	6.3	2.3
East	3.8	3.7	4.5	4.8	6.8	6.6	5.6	6.8	1.7
SE	6.9	7.4	5.2	6.8	7.3	6.2	6.7	6.8	2.3
SW	7.1	7.5	5.7	5.8	4.3	5.8	4.7	4.7	1.9
NW	6.5	5.9	4.7	5.0	4.3	5.3	5.2	5.7	1.9
Wales	7.4	4.6	7.6	7.4	5.0	4.3	7.1	6.5	2.2
Scotland	5.7	4.9	7.9	5.6	7.2	4.1	5.0	3.7	1.8
All	2.2	2.1	2.2	2.2	2.1	2.0	2.1	2.1	0.8

Table 11.3.3.1.2 Response rates by total farm area and farm type (given as %).

Area	<1ha	1 - 10 ha	11 - 100 ha	100ha +
Farm type:				
Cereals	20.0	17.4	29.9	33.7
General	*	6.5	29.3	32.0
Horticulture	26.2	33.6	27.6	*
Pigs & Poultry	33.9	26.7	29.9	31.3
Dairy	*	0.0	27.1	32.1
Cattle & Sheep	23.5	18.7	24.8	25.0
Mixed	*	15.4	23.1	34.1
Other	33.3	26.0	18.1	*

* indicates less than ten holdings in group.

11.3.3.2 Non-respondents

Individual responses cannot be detailed, as covering letters stated that replies would be treated in the strictest confidence and it would be assumed that this applied to non-respondents' comments as well.

Of the initial sample of 3% of owner/occupier non-respondents contacted, only one had undertaken control and this had not been lethal. Seventy-four percent of non-respondents reported having no problems at all and 4% had problems. The remaining 23% either didn't know or wouldn't say whether these birds were a problem. Eleven percent claimed never to have seen the form or did not remember it. Ten percent remembered the form but did not return it, several reasons being given including having no problems and having too many forms to fill in. Many were vague about whether or not they had received the form. One individual said he had returned it and three declined to answer any questions. Of the large farm sample, 17 of the 18 contacted reported having no problems. One had minor problems with Starlings, but did not cull them.

11.3.3.3 Numbers culled

Thirty-two owner/occupiers (3.3%) reported the use of lethal techniques against Starlings and 15 (1.5%) against House Sparrows. The proportion of holdings undertaking lethal control was investigated using a logistic regression model. A generalised linear mixed model (or GLMM) was used so that all years could be incorporated in a single analysis for each species whilst allowing for the correlation in results between years. Terms for farm type, region, a linear temporal trend and a linear effect of log-transformed farm size were fitted. Interactions and other more complex terms were not fitted, as the low number of positive responses would have made it impossible to provide sensible estimates.

Results are shown in Table 11.3.3.3.1. The most notable effect is that the use of lethal control for Starling is strongly associated with farm size. Various other effects are of borderline significance, including the temporal trend for House Sparrow, but these results should be treated with caution, given the low number of positive responses.

Table 11.3.3.3.1 Results of logistic regression models for the presence of lethal control.**a) Starling**

Term	χ^2	d.f.	P
logarea	18.19	1	< 0.001
Region	7.66	6	0.264
Farm type	13.87	7	0.054
Linear effect of year	0.01	1	0.943

b) House Sparrow

Term	χ^2	d.f.	P
logarea	3.90	1	0.048
Region	10.52	6	0.104
Farm Type	7.77	7	0.353
Linear effect of year	4.59	1	0.032

Table 11.3.3.3.2 shows the relationship between holding area and the presence of lethal control at any time (i.e. in any of the four periods). Note the higher proportion of farms over 100 ha using lethal control. Interestingly the three farms less than 5 ha using lethal control for Starlings all have large numbers of pigs or poultry, so they are large in economic terms. One of the holdings using lethal control for House Sparrows is a genuine small holding, but it only reports a few killed many years ago.

Table 11.3.3.3.2 Size distribution of holdings tabulated according to whether they have used lethal control.

	Lethal control - Starling			Lethal control - House Sparrow			All holdings
	No	Yes	% yes	No	Yes	% yes	
Total area							
< 5 ha	229	3	1	230	2	1	232
5 - 20 ha	156	1	1	157	0	0	157
20-100 ha	331	11	3	337	5	1	342
100 ha +	232	17	7	241	8	3	249
All	948	32	3.3	965	15	2	980

Table 11.3.3.3.2 shows that the vast majority (97%) of owner/occupier respondents reported that no lethal control of Starlings or House Sparrows had been undertaken on their holdings. However, on the 16 holdings undertaking lethal control which were able to provide information on the numbers of Starling killed in the current year, the numbers were quite high (1,185), resulting in an extreme skew to the data. Similarly for House Sparrows: a total of 320 birds were killed on the seven holdings able to estimate numbers.

Table 11.3.3.3.3 gives estimates of numbers killed in each of the time periods, assuming respondents to the survey are representative of all farms in Great Britain. Using this method, currently about 270,000 Starlings and 50,000 House Sparrows are estimated to be killed per annum in Great Britain under General Licence. The confidence limits are very wide, and this is mainly due to the lower than expected response rate, coupled with the skew to the data. These numbers appear not to have changed markedly over the last ten years but, prior to this, numbers killed were greater (329,000 Starlings and

112,000 House Sparrows per year). Due to the small number of holdings reporting lethal control, it was not possible to analyse numbers killed by region or farm type.

Table 11.3.3.3 Point estimates of numbers of birds killed with associated standard errors and 95% confidence limits calculated using bootstrapping. Results are adjusted for the relationship between non-response and farm size and are shown in thousands.

'000s killed	Starling				House Sparrow			
	Current	1-5 yrs	6-10 yrs	>10 yrs	Current	1-5 yrs	6-10 yrs	>10 yrs
Estimate	271	267	266	329	52	59	49	112
s.e.	157	154	154	163	35	35	34	53
Lower 95%	53	59	64	88	5	9	4	26
Upper 95%	624	620	619	710	132	140	125	232

11.3.3.4 Numbers killed, assuming non-respondents culled none

It is possible that the non-respondents were not a random subset of the holdings sampled, but were instead mainly those who discarded the form because they had no Starling or House Sparrow problems. Although it is impossible to judge to what extent this is the case, the telephone contact with non-respondents suggests this is a reasonable assumption. We can arrive at an alternative estimate by assuming that no House Sparrows or Starlings were killed on any of the non-responding farms.

From the 980 responding farms there were a total of 1,185 Starlings killed, an average of about 1.2 per farm. On the other hand, if we assume that no Starlings were killed on the non-responding farms we have an average killed per farm of 0.34. The figures given in Table 11.3.3.4.1 are the bootstrapped estimates of the numbers killed in Great Britain, and their confidence limits.

Table 11.3.3.4.1 Point estimates of numbers of birds killed with associated standard errors and 95% confidence limits calculated using bootstrapping. Results are adjusted for the relationship between non-response and farm size and are shown in thousands.

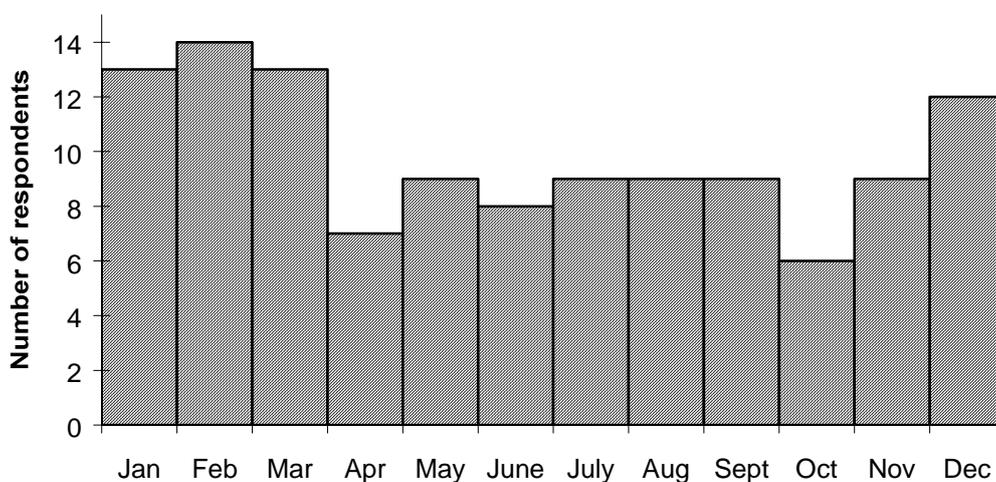
'000s killed	Starling				House Sparrow			
	Current	1-5 yrs	6-10 yrs	>10 yrs	Current	1-5 yrs	6-10 yrs	>10 yrs
Estimate	74	71	70	86	16	19	15	37
s.e.	40	39	38	41	12	12	10	19
Lower 95%	17	17	20	26	1	2	1	6
Upper 95%	164	162	156	177	45	48	39	80

11.3.3.5 The timing of control

The time of the year in which lethal control is undertaken is important when considering its effect on the population. Responses were therefore tabulated by month or implied month of control (e.g. 'winter months' were taken to be December through February) and Figure 11.3.3.5.1 shows the number of respondents reporting lethal control for each month. However, these results should be treated with caution due to the low number and generality of responses.

Lethal control of both species occurred in all months of the year. Starling control tended to be concentrated from December through March, whereas House Sparrow control tended to be shifted more towards the breeding season (March through May).

(a) Starling (32 respondents)



(b) House Sparrow (14 respondents)

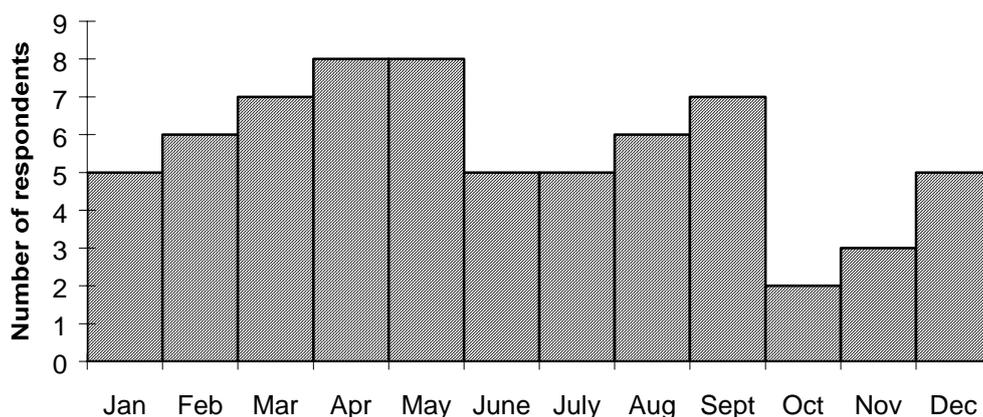


Figure 11.3.3.5.1 The number of owner/occupier respondents reporting lethal control of: (a) Starling and (b) House Sparrow, in each month of the year. Note that not all of these respondents were able to specify the numbers killed.

11.3.3.6 Perception of change in numbers

Table 11.3.3.6.1 shows the changes in numbers of Starling and House Sparrows as perceived by owner/occupiers. Only 11% consider numbers of either species to have increased either significantly or slightly on their holding. In contrast, 29% thought Starlings had decreased significantly and 31% thought House Sparrows had decreased significantly.

Table 11.3.3.6.1 Perceived changes in numbers on holdings over the last ten years. Blank replies are excluded.

	Starling			House Sparrow		
	n	%	s.e.	n	%	s.e.
Increased significantly	47	5.3	0.75	26	3.0	0.58
Increased slightly	49	5.5	0.76	73	8.5	0.95
Remained the same	251	28.2	1.51	238	27.6	1.52
Decreased slightly	184	20.7	1.36	164	19.0	1.34
Decreased significantly	259	29.1	1.52	269	31.2	1.58
Don't know	101	11.3	1.06	92	10.7	1.05
All	891	100.0		862	100.0	

Table 11.3.3.6.2 shows the responses to this question for each species separately. There is a high correlation between replies. Note how many are in the shaded diagonal, indicating the same reply for both species.

Table 11.3.3.6.2 Cross-tabulation of changes in numbers for Starling and House Sparrow. Blank replies for either species are excluded. Categories as in Table 11.3.3.6.1.

House Sparrows	IS	ISL	SM	DSL	DS	DK
Starlings						
IS	11	9	10	4	1	3
ISL	4	15	9	7	9	0
SM	7	21	147	31	32	3
DSL	2	13	22	78	61	2
DS	1	7	39	39	161	4
DK	0	6	5	3	4	80

To test for differences between regions, farm types and farm areas, the above categorical data were converted into a score ranging from +2 for 'increased significantly' to -2 for 'decreased significantly' and analysed by regression. Only regional differences are significant ($F=9.66$ with 6 and 783 d.f., $P<0.001$ for Starling, $F=12.07$ with 6 and 763 d.f., $P<0.001$ for House Sparrow), mainly due to the scores for Wales and, to a lesser extent, Scotland being higher (i.e. respondents in these regions thought the decline was less than those from other regions; Table 11.3.3.6.3).

The relationship between the perception of changes in numbers and whether or not owners/occupiers controlled Starlings or House Sparrows was examined (Table 11.3.3.6.4). As expected, respondents who undertook no control were more likely to believe Starlings had decreased significantly and respondents who undertook lethal control were more likely to believe Starlings had increased on their holding (ANOVA on scores, $F= 9.27$ with 3 and 786 d.f., $P<0.001$). In contrast, there was no significant relationship for House Sparrow ($F = 1.67$ with 3 and 766 d.f., $P=0.173$). This may reflect the small number of farms using House Sparrow control, resulting in low power for the test.

Table 11.3.3.6.3 Perception of changes in numbers of Starling and House Sparrow on owner/occupier respondents' holdings. Figures are mean scores by region. Scores were calculated as 'increased significantly' = 2 down to 'decreased significantly' = -2.

Region	Starling		House Sparrow	
	Mean	s.e.	Mean	s.e.
NE	-0.44	0.13	-0.70	0.12
East	-0.90	0.08	-1.09	0.08
SE	-1.05	0.12	-1.17	0.12
SW	-0.82	0.10	-0.55	0.10
NW	-0.97	0.11	-0.89	0.11
Wales	-0.18	0.13	-0.17	0.13
Scotland	-0.29	0.11	-0.36	0.10

Table 11.3.3.6.4 Changes in numbers tabulated against type of control. Categories as in Table 11.3.3.6.1. Mean scores were calculated as 'increased significantly' = 2 down to 'decreased significantly' = -2.

a) Starling

Change in numbers type	IS	ISL	SM	DSL	DS	DK	Mean score
No control	25	34	223	162	227	98	-0.793
Non-lethal	13	7	19	11	20	3	-0.257
Lethal	5	3	3	4	4	0	0.053
Both	4	5	6	7	8	0	-0.333
All	47 5%	49 5%	251 28%	184 21%	259 29%	101 11%	-0.721

b) House Sparrow

Change in numbers type	IS	ISL	SM	DSL	DS	DK	Mean score
No control	20	61	218	146	247	90	-0.779
Non-lethal	4	8	17	13	15	2	-0.474
Lethal	1	2	2	3	4	0	-0.583
Both	1	2	1	2	3	0	-0.444
All	26 3%	73 8%	238 28%	164 19%	269 31%	92 11%	-0.755

11.3.3.7 The seriousness and extent of perceived problems

(N.B. The nature of the perceived problems are discussed below in section 11.3.3.9)

In the owners/occupiers survey, 85% of respondents reported no current problems (no damage) with Starlings and 87% no problems with House Sparrows (Table 11.3.3.7.1). The percentages reporting moderate problems (damage, but can usually be tolerated) were 12% for both Starlings and House Sparrows. Only a small number of holdings (3% for Starling and 0.5% for House Sparrow) reported

damage so severe that farm income was affected. Of the 27 holdings reporting severe damage by Starlings, ten are using lethal control, as is one of the four holdings reporting severe House Sparrow damage.

Table 11.3.3.7.1 Numbers of holdings reporting no, moderate or severe problems, together with percentages and standard errors of the percentages.

a) Starling

	Current			1-5 years ago			6-10 years ago			Over 10 years ago		
	n	%	s.e.	n	%	s.e.	n	%	s.e.	n	%	s.e.
Damage												
No	751	85.0	1.20	675	81.4	1.35	621	77.8	1.47	608	75.1	1.52
Mod	106	12.0	1.09	126	15.2	1.25	157	19.7	1.41	164	20.2	1.41
Severe	27	3.1	0.58	28	3.4	0.63	20	2.5	0.55	38	4.7	0.74
All	884	100.0	0.00	829	100.0	0.00	798	100.0	0.00	810	100.0	0.00

b) House Sparrow

	Current			1-5 years ago			6-10 years ago			Over 10 years ago		
	n	%	s.e.	n	%	s.e.	n	%	s.e.	n	%	s.e.
Damage												
No	749	87.4	1.13	673	84.9	1.27	624	81.5	1.40	606	77.4	1.49
Mod	104	12.1	1.12	117	14.8	1.26	136	17.8	1.38	162	20.7	1.45
Severe	4	0.5	0.23	3	0.4	0.22	6	0.8	0.32	15	1.9	0.49
All	857	100.0	0.00	793	100.0	0.00	766	100.0	0.00	783	100.0	0.00

The percentage of holdings reporting serious damage appears to have declined in recent years. This was analysed further by means of a mixed logistic regression model. This combines years in order to analyse the proportion of holdings reporting damage over time. With both species the year to year differences are highly significant and show an interaction with region, particularly for House Sparrow (region \times year $\chi^2 = 33.18$, 18 d.f., $P=0.016$ for Starlings and $\chi^2 = 532.08$ with 18 d.f., $P<0.001$ for House Sparrows). This indicates that damage rates change differently over time in different regions, the most notable effect being a big decline in the proportion of farmers reporting damage in the East (East Midlands and East Anglia, Table 11.3.3.7.2).

Table 11.3.3.7.2 Proportion of farms reporting damage (moderate or serious) by year and region.**a) Starling**

	Current			1-5 years ago			6-10 years ago			Over 10 years ago		
	n	%	s.e.	n	%	s.e.	n	%	s.e.	n	%	s.e.
NE	91	19.8	4.18	85	21.2	4.43	85	21.2	4.43	88	26.1	4.68
East	195	15.4	2.58	187	18.2	2.82	183	28.4	3.33	189	38.1	3.53
SE	99	12.1	3.28	96	20.8	4.14	92	21.7	4.30	93	23.7	4.41
SW	145	6.2	2.00	139	10.8	2.63	131	12.2	2.86	131	13.0	2.94
NW	129	12.4	2.90	119	16.8	3.43	113	22.1	3.90	113	23.0	3.96
Wales	90	20.0	4.22	79	26.6	4.97	75	25.3	5.02	75	22.7	4.83
Scotland	135	22.2	3.58	124	21.0	3.66	119	22.7	3.84	121	20.7	3.68
All	884	15.0	1.20	829	18.6	1.35	798	22.2	1.47	810	24.9	1.52

b) House Sparrow

	Current			1-5 years ago			6-10 years ago			Over 10 years ago		
	n	%	s.e.	n	%	s.e.	n	%	s.e.	n	%	s.e.
NE	92	10.9	3.25	86	11.6	3.46	85	11.8	3.49	87	18.4	4.15
East	188	15.4	2.63	180	20.6	3.01	174	32.2	3.54	184	42.4	3.64
SE	96	7.3	2.65	91	9.9	3.13	88	15.9	3.90	90	21.1	4.30
SW	141	5.0	1.83	128	6.2	2.14	123	6.5	2.22	124	6.5	2.21
NW	125	11.2	2.82	116	14.7	3.28	110	16.4	3.53	109	22.0	3.97
Wales	85	16.5	4.02	75	18.7	4.50	72	16.7	4.39	73	13.7	4.02
Scotland	130	20.8	3.56	117	21.4	3.79	114	21.1	3.82	116	19.0	3.64
All	857	12.6	1.13	793	15.1	1.27	766	18.5	1.40	783	22.6	1.49

There are also significant differences between farm types in the proportion reporting damage ($\chi^2 = 23.14$, 7 d.f., $P=0.002$ for Starlings and $\chi^2 = 35.74$, 7 d.f., $P<0.001$ for House Sparrows). In the case of Starling, these effects do not appear to vary with time ($\chi^2 = 13.18$, 21 d.f., $P=0.90$), but for House Sparrow there is an interaction ($\chi^2 = 54.46$, 21 d.f., $P<0.001$). The most obvious feature of these data is that House Sparrow damage rates seem to have declined less on dairy and on cattle & sheep farms (Table 11.3.3.7.3).

Table 11.3.3.7.3 Proportion of farms reporting damage (moderate or serious) by year and farm type.**a) Starling**

	Current			1-5 years ago			6-10 years ago			Over 10 years ago		
	n	%	s.e.	n	%	s.e.	n	%	s.e.	n	%	s.e.
Cereals	125	13.6	3.07	117	13.7	3.18	116	21.6	3.82	113	26.5	4.15
General	112	21.4	3.88	112	21.4	3.88	111	28.8	4.30	112	35.7	4.53
Hort.	121	2.5	1.41	112	8.0	2.57	105	8.6	2.73	112	14.3	3.31
Pigs & Poultry	108	17.6	3.66	105	21.0	3.97	98	23.5	4.28	99	24.2	4.31
Dairy	120	20.0	3.65	116	24.1	3.97	113	23.9	4.01	113	26.5	4.15
Cattle & Sheep	98	15.3	3.64	86	17.4	4.09	83	18.1	4.22	83	16.9	4.11
Mixed	110	24.5	4.10	103	34.0	4.67	100	40.0	4.90	101	41.6	4.90
Other	90	4.4	2.17	78	6.4	2.77	72	8.3	3.26	77	7.8	3.05
Total	884	15.0	1.20	829	18.6	1.35	798	22.2	1.47	810	24.9	1.52

b) House Sparrow

	Current			1-5 years ago			6-10 years ago			Over 10 years ago		
	n	%	s.e.	n	%	s.e.	n	%	s.e.	n	%	s.e.
Cereals	121	13.2	3.08	114	17.5	3.56	114	26.3	4.12	113	35.4	4.50
General	115	21.7	3.85	112	24.1	4.04	110	24.5	4.10	113	32.7	4.41
Hort.	122	3.3	1.61	110	4.5	1.99	103	8.7	2.78	109	12.8	3.20
Pigs & Poultry	104	10.6	3.02	98	13.3	3.43	91	14.3	3.67	97	21.6	4.18
Dairy	112	14.3	3.31	108	13.9	3.33	105	15.2	3.51	105	17.1	3.68
Cattle & Sheep	92	10.9	3.25	77	13.0	3.83	77	16.9	4.27	75	13.3	3.93
Mixed	106	18.9	3.80	100	25.0	4.33	98	30.6	4.66	97	32.0	4.73
Other	85	7.1	2.78	74	6.8	2.92	68	5.9	2.85	74	8.1	3.17
Total	857	12.6	1.13	793	15.1	1.27	766	18.5	1.40	783	22.6	1.49

A slight note of caution is perhaps necessary regarding these data. In common with the responses to the question on changes in numbers, there is quite a high correlation (0.53) between the House Sparrow and Starling responses.

11.3.3.8 Relationship between the presence of a problem and crop areas and livestock numbers

For this analysis, respondents reporting “moderate” and “serious” problems were combined, as there were few of the latter. Table 11.3.3.8.1 shows the odds ratio for each crop or livestock factor (larger values indicate that holdings with these crops or livestock are more likely to report damage). Holdings with fodder beet/mangolds, indoor pigs, cattle, sheep and reseeded grass appear more likely to report starling damage, in that order. Holdings with fodder beet/mangolds and sugar beet are more likely to report house sparrow damage, in that order, and holdings with spring oilseed rape are less likely to report house sparrow damage.

Table 11.3.3.8.1 Relationships between reported problems and crops/livestock. Results shown are deviance tests for adding each crop (as a presence/absence dummy variable) to a logistic regression model with region and log area fitted. Significant results are highlighted in bold. 'Odds' is the odds ratio – for example the value of 5.26 for fodder beet means that holdings with fodder beet are more than five times as likely to report damage, after allowing for the effects of log area and region.

Crop	Starling				House Sparrow			
	Odds	χ^2	d.f.	P	Odds	χ^2	d.f.	P
All wheat	1.03	0.02	1	0.895	1.31	0.92	1	0.338
Spring wheat	1.16	0.18	1	0.672	1.87	3.00	1	0.082
Spring barley	1.53	3.07	1	0.080	1.49	2.26	1	0.133
Winter barley	1.07	0.08	1	0.779	0.76	1.00	1	0.316
Oilseed spring	0.43	2.18	1	0.140	0.19	4.35	1	0.037
Oilseed winter	0.62	2.69	1	0.101	0.79	0.53	1	0.468
Linseed	0.38	2.98	1	0.084	0.32	3.19	1	0.074
Maize	1.09	0.04	1	0.839	0.94	0.02	1	0.893
Potatoes	1.48	2.04	1	0.153	1.46	1.64	1	0.201
Turnips & swedes	1.75	1.30	1	0.255	1.40	0.39	1	0.534
Fodder beet/mangolds	5.26	13.39	1	<0.001	5.39	12.26	1	<0.001
Sugar beet	1.08	0.04	1	0.847	2.27	4.64	1	0.031
Other grass	1.31	1.30	1	0.253	0.93	0.09	1	0.758
Rough grazing	0.92	0.11	1	0.735	0.74	1.26	1	0.262
Grass <5 years old	1.63	5.53	1	0.019	1.32	1.46	1	0.227
Orchards	1.05	0.01	1	0.918	0.44	1.49	1	0.222
Fruit	1.29	0.19	1	0.665	0.33	1.64	1	0.200
Kale etc	1.54	0.74	1	0.390	1.18	0.09	1	0.770
Peas & beans	0.87	0.21	1	0.645	1.16	0.22	1	0.642
All other vegetables	0.88	0.12	1	0.728	1.19	0.23	1	0.632
Woodland	0.66	3.71	1	0.054	0.68	2.64	1	0.104
Set aside	0.90	0.20	1	0.655	1.25	0.71	1	0.400
Bare fallow	0.58	1.70	1	0.193	0.59	1.31	1	0.253
All pigs	2.53	8.61	1	0.003	1.02	0.00	1	0.955
Indoor pigs	2.78	9.83	1	0.002	1.44	0.89	1	0.344
Outdoor pigs	1.30	0.15	1	0.695	0.90	0.02	1	0.889
All fowls	0.72	1.27	1	0.261	1.27	0.64	1	0.422
Indoor fowls	0.60	1.49	1	0.222	0.476	2.29	1	0.130
outdoor fowls	1.31	0.94	1	0.331	1.605	2.61	1	0.106
Cattle	1.78	6.88	1	0.009	1.18	0.48	1	0.490
Sheep	1.65	5.23	1	0.022	1.29	1.08	1	0.298
Stocking rates:								
Sheep winter/spring	0.50	0.64	1	0.423	0.83	1.38	1	0.239
Sheep summer/autumn	0.35	0.23	1	0.629	1.386	2.93	1	0.087
Cattle	0.96	2.71	2	0.257	0.051	0.32	2	0.851

The relationships with fodder beet/mangolds are particularly interesting, despite the low numbers of holdings growing the crop. Unlike many of the other terms, they are statistically significant whether fitted untransformed or as presence/absence and whatever other terms are fitted. The difference is even significant if farm type is added to the model, and so the term is doing more than just picking out mixed farms. All significant terms in Table 11.3.3.8.1 are illustrated in Table 11.3.3.8.2.

Table 11.3.3.8.2 Holdings classified by whether they reported Starling and/or House Sparrow problems and whether they grew the relevant crop in 2000.**a) Starling**

	No problems		With problems		All	
	n	%	n	%	n	%
Fodder beet mangolds						
Not grown	738	85.9	121	14.1	859	100.0
Grown	13	52.0	12	48.0	25	100.0
All	751	85.0	133	15.0	884	100.0

	No problems		With problems		All	
	n	%	n	%	n	%
Grass < 5 years						
Not present	491	88.5	64	11.5	555	100.0
Present	260	79.0	69	21.0	329	100.0
All	751	85.0	133	15.0	884	100.0

	No problems		With problems		All	
	n	%	n	%	n	%
All pigs						
Not kept	701	86.0	114	14.0	815	100.0
Kept	50	72.5	19	27.5	69	100.0
All	751	85.0	133	15.0	884	100.0

	No problems		With problems		All	
	n	%	n	%	n	%
Indoor pigs						
Not kept	703	86.0	114	14.0	817	100.0
Kept	42	68.9	19	31.1	61	100.0
All	745	84.9	133	15.1	878	100.0

	No problems		With problems		All	
	n	%	n	%	n	%
Cattle						
Not kept	468	88.8	59	11.2	527	100.0
Kept	283	79.3	74	20.7	357	100.0
All	751	85.0	133	15.0	884	100.0

	No problems		With problems		All	
	n	%	n	%	n	%
Sheep						
Not kept	585	87.1	87	12.9	672	100.0
Kept	166	78.3	46	21.7	212	100.0
All	751	85.0	133	15.0	884	100.0

Table 11.3.3.8.2 continued

b) House Sparrow

	No problems		With problems		All	
	n	%	n	%	n	%
Spring oilseed rape						
Not grown	719	87.0	107	13.0	826	100.0
Grown	30	96.8	1	3.2	31	100.0
All	749	87.4	108	12.6	857	100.0

	No problems		With problems		All	
	n	%	n	%	n	%
Fodder beet mangolds						
Not grown	733	88.2	98	11.8	831	100.0
Grown	16	61.5	10	38.5	26	100.0
All	749	87.4	108	12.6	857	100.0

	No problems		With problems		All	
	n	%	n	%	n	%
Sugar beet						
Not grown	703	88.4	92	11.6	795	100.0
Grown	46	74.2	16	25.8	62	100.0
All	749	87.4	108	12.6	857	100.0

11.3.3.9 The nature of the problem

Table 11.3.3.9.1 shows the number of owner/occupier respondents reporting the different types of problems listed on the questionnaire, the crops or commodities affected, and the mean cost of the damage where respondents were able to estimate it. The most common problem caused by both Starlings and House Sparrows was the contamination of livestock feed (14% and 7% of respondents), closely followed by the consumption of livestock feed (12% and 8%). Other common problems included reduced crop yield (4% and 5% of respondents) and the contamination of food for human consumption (3% and 2% of respondents). The cost of the damage was estimated by a small number of respondents, and was greatest when food for human consumption was affected (>£1,500 per annum for Starlings and >£250 for House Sparrows). Respondents estimated that reduction of crop yield was the next most costly damage (£780 for Starlings and £392 for House Sparrows) followed by contamination of livestock feed (£546 for Starlings and £253 for House Sparrows). Uneven crop ripening was less common (reported by about 1% of respondents) and thought to be less costly (mean of £180 for Starlings and £78 for House Sparrows).

Tables 11.3.3.9.2, 11.3.3.9.3 and 11.3.3.9.4 show the different types of problems reported by owners/occupiers tabulated by region, farm type and farm area respectively. Significance levels are also shown based on a logistic regression model with the dependent variable being the presence of the problem and the independent variables being region, type and log area, with each variable being tested after allowing for the effects of the other two. As would be expected, problems vary more with farm type than regions and there is also a tendency for most problems to be more commonly reported on large farms.

Respondents in the East and South East regions were more likely to think Starlings and House Sparrows caused a reduction in crop yield (though this was not significant for Starlings). To specify

the farm type differences, general and mixed farm respondents were more likely to think Starlings caused reduced crop yield, (and for House Sparrows cereal farms too). General farm respondents were also more likely to think House Sparrows caused uneven crop ripening. Farm types with livestock (pigs and poultry, dairy, cattle & sheep and mixed), as expected, were more likely to think Starlings and House Sparrows contaminated and consumed livestock feed. General and cereal farms and horticulture respondents, in particular, were more likely to think Starlings and House Sparrows contaminated and consumed food for human consumption.

Table 11.3.3.9.1 The number of owner/occupiers reporting the problems specified on the questionnaire form, the crops or commodities affected and the mean cost of the damage where respondents were able to estimate it.

	Number of respondents reporting problem	% respondents reporting problem	Crop/commodity	Mean value (£ per annum)	N	Range (£)
STARLING						
Type of problem:						
Reduced crop yield	43	4	cereals, rape, fruit	780	21	5 – 5,000
Uneven crop ripening	14	1	cereals, rape	180	3	40 - 400
Contamination of livestock feed	134	14	cattle, pig, sheep, and fowl feed	546	42	20 - 1,000
Consumption of livestock feed	122	12	cattle, pig, sheep, and fowl feed	345	41	20 - 2,000
Contamination of food for human consumption	25	3	cereals, rape, fruit, market vegetables	1,529	6	25 - 5,000
Consumption of food for human consumption	18	2	cereals, rape, fruit	2,118	7	25 - 10,000
	Number of respondents with problem	% respondents reporting problem	Crop/commodity	Mean value (£ per annum)	N	Range (£)
HOUSE SPARROW						
Type of problem:						
Reduced crop yield	53	5	cereals, rape, market vegetables	392	21	20 - 150
Uneven crop ripening	12	1	cereals, rape	78	4	2 - 2,000
Contamination of livestock feed	70	7	cattle, pig, sheep and fowl feed	253	18	5 - 2,000
Consumption of livestock feed	79	8	cattle, pig, sheep and fowl feed	111	23	1 - 500
Contamination of food for human consumption	21	2	cereals, market vegetables	491	6	20 - 2,000
Consumption of food for human consumption	18	2	cereals	289	5	20 - 1,000

Table 11.3.3.9.2 Problems tabulated by region. 'n' is the number of responding holdings and 'pr' is the number reporting each problem. 'All' refers to all responding holdings and is not weighted to reflect all farms in Britain. Significant results are highlighted in bold.

a) Starling

	n	Reduced yield			Uneven crop			Contamination of livestock feed			Consumption of livestock feed			Contamination of human food			Consumption of human food		
		pr	%	se	pr	%	se	pr	%	se	pr	%	se	pr	%	se	pr	%	se
NE	99	2	2.0	1.41	2	2.0	1.41	13	13.1	3.39	14	14.1	3.50	4	4.0	1.98	1	1.0	1.00
East	217	18	8.3	1.87	4	1.8	0.91	33	15.2	2.44	31	14.3	2.38	11	5.1	1.49	7	3.2	1.20
SE	111	10	9.0	2.72	2	1.8	1.26	10	9.0	2.72	11	9.9	2.84	4	3.6	1.77	3	2.7	1.54
SW	162	2	1.2	0.87	0	0.0	0.00	24	14.8	2.79	19	11.7	2.53	1	0.6	0.62	2	1.2	0.87
NW	140	3	2.1	1.22	2	1.4	1.00	18	12.9	2.83	15	10.7	2.61	2	1.4	1.00	2	1.4	1.00
Wales	103	2	1.9	1.36	1	1.0	0.97	12	11.7	3.16	14	13.6	3.38	1	1.0	0.97	1	1.0	0.97
Scotland	148	6	4.1	1.62	3	2.0	1.16	24	16.2	3.03	18	12.2	2.69	2	1.4	0.95	2	1.4	0.95
All	980	43	4.4	0.65	14	1.4	0.38	134	13.7	1.10	122	12.4	1.05	25	2.6	0.50	18	1.8	0.43
χ^2		11.61			5.04			5.61			4.38			6.38			1.97		
d.f.		6			6			6			6			6			6		
<i>P</i>		0.07			NS			NS			NS			NS			NS		

Table 11.3.3.9.2 (continued)

b) House Sparrow

	n	Reduced yield			Uneven crop			Contamination of livestock feed			Consumption of livestock feed			Contamination of human food			Consumption of human food		
		pr	%	se	pr	%	se	pr	%	se	pr	%	se	pr	%	se	pr	%	se
NE	99	2	2.0	1.41	2	2.0	1.41	8	8.1	2.74	9	9.1	2.89	4	4.0	1.98	2	2.0	1.41
East	217	25	11.5	2.17	5	2.3	1.02	15	6.9	1.72	25	11.5	2.17	11	5.1	1.49	11	5.1	1.49
SE	111	10	9.0	2.72	1	0.9	0.90	6	5.4	2.15	6	5.4	2.15	3	2.7	1.54	3	2.7	1.54
SW	162	3	1.9	1.06	1	0.6	0.62	8	4.9	1.70	7	4.3	1.60	1	0.6	0.62	1	0.6	0.62
NW	140	3	2.1	1.22	0	0.0	0.00	9	6.4	2.07	11	7.9	2.27	1	0.7	0.71	1	0.7	0.71
Wales	103	1	1.0	0.97	0	0.0	0.00	8	7.8	2.64	8	7.8	2.64	0	0.0	0.00	0	0.0	0.00
Scotland	148	9	6.1	1.96	3	2.0	1.16	16	10.8	2.55	13	8.8	2.33	1	0.7	0.67	0	0.0	0.00
All	980	53	5.4	0.72	12	1.2	0.35	70	7.1	0.82	79	8.1	0.87	21	2.1	0.46	18	1.8	0.43
χ^2				19.37			5.85			6.40			6.27			10.21			9.26
d.f.				6			6			6			6			6			6
<i>P</i>				<0.01			NS			NS			NS			NS			NS

Table 11.3.3.9.3 Problems tabulated by farm type. 'n' is the number of responding holdings and 'pr' is the number reporting each problem. 'All' refers to all responding holdings and is not weighted to reflect all farms in Britain. Significant results are highlighted in bold.

a) Starling

	n	Reduced yield			Uneven crop			Contamination of livestock feed			Consumption of livestock feed			Contamination of human food			Consumption of human food		
		pr	%	se	pr	%	se	pr	%	se	pr	%	se	pr	%	se	pr	%	se
Cereals	135	5	3.7	1.63	1	0.7	0.74	19	14.1	2.99	20	14.8	3.06	7	5.2	1.91	5	3.7	1.63
General	124	18	14.5	3.16	5	4.0	1.77	15	12.1	2.93	9	7.3	2.33	7	5.6	2.07	3	2.4	1.38
Horticulture	137	8	5.8	2.00	1	0.7	0.73	2	1.5	1.02	2	1.5	1.02	5	3.6	1.60	7	5.1	1.88
Pigs & Poultry	127	1	0.8	0.78	1	0.8	0.78	23	18.1	3.42	27	21.3	3.63	2	1.6	1.10	1	0.8	0.78
Dairy	124	1	0.8	0.80	0	0.0	0.00	36	29.0	4.08	31	25.0	3.89	0	0.0	0.00	0	0.0	0.00
Cattle & Sheep	104	1	1.0	0.96	1	1.0	0.96	14	13.5	3.35	10	9.6	2.89	1	1.0	0.96	1	1.0	0.96
Mixed	117	8	6.8	2.33	5	4.3	1.87	24	20.5	3.73	21	17.9	3.55	2	1.7	1.20	1	0.9	0.85
Other	112	1	0.9	0.89	0	0.0	0.00	1	0.9	0.89	2	1.8	1.25	1	0.9	0.89	0	0.0	0.00
All	980	43	4.4	0.65	14	1.4	0.38	134	13.7	1.10	122	12.4	1.05	25	2.6	0.50	18	1.8	0.43
χ^2		27.74			11.66			53.36			60.40			13.65			25.94		
d.f.		7			7			7			7			7			7		
<i>P</i>		<0.001			NS			<0.001			<0.001			0.058			<0.01		

Table 11.3.3.9.3 (continued)

b) House Sparrow

	n	Reduced yield			Uneven crop			Contamination of livestock feed			Consumption of livestock feed			Contamination of human food			Consumption of human food		
		pr	%	se	pr	%	se	pr	%	se	pr	%	se	pr	%	se	pr	%	se
Cereals	135	16	11.9	2.78	3	2.2	1.27	10	7.4	2.25	14	10.4	2.62	6	4.4	1.77	3	2.2	1.27
General	124	15	12.1	2.93	5	4.0	1.77	11	8.9	2.55	16	12.9	3.01	7	5.6	2.07	11	8.9	2.55
Horticulture	137	5	3.6	1.60	0	0.0	0.00	2	1.5	1.02	4	2.9	1.44	5	3.6	1.60	3	2.2	1.25
Pigs & Poultry	127	1	0.8	0.78	0	0.0	0.00	11	8.7	2.50	16	12.6	2.94	1	0.8	0.78	1	0.8	0.78
Dairy	124	2	1.6	1.13	0	0.0	0.00	14	11.3	2.84	15	12.1	2.93	0	0.0	0.00	0	0.0	0.00
Cattle & Sheep	104	2	1.9	1.35	0	0.0	0.00	11	10.6	3.02	6	5.8	2.29	0	0.0	0.00	0	0.0	0.00
Mixed	117	10	8.5	2.58	4	3.4	1.68	11	9.4	2.70	6	5.1	2.04	2	1.7	1.20	0	0.0	0.00
Other	112	2	1.8	1.25	0	0.0	0.00	0	0.0	0.00	2	1.8	1.25	0	0.0	0.00	0	0.0	0.00
All	980	53	5.4	0.72	12	1.2	0.35	70	7.1	0.82	79	8.1	0.87	21	2.1	0.46	18	1.8	0.43
χ^2		15.30			15.31			20.55			19.67			17.90			24.51		
d.f.		7			7			7			7			7			7		
<i>P</i>		<0.05			<0.05			<0.01			<0.01			<0.05			<0.01		

Table 11.3.3.9.4 Problems tabulated by farm area. Area is grouped for tabulation, but the test statistics are for fitting it as a continuous variable on the log scale. 'n' is the number of responding holdings and 'pr' is the number reporting each problem. 'All' refers to all responding holdings and is not weighted to reflect all farms in Britain. Significant results are highlighted in bold.

a) Starling

	n	Reduced yield			Uneven crop			Contamination of livestock feed			Consumption of livestock feed			Contamination of human food			Consumption of human food			
		pr	%	se	pr	%	se	pr	%	se	pr	%	se	pr	%	se	pr	%	se	
Area (ha)																				
<10	311	3	1.0	0.55	0	0.0	0.00	7	2.3	0.84	15	4.8	1.21	4	1.3	0.64	3	1.0	0.55	
11 - 50	252	14	5.6	1.44	2	0.8	0.56	35	13.9	2.18	28	11.1	1.98	4	1.6	0.79	4	1.6	0.79	
51 - 100	168	14	8.3	2.13	8	4.8	1.64	33	19.6	3.07	27	16.1	2.83	7	4.2	1.54	3	1.8	1.02	
100+	249	12	4.8	1.36	4	1.6	0.80	59	23.7	2.69	52	20.9	2.58	10	4.0	1.24	8	3.2	1.12	
All	980	43	4.4	0.65	14	1.4	0.38	134	13.7	1.10	122	12.4	1.05	25	2.6	0.50	18	1.8	0.43	
χ^2				3.43			5.14			37.42			25.80			6.23			13.29	
d.f.				1			1			1			1			1			1	
P				0.064			<0.05			<0.001			<0.001			<0.05			<0.001	

b) House Sparrow

	n	Reduced yield			Uneven crop			Contamination of livestock feed			Consumption of livestock feed			Contamination of human food			Consumption of human food			
		pr	%	se	pr	%	se	pr	%	se	pr	%	se	pr	%	se	pr	%	se	
Area (ha)																				
<10	311	5	1.6	0.71	0	0.0	0.00	5	1.6	0.71	12	3.9	1.09	3	1.0	0.55	2	0.6	0.45	
11 - 50	252	11	4.4	1.29	3	1.2	0.68	21	8.3	1.74	18	7.1	1.62	4	1.6	0.79	1	0.4	0.40	
51 - 100	168	6	3.6	1.43	2	1.2	0.84	14	8.3	2.13	16	9.5	2.26	5	3.0	1.31	3	1.8	1.02	
100+	249	31	12.4	2.09	7	2.8	1.05	30	12.0	2.06	33	13.3	2.15	9	3.6	1.18	12	4.8	1.36	
All	980	53	5.4	0.72	12	1.2	0.35	70	7.1	0.82	79	8.1	0.87	21	2.1	0.46	18	1.8	0.43	
χ^2				2.96			0.01			9.91			8.03			4.69			9.99	
d.f.				1			1			1			1			1			1	
P				0.085			NS			<0.01			<0.01			<0.05			<0.01	

House Sparrow and Starling control

Owners/occupiers were also asked if they were concerned about disease transmission and safety on the holding. The diseases and species at risk were tabulated and are shown in Table 11.3.3.9.5. The most common diseases of concern were *Salmonella* and Foot and Mouth. The most common species at risk were pigs and cattle. The number of respondents for which safety was an issue are shown in Table 11.3.3.9.6. Responses in this section were almost entirely related to slippery walkways and droppings. Other problems which were specified in the comments box attached to this question are listed in Table 11.3.3.9.7 and include damage to trees and pulling up wheat shoots.

Table 11.3.3.9.5 Respondents concerned about disease transmission: the nature of the disease and the species at risk.

Nature of the disease	Starling	House Sparrow	Species at risk	Starling	House Sparrow
<i>Salmonella</i>	11	6	Pigs	13	4
Foot and Mouth	9	1	Cattle	6	2
TB (unspecified)	3	2	Poultry	4	1
Avian TB	3	1	Sheep	2	1
Coccydiosis	2	0	Humans	2	0
PDNS/PMWS	1	1			
Gastroenteritis	1	1			
Botulism	1	1			
Ringworm	1	1			
<i>E. coli</i>	1	0			
Bacterial scour	1	0			
Sheep scab	1	0			
Blue scour	1	0			
Swine fever	0	1			
Dust inhalation	0	1			

Table 11.3.3.9.6 Respondents for which safety is an issue: the situation in which they are affected.

Situation	Starling	House Sparrow
Slippery walkways/droppings	25	12
Blocked chimneys	2	0
Scraping mortar out of buildings	1	0
Blocked gutters	0	1

Table 11.3.3.9.7 Other problems specified by respondents in comments box.

Nature of problem	Number of respondents reporting problem (out of a total of 980)	
	Starling	House Sparrow
Killing/establishment of trees	3	0
Pulling up wheat shoots	3	0
Noise	2	0
Contamination of water courses	1	0
Contamination of wool on housed sheep	1	0
Nests in machinery	1	0
Droppings on machinery	0	3
Pecking foam insulation of grain stores	0	1
Blocking gutters	0	1

11.3.3.10 Control activities

The numbers of owners/occupiers reporting the use of control methods was low. Eighty percent of respondents reported that they did not use any control methods against Starlings and 81% did not use any against House Sparrows (Table 11.3.3.10.1, next page).

Table 11.3.3.10.1 Methods of control. Chemical repellents were not reported for either species and have been omitted from this table.

(a) Starling

	Numbers of respondents				Percentage of respondents	Percentage of users		
	Using method	Finding no effect	Finding slight reduction	Finding sig. reduction	Using method	Finding no effect	Finding slight reduction	Finding sig. reduction
Removal of spilt grain	21	5	11	5	2.14	23.81	52.38	23.81
Removal or modification of lights	9	4	1	4	0.92	44.44	11.11	44.44
Netting of vent flaps	52	18	15	19	5.31	34.62	28.85	36.54
Other exclusion nets	44	12	12	20	4.49	27.27	27.27	45.45
Auditory bird scarers	34	10	21	3	3.47	29.41	61.76	8.82
Visual bird scarers	21	7	12	2	2.14	33.33	57.14	9.52
Wires	5	2	2	1	1.51	40.00	40.00	20.00
Cage trapping	2	1	0	1	0.20	50.00	0.00	50.00
Netting	1	1	0	0	0.10	100.00	0.00	0.00
Stupefying baits	1	0	1	0	0.10	0.00	100.00	0.00
Shooting	47	16	26	5	4.80	34.04	55.32	10.64
Egg control	3	2	1	0	0.31	66.67	33.33	0.00

Table 11.3.3.10.1 (continued)

(b) House Sparrow

	Numbers of respondents				Percentage of respondents	Percentage of users		
	Using method	Finding no effect	Finding slight reduction	Finding sig. reduction	Using method	Finding no effect	Finding slight reduction	Finding sig. reduction
Removal of spilt grain	22	9	9	4	2.24	40.91	40.91	18.18
Removal or modification of lights	12	6	2	4	1.22	50.00	16.67	33.33
Netting of vent flaps	36	8	12	16	3.67	22.22	33.33	44.44
Other exclusion nets	35	11	12	12	3.57	31.43	34.29	34.29
Auditory bird scarers	9	3	5	1	0.92	33.33	55.56	11.11
Visual bird scarers	7	4	1	2	0.71	57.14	14.29	28.57
Wires	3	2	0	1	0.31	66.67	0.00	33.33
Cage trapping	6	0	4	2	0.61	0.00	66.67	33.33
Netting	2	0	2	0	0.20	0.00	100.00	0.00
Stupefying baits	1	0	1	0	0.10	0.00	100.00	0.00
Shooting	11	4	7	0	1.12	36.36	63.64	0.00
Egg control	6	4	1	1	0.61	66.67	16.67	16.67

House Sparrow and Starling control

The most common method of control, used by 52 respondents against Starlings (5.3%) and 36 respondents against House Sparrows (3.7%), was the netting of vent flaps. However, this was perceived as being only partially effective, with slightly more than a third of users finding that it reduced numbers significantly, and a further third that it reduced numbers slightly. The level of effectiveness against House Sparrows was similar. The second most common method of control of Starlings was shooting, used by 47 respondents (4.8%). Fifty-five percent of those found that it resulted in a slight reduction in numbers and 11%, a significant reduction. Shooting was used less frequently against House Sparrows (11 respondents) with 64% finding it resulted in a slight reduction in number, and none a significant reduction. Exclusion nets other than vent flaps were used by 44 respondents against Starlings and 35 respondents against House Sparrows. About 45% of those felt that they resulted in a significant reduction in numbers of Starlings and 34% in numbers of House Sparrows.

Thirty-four respondents (3.5%) used auditory bird scarers against Starlings, with 62% of those finding that they reduced numbers slightly, and 9% significantly. Twenty-one respondents used visual bird scarers against Starlings with a similar level of effectiveness to the auditory scarers. Removal of spilt grain was practiced by about 2% of respondents, with 52% of those finding starling numbers were slightly reduced (41% for House Sparrow), and 24% finding Starlings were significantly reduced (18% for House Sparrows).

Other methods listed in the questionnaire (removal or modification of lights, wires, cage trapping, netting, stupefying baits and egg control) were each used by only a few respondents (<13), and chemical repellents by none.

Table 11.3.3.10.2 looks at the relationship between lethal and non-lethal control. For both species the association is highly significant (Fisher's exact test, $P < 0.001$ in both cases) and it is particularly marked for Starlings, with the majority of farms using lethal control measures for this species also adopting non-lethal ones.

Table 11.3.3.10.2 Relationship between the use of lethal and non-lethal control. Figures are number of holdings.

a) Starling

Lethal control	Non-lethal control		Count
	No	Yes	All
No	856	74	930
Yes	19	31	50
All	875	105	980

b) House Sparrow

Lethal control	Non-lethal control		Count
	No	Yes	All
No	900	59	959
Yes	12	9	21
All	912	68	980

11.3.3.11 General comments

Comments made by three or more owner/occupiers are shown in Table 11.3.3.11.1. The four most common were all related to the possible causes of population declines in farmland birds. An increase in birds of prey was cited by 61 respondents, followed by sealed grain stores (44 respondents), an increase in magpies (39 respondents) and crows and rooks (35 respondents).

Table 11.3.3.11.1 General comments on the survey made by owners/occupiers.

	Number of respondents commenting (out of a total of 980)		
Population decline related to an increase in birds of prey		61	
Necessity for sealed grain stores and livestock feeding areas (to achieve "assured" status or similar)		44	
Population decline related to an increase in Magpies		39	
Population decline related to an increase in Crows and Rooks		35	
Feral and Woodpigeons are more of a problem		21	
Population decline related to an increase in (feral) cats		12	
Survey is a waste of time/money		11	
Population decline related to a decrease in livestock farming		10	
Starlings eat crop pests		8	
Rabbits and rats are more of a problem		7	
Starlings and House Sparrows are actively encouraged on the holding		7	
Damage was more severe >10 years ago		6	
There is less spilt grain available as food		6	
The increased use of pesticides is an important factor		5	
Blackbirds are more of a problem (for fruit and alpiners)		5	
There are fewer nesting sites in modern buildings		4	
Collared Doves are more of a problem		4	
Change in weather has been an important factor		3	
There are less over-wintered stubbles now		3	
Decline in mixed farming has been important		3	
Starlings cause problem by nesting in chimneys and soffits		3	
Decline in ramblers/FMD has led to recent increase in populations		3	

11.3.4 DISCUSSION

A questionnaire survey designed primarily to quantify the numbers of Starlings and House Sparrows killed under general licence was sent to a stratified sample of 3,533 owner/occupiers of agricultural holdings in England, Wales and Scotland at the end of October, 2001. The final response rate was 28%. The outbreak of Foot and Mouth disease undoubtedly had an impact on the survey, reducing the response rate below the 30-50% estimated from a previous survey of badger damage (Moore *et al.* 1998). Response rates were found not to vary by region or farm type. They did, however, vary by farm size; large farms were more likely to respond (the usual pattern in agricultural surveys).

Of the 980 owner/occupiers who returned completed forms, the vast majority (97%) undertook no lethal control. A total of 16 had culled 1,185 Starlings and seven had culled 320 House Sparrows in the survey year. This extreme skew to the data imposed limitations on subsequent data analysis. If respondents are assumed to be representative of non-respondents, then 271,000 Starlings and 52,000 House Sparrows were estimated to have been killed under general licence in the current year. If, however, non-respondents are assumed not to have culled any Starlings or House Sparrows (as is suggested by telephone contact with a sample of non-respondents), then 74,000 Starlings and 16,000 House Sparrows can be estimated to have been killed in the survey year. Numbers killed per year are similar to those of one to five years ago and six to ten years ago, but are estimated at 86,000 Starlings and 37,000 House Sparrows per annum for over ten years ago (assuming non-respondents killed no birds). The use of lethal control for Starlings was strongly associated with farm size, except for farms with large numbers of pigs or poultry. This suggests that 'economic size' of holding may explain this relationship and be a better predictor of lethal control. A small number of respondents provided information that indicated lethal control of Starlings was more likely in the pre-breeding season and of House Sparrows during the breeding season. The killing of Starlings in winter is less likely to affect the population breeding in Britain than killing at other times of the year, as at least 50% are likely to be migrants from Northern Europe and Scandinavia (Fliege 1984: Feare, in press).

Holdings growing fodder beet/mangolds, and to a lesser extent reseeded grass, and with livestock (indoor pigs, cattle and sheep) were more likely to report damage by Starlings. Holdings growing fodder beet/mangolds and sugar beet were more likely to report damage by House Sparrows, and those growing spring rape less likely. These relationships may reflect the distribution of winter food resources. Decreases in the amount of grassland and fallow land and increases in the amount of autumn-sown crops have been implicated in the decline of Starling numbers via a reduction in winter invertebrate food (Feare, 1994).

In line with current population trends, most owner/occupier respondents thought that Starlings and House Sparrows had decreased on their holdings. Respondents in Wales, and to a lesser extent Scotland, however, were less likely than respondents in other regions to think that they had declined. The BTO Common Bird Census (CBC) data indicates that Starlings have been in decline, particularly since the early 1980s (see Chapter 2), but the BTO/JNCC/RSPB Breeding Bird Survey (BBS) shows that over the past six years, the population has increased in Scotland and Wales (see Chapter 2). This supports the perception of Scottish and Welsh respondents. CBC data and the BTO's Garden Bird Feeding Survey indicate House Sparrows have declined rapidly since the 1970s. BBS data again suggest populations have increased in Wales and Scotland (see Chapter 2). This corresponds with the perception of respondents in the CSL survey.

Respondents carrying out lethal control were also more likely to think Starlings had increased in number on their holdings, and were more likely to be experiencing problems with Starlings. Lethal and non-lethal control were positively associated suggesting that the two strategies are used in conjunction with one another, rather than as alternatives. This is in accordance with the sentiments of the Wildlife and Countryside Act (1981) and current DEFRA policy, that lethal methods of control should only be used to augment non-lethal methods which have been tried and proved ineffective on their own. The preponderance of non-lethal control techniques and a few relevant comments

House Sparrow and Starling control

volunteered by respondents suggests that the purpose of most lethal control is to scare rather than to limit populations, which again is in line with the sentiments of the Wildlife and Countryside Act. This view is also supported by the observation that shooting was used by more owner/occupier respondents than lethal control, which suggests that most shooting was to scare rather than to kill.

Currently, 85% of owner/occupiers reported no problems with Starlings or House Sparrows. Less than 5% of respondents reported serious problems (affecting farm income). It appears, therefore, that neither species causes a serious or widespread problem. However, over ten years ago the percentage holdings sustaining damage was greater. There were regional differences as well, most notably a large decline in the proportion of owner/occupiers reporting Starling and House Sparrow damage in the East Midlands and East Anglia, over the period covered by this survey. This coincides with the lower decline in House Sparrow damage on dairy and cow and sheep farms (most of which are in the West).

The owner/occupier responses to questions on the severity of the problem and changes in the numbers of Starlings and House Sparrows were found to correlate quite highly between Starlings and House Sparrows. This may be a genuine effect, due to patterns of damage for the species being similar in time and space. However it may indicate a tendency for respondents to tick the same boxes for each species when they are unsure. Similar comments apply to varying extents to all the data in this survey.

The most common Starling and House Sparrow problems reported by owner/occupiers were contamination and consumption of livestock feed, reduced crop yield and contamination of food for human consumption. The cost of this damage was generally estimated to be less than £1,500 per annum per holding. A word of caution should perhaps be inserted here. These estimates were based on rough guesses supplied without evidence, by only a small number of respondents. Types of damage and estimated costs for Starlings are reviewed in Feare (1980 and 1984) and include damage to fruit (up to £1,296/ha for cherries), germinating winter cereals (very little cost) and removal of animal food (up to £30,000 for a large poultry farm). Twedt and Glahn (1982) investigated starling depredations at livestock feeding operations in the United States and Great Britain and suggested changes to management practices to reduce the problem. This survey also suggested that changes in management practices, such as removal of spilt grain and protection of livestock feeding sites, were effective.

A small number of owner/occupier respondents were concerned about disease transmission (most commonly *Salmonella* and Foot and Mouth, and mainly to pigs and cattle) and safety (slippery walkways). Feare (1980 and 1984) reviews the evidence for disease transmission and concludes Starlings are unlikely to be involved in the spread of FMD and that there is little evidence they transmit *Salmonella*.

Most respondents reporting Starling or House Sparrow problems used control techniques. The most commonly used non-lethal techniques were bird-proofing measures (netting of vent flaps and other exclusion nets), with about a third to a half of respondents finding a significant reduction in the number of birds present. Auditory and visual bird scarers appeared to be less effective, with fewer respondents (<10%) reporting a significant reduction in numbers. The effectiveness of shooting appeared to be similar to that of the bird scarers, in that most respondents (55%) found only a slight reduction in numbers. Methods of starling control are discussed by Feare (1984) who notes that many traditionally used methods are not effective and suggests the best techniques are 'a man with a gun', the broadcasting of distress calls, chemical repellents, changes to farm management (such as sowing crops early) and exclusion.

No owner/occupiers reported the use of chemical repellents. This may be because there are few chemicals commercially available licensed to be used for this purpose (Gill *et al.* 1999) and because the addition of further chemicals to stored livestock and human food (the contamination and

consumption of which are the most common problems) would be undesirable. Nevertheless, Moran (2001) investigated using methyl anthranilate (MA) to protect animal feed from House Sparrows and Wager-Page & Mason (1996) the use of pulegone to reduce Starling damage to apples. Chemical repellents could potentially be used to reduce fouling of public areas, damage to public property, and help solve safety problems caused by roosting on machinery, above walkways etc. Stevens & Clark (1998) investigated the use of a MA aerosol to keep Starlings out of specific areas and Clark (1997) tested natural plant products as dermal contact repellents to prevent Starlings from roosting on architectural structures. Both of these methods showed potential.

When invited to make general comments on the survey, most responses related to the possible causes of the declines in farmland bird populations, based on personal observations. The two most frequently cited were an increase in populations of predators, and the necessity for sealing grain stores and other hygiene measures in order to achieve 'farm assured' or similar status. Changes in the nature of the farmland habitat, resulting in changes to the distribution of the food of farmland birds and the numbers, distribution or hunting success of their predators, have been identified in the literature as possible causes of the decline in Starlings and House Sparrows (Robinson *et al.* 2001; Jobin *et al.* 1998; Baillie *et al.* 1998). However, Newton *et al.* (1997) found little evidence that Sparrowhawks *Accipiter nisus* affected the local breeding density of Starlings and Baillie *et al.* (1998) thought predation is unlikely to have made a major contribution to the declines.

11.4 LOCAL AUTHORITY SURVEY

11.4.1 Introduction and aim

A survey of Local Authorities was undertaken by DEFRA European Wildlife, with a similar aim to the owner-occupier survey: to estimate the numbers of Starlings and House Sparrows killed by Local Authorities over the last year, one to five years ago, six to ten years ago, and over ten years ago, and to collect additional information on: (a) the seriousness and extent of any problems and (b) the use and effectiveness of control techniques.

11.4.2 Methods

A questionnaire form and covering letter similar to the ones to be sent to landowners/occupiers were sent to all 410 Local Authorities in the UK at the end of June, 2001 (Appendices 11.3 and 11.4). The statistics presented in the results section are the number of responding Local Authorities and the percentage of the Local Authorities that this represents. Significance tests are not appropriate due to the small sample sizes of respondents involved.

11.4.2.1 Non-respondents

Twenty-nine Local Authorities had responded by 29 July, an initial response rate of about 7%. Approximately 12% of non-respondents in England were randomly selected and contacted by e-mail at the end of August, 2001 and asked again to complete the form. Those that did not have e-mail addresses detailed on their web sites were telephoned.

11.4.3 Results

11.4.3.1 Response rates

With 42 completed questionnaires, the final response rate for the Local Authority survey was 10.2%.

11.4.3.2 Non-respondents

In addition to the 42 Local Authorities finally sending in completed questionnaire forms, six (1.5%) stated over the telephone that they had no problem with either species and so were not interested in completing the form. Non-respondents' comments indicated that the reasons for not replying were not related to the questions asked in the survey, so national averages could be estimated from the survey sample.

11.4.3.3 Numbers killed

Of the 48 Local Authorities that provided information, none had culled Starlings or House Sparrows within the last ten years, although 17% used non-lethal methods to manage problems.

11.4.3.4 Perception of changes in numbers

Most Local Authorities thought Starlings had decreased or stayed the same in their area (Table 11.4.3.4.1). Only three Local Authorities thought they had increased in number. This is in contrast to House Sparrows, for which no Local Authorities thought they had increased in number, and a greater percentage thought they had decreased significantly.

Table 11.4.3.4.1 Local Authority perception of population changes in the last ten years.

Authorities reporting change	Starling		House Sparrow	
	No.	%	No.	%
Increased significantly	2	5	0	0
Increased slightly	1	2	0	0
Remained the same	9	21	7	17
Decreased slightly	5	12	2	5
Decreased significantly	10	24	12	29
Don't know	15	36	20	48

11.4.3.5 The seriousness and extent of perceived problems

From the 42 Local Authorities that returned the survey form, it is clear that currently neither species is a widespread problem; in fact six Local Authorities commented that feral pigeons were more of a concern. For Starling, only two Local Authorities had a serious problem (i.e. affecting budgets) and two had a moderate problem (i.e. with cost implications, but can be tolerated). Over six years ago the Starling problem was more widespread, but less serious, with eight to ten Local Authorities reporting moderate damage and none reporting serious damage. No Local Authorities have or have had a problem with House Sparrows.

11.4.3.6 The nature of the problem

The most common problem caused by Starlings for Local Authorities was fouling of public areas, which was reported by one in five responding Authorities. The mean cost of which was estimated at £950 per year (Table 11.4.3.6.1). Following this were concerns over public health (£750 per year), damage to property (£500 per year) and safety (public footpaths specified). Crude estimates of national cost are also given in Table 11.4.3.6.1, assuming that respondents are representative of non-respondents (a reasonable assumption given the comments of non-responding Local Authorities). These costs should be treated with caution as only one or two Local Authorities were able to provide estimates in each case.

In relation to damage to property, the cost to Housing Departments to proof roof spaces, and damage to paint on cars were commented upon. Disease transmission was only mentioned by one Local Authority in terms of complaints from the public. Noise and the nuisance factor were brought up by four Local Authorities. No Local Authority reported problems specific to House Sparrows.

Table 11.4.3.6.1 The nature of the problem cause by Starlings, and the estimated cost per annum and estimated national cost.

Problem	Local Authorities reporting problem		Estimated cost per Authority per annum (mean and range)	Estimated national cost per annum
	No.	%		
Fouling of public areas	9	21	£950 (£900-£1000)	£83,500
Public health	7	17	£750 (£500 - £1000)	£51,000
Damage to property	5	12	£500 ('minimal' - £500)	£24,500
Safety	3	7	Not specified	

11.4.3.7 Control techniques used by Local Authorities

Seventeen percent of responding Local Authorities used non-lethal Starling control techniques (Table 11.3.3.7.1). The most common method, used by five Local Authorities, was auditory scaring, and three of these reported that it resulted in a significant reduction in numbers of Starlings. Two Local Authorities used visual scarers, one used exclusion nets (both methods resulting in a significant reduction in numbers) and one Authority used chemical repellents (slight reduction in numbers). One Authority reported the use of Starling distress calls, and one stated that tree lopping (i.e. removing roosting places) has proved by far the best local method, although the birds do relocate elsewhere.

Table 11.4.3.7.1 Control techniques used by Local Authorities against Starlings.

Technique	Number of Authorities using the technique	Number with slight reduction	Number with significant reduction
Auditory scarers	5	0	3
Visual scarers	2	0	1
Exclusion nets	1	0	1
Chemical repellents	1	1	0

House Sparrow and Starling control

11.4.3.8 General comments

The last question on the forms asked respondents if they had any further comments relating to the survey. Local Authority comments are shown in Table 11.4.3.8.1

Table 11.4.3.8.1 General comments on the survey made by Local Authorities.

	Number of authorities commenting (out of 42 responding)
No problems with either species in this area	7
Feral Pigeons are our main problem	6
Canada geese are more of a problem	1
Gulls are more of a problem	1
The problem is related to the weather	1
These species cause a nuisance only	1

11.4.4 Discussion

A questionnaire survey designed primarily to quantify the numbers of Starlings and House Sparrows killed under general licence was sent to all 410 Local Authorities in England, Wales, Scotland and Northern Ireland at the end of June, 2001. The final response rate was 10%.

Of the 48 Local Authorities that provided information, none currently or have ever culled Starlings or House Sparrows or reported doing so in recent years. It therefore seems unlikely that Local Authority control has been a factor in the decline of either species. However, this result is based on a low response rate and an assumption that responses were not biased towards those Local Authorities not undertaking control. Contact with non-respondents indicated this assumption was valid.

In line with current population trends, most Local Authority respondents thought that Starlings and House Sparrows had decreased in their Authority. The BTO Common Bird Census (CBC) data indicates that Starlings have been in decline, particularly since the early 1980s (see Chapter 2). Common Birds Census data and the BTO's Garden Bird Feeding Survey indicate House Sparrows have declined rapidly since the 1970s.

Currently, over 90% of Local Authorities reported no problems with Starlings or House Sparrows. Less than 5% reported serious problems (affecting budgets). It appears, therefore, that neither species causes a serious or widespread problem for Local Authorities. However, over six years ago, the problem was more widespread, with more Local Authorities experiencing problems, albeit of a moderate level of severity.

The most common problem caused by Starlings to Local Authorities was fouling of public areas, then concerns over public health, damage to property, safety and protecting wild birds, in that order. The cost of the damage was generally estimated to be below £1,000 a year (for the Local Authority affected). This can be translated into a crude national estimate of about £159,000 per annum. Again, a word of caution: the mean costs of damage, and hence these national estimates, were based on rough guesses supplied without evidence, by only a small number of respondents. No Authorities reported damage by House Sparrows. Gautsch *et al.* (2000) investigated the risk of Starlings to human health in Basle, Switzerland, and concluded that it was improbable that birds were a constant direct source of disease infection for human beings. Similar conclusions were reached by Chilvers *et al.* (1998) for Starlings and House Sparrows on farms in New Zealand.

Most Local Authority respondents reporting Starling or House Sparrow problems used control techniques, the most common being auditory scarers, which were perceived to be partially effective. One Local Authority reported the use of chemical repellents. This may be because there are few

chemicals commercially available licensed to be used for this purpose (Gill *et al.* 1999). Some success with chemical repellents has been reported in the literature, albeit at the experimental stage of testing (see Section 11.3.4). Chemical repellents could potentially be used to reduce fouling of public areas and damage to public property. Stevens & Clark (1998) investigated the use of a MA aerosol to keep Starlings out of specific areas and Clark (1997) tested natural plant products as dermal contact repellents to prevent Starlings from roosting on architectural structures. Both of these methods showed potential.

When invited to make general comments on the survey, most Local Authority responses were related to the absence of a problem with Starlings or House Sparrows and a suggestion that Feral Pigeons were more of a concern.

11.5 CONCLUSIONS

In conclusion, the questionnaire surveys of land-owner/occupiers and Local Authorities showed that large numbers of Starlings and House Sparrows are killed by owner/occupiers under the general licence in Britain. However, these are relatively small compared to the national population size estimates reported in Chapters 2 and 3. Neither species appears to be a widespread or serious problem and only very small numbers of respondents suggested that damage has any economic impact.

Appendix 11.1 Owner/occupier questionnaire form.

CSL STARLING AND HOUSE SPARROW CONTROL SURVEY

CSL REFERENCE NUMBER Please return the completed questionnaire in the prepaid envelope provided to:
 Helen McKay, Room 02F11, Central Science Laboratory, Sand Hutton, York, YO41 1LZ



1. Has the main land use of your holding (e.g. horticulture, dairy, pigs, poultry, beef, sheep, arable or mixed) changed over the last 1-5 years, 6-10 years or prior to this?

	Yes	No	
1 - 5 years ago	<input type="checkbox"/>	<input type="checkbox"/>	Please describe the changes <input style="width: 100%; height: 40px;" type="text"/>
6 - 10 years ago	<input type="checkbox"/>	<input type="checkbox"/>	Please describe the changes <input style="width: 100%; height: 40px;" type="text"/>
Over 10 years ago	<input type="checkbox"/>	<input type="checkbox"/>	Please describe the changes <input style="width: 100%; height: 40px;" type="text"/>

2. If you grow/grew wheat, what proportion is/was spring-sown?

Over the past year	1 - 5 years ago	6 - 10 years ago	Over 10 years ago
<input style="width: 40px; height: 20px;" type="text"/>			

3. Please give details of the total numbers of livestock held on your holding currently, or when you last held livestock (please indicate the year).

	Total number		Stocking rate (number of livestock/hectare)		Year
	Ewes	Lambs	Winter/Spring	Summer/Autumn	
SHEEP	<input style="width: 60px;" type="text"/>	<input style="width: 60px;" type="text"/>	<input style="width: 100px;" type="text"/>	<input style="width: 100px;" type="text"/>	<input style="width: 60px;" type="text"/>
CATTLE (including beef, dairy and calves)	<input style="width: 120px;" type="text"/>		<input style="width: 120px;" type="text"/>		<input style="width: 60px;" type="text"/>
	Number indoor		Number outdoor		
PIGS	<input style="width: 120px;" type="text"/>		<input style="width: 120px;" type="text"/>		
FOWLS	<input style="width: 120px;" type="text"/>		<input style="width: 120px;" type="text"/>		
	Total number		Please specify		
OTHER	<input style="width: 120px;" type="text"/>		<input style="width: 120px;" type="text"/>		

Appendix 11.1 continued

**4. How serious a problem have starlings or house sparrows been on your holding?
Please tick where appropriate.**

None - No damage
Moderate - Some damage, but can usually be tolerated
Serious - Significantly affecting income and cannot be tolerated

	STARLINGS			HOUSE SPARROWS		
	None	Moderate	Serious	None	Moderate	Serious
Over the past year	<input type="checkbox"/>					
1 - 5 years ago	<input type="checkbox"/>					
6 - 10 years ago	<input type="checkbox"/>					
Over 10 years ago	<input type="checkbox"/>					

5. Please indicate the type of problem you have experienced with starlings and house sparrows, the crop or commodity affected and the estimated loss in value for the years in which they were a problem.

	STARLINGS			HOUSE SPARROWS		
	Yes	Crop/commodity	Value (£)	Yes	Crop/commodity	Value (£)
Reduced crop yield	<input type="checkbox"/>	<input type="text"/>	<input type="text"/>	<input type="checkbox"/>	<input type="text"/>	<input type="text"/>
Uneven crop ripening	<input type="checkbox"/>	<input type="text"/>	<input type="text"/>	<input type="checkbox"/>	<input type="text"/>	<input type="text"/>
Contamination of livestock feed	<input type="checkbox"/>	<input type="text"/>	<input type="text"/>	<input type="checkbox"/>	<input type="text"/>	<input type="text"/>
Consumption of livestock feed	<input type="checkbox"/>	<input type="text"/>	<input type="text"/>	<input type="checkbox"/>	<input type="text"/>	<input type="text"/>
Contamination of food for human consumption	<input type="checkbox"/>	<input type="text"/>	<input type="text"/>	<input type="checkbox"/>	<input type="text"/>	<input type="text"/>
Consumption of food for human consumption	<input type="checkbox"/>	<input type="text"/>	<input type="text"/>	<input type="checkbox"/>	<input type="text"/>	<input type="text"/>

	STARLINGS	HOUSE SPARROWS
Where disease transmission is a problem please record the nature of the disease and the species at risk	<input type="text"/>	<input type="text"/>

Where safety on the holding is an issue please describe the situations in which you are affected. e.g. droppings on stairways etc.	<input type="text"/>	<input type="text"/>
--	----------------------	----------------------

Comments and other problems (please specify):	<input type="text"/>	<input type="text"/>
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Appendix 11.1 continued

6. Over the last 10 years how have starling and house sparrow numbers changed on your holding? Please tick where appropriate.

	STARLINGS		HOUSE SPARROWS	
Increased significantly	<input type="checkbox"/>		<input type="checkbox"/>	
Increased slightly	<input type="checkbox"/>		<input type="checkbox"/>	
Remained the same	<input type="checkbox"/>		<input type="checkbox"/>	
Decreased slightly	<input type="checkbox"/>		<input type="checkbox"/>	
Decreased significantly	<input type="checkbox"/>		<input type="checkbox"/>	
Don't know	<input type="checkbox"/>		<input type="checkbox"/>	
Comments	<input type="text"/>		<input type="text"/>	

7. Have you used any of the following methods of controlling starlings and house sparrows and do you think they reduced the problem? Please tick where appropriate.

	STARLINGS			HOUSE SPARROWS		
	Yes	Slight reduction	Significant reduction	Yes	Slight reduction	Significant reduction
None used	<input type="checkbox"/>			<input type="checkbox"/>		
Physical measures:						
Removal of spilt grain	<input type="checkbox"/>					
Removal or modification of lights	<input type="checkbox"/>					
Netting of vent flaps	<input type="checkbox"/>					
Other exclusion nets	<input type="checkbox"/>					
Auditory bird scarers	<input type="checkbox"/>					
Visual bird scarers	<input type="checkbox"/>					
Chemical repellents	<input type="checkbox"/>					
Wires	<input type="checkbox"/>					
Lethal control:						
Cage trapping	<input type="checkbox"/>					
Netting	<input type="checkbox"/>					
Stupefying bait	<input type="checkbox"/>					
Shooting	<input type="checkbox"/>					
Egg control	<input type="checkbox"/>					

Appendix 11.1 continued.

8. If you have used lethal control methods for starlings and house sparrows, please indicate the average number killed annually.

	STARLINGS	HOUSE SPARROWS
Over the past year	<input type="text"/>	<input type="text"/>
1 -5 years ago	<input type="text"/>	<input type="text"/>
6 - 10 years ago	<input type="text"/>	<input type="text"/>
Over 10 years ago	<input type="text"/>	<input type="text"/>
Comments	<input type="text"/>	<input type="text"/>

9. If you used lethal control methods please indicate the month(s) during which starlings or house sparrows were controlled. Please also indicate if this has differed over the years.

	STARLINGS	HOUSE SPARROWS
Months of control	<input type="text"/>	<input type="text"/>

10. If you have any further comments relating to this survey, please record them in the box below.

If you have any questions relating to this survey please do not hesitate to phone Helen McKay at the Central Science Laboratory on 01904 462 060 or write to her at: Room 02F11, Central Science Laboratory, Sand Hutton, York, YO41 1LZ or e-mail: h.mckay@csl.gov.uk



ALL REPLIES WILL BE TREATED IN THE STRICTEST CONFIDENCE

Appendix 11.2 Owner/occupier covering letter.

Date, 2001

Dear Land Owner/Occupier,

STARLING AND HOUSE SPARROW CONTROL SURVEY

The Central Science Laboratory (an Agency of DEFRA) is currently conducting a survey to investigate the nature of the problems caused by starlings and house sparrows, and the type of measures used to control them. This survey is part of a wider project to investigate the **many** potential causes of declines in starling and house sparrow populations in urban as well as countryside areas. The work is being carried out on behalf of the Department for the Environment, Food and Rural Affairs (DEFRA), and has the support of the Country Land & Business Association (CLA).

For the survey to be meaningful, it is vital that information is gathered from as many land use interests as possible and your co-operation in completing the questionnaire is therefore extremely important. The survey is completely voluntary and should take only a few minutes to complete.

Even if you do not undertake any control of these species, which is currently licensed by DEFRA, I would be grateful if you would take the trouble to complete all of the questions.

Please note that all replies will be treated in the strictest confidence and that your name and address will not appear on any database, hence the use of a reference number. Thank you for your participation.

Yours sincerely,

Helen M^cKay

Appendix 11.3 Local Authority questionnaire form

STARLING AND HOUSE SPARROW CONTROL SURVEY

1. How serious a problem have starlings and house sparrows been in your local authority area?
Please tick where appropriate.

	STARLINGS			HOUSE SPARROWS		
	none	*moderate	*serious	none	*moderate	*serious
Currently	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
1-5 years ago	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6-10 years ago	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Over 10 years ago	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

* Moderate problem to be defined as one which has cost implications, but can be easily tolerated.
* Serious problem to be defined as one which costs may affect budgets.

2. Please indicate the type of problem you have experienced with starlings and house sparrows, the commodity affected and the estimated cost/loss as an average value per year.

	STARLINGS		HOUSE SPARROWS	
	Yes/No	Value/Cost	Yes/No	Value/Cost
Concerns over public health	<input type="checkbox"/> no	<input type="checkbox"/> nil	<input type="checkbox"/> no	<input type="checkbox"/> nil
Protecting wild birds	<input type="checkbox"/> no	<input type="checkbox"/>	<input type="checkbox"/> no	<input type="checkbox"/>
Fouling of public areas	<input type="checkbox"/> no	<input type="checkbox"/>	<input type="checkbox"/> no	<input type="checkbox"/>
Damage to property	<input type="checkbox"/> no	<input type="checkbox"/>	<input type="checkbox"/> no	<input type="checkbox"/>

House Sparrow and Starling control

Appendix 11.3 continued

Where disease transmission is a problem please record the nature of the disease

Where safety is an issue please describe the situations in which your authority is affected

Other (please specify)

3. Over the last 10 years how have starlings and house sparrow numbers changed in your authority area? Please tick where appropriate and provide evidence on which this assessment is based.

	STARLINGS		HOUSE SPARROWS
	Notes		Notes
Increase significantly	<input type="checkbox"/>		<input type="checkbox"/>
Increased slightly	<input type="checkbox"/>		<input type="checkbox"/>
Remained the same	<input type="checkbox"/>		<input type="checkbox"/>
Decreased slightly	<input type="checkbox"/>		<input type="checkbox"/>
Decreased significantly	<input type="checkbox"/>		<input type="checkbox"/>
Don't know	<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>

Comments

We have not received any requests for service for sparrows or starlings in last 13 years.

Appendix 11.3 continued

4. Have you used any of the following methods of controlling starlings and /or house sparrows and do you think they reduced the problem slightly or significantly? Please tick where appropriate and provide evidence on which this assessment is based.

	STARLINGS			HOUSE SPARROWS		
	Yes/No	Slight reduction	Significant reduction	Yes/No	Slight reduction	Significant reduction
Anti-roofing and proofing measures						
Exclusion nets	<input type="checkbox"/>					
Auditory bird scarers	<input type="checkbox"/>					
Visual birds scarers	<input type="checkbox"/>					
Chemical repellents	<input type="checkbox"/>					
Wires	<input type="checkbox"/>					
 <u>Lethal population control</u>						
Cage trapping	<input type="checkbox"/>					
Netting	<input type="checkbox"/>					
Stupefying bait	<input type="checkbox"/>					
Shooting	<input type="checkbox"/>					

5. If you have used direct population control methods for starlings and house sparrows please indicate the average number of birds culled annually.

	STARLINGS	HOUSE SPARROWS
Currently	<input type="text"/>	<input type="text"/>
1-5 years ago	<input type="text"/>	<input type="text"/>
6-10 years ago	<input type="text"/>	<input type="text"/>
Over 10 years ago	<input type="text"/>	<input type="text"/>

Comments

No work carried out on either species.

House Sparrow and Starling control

Appendix 11.3 continued

6. If you used direct population control methods during which time of year were such methods employed? Please indicate the month during which starlings and sparrows were controlled e.g. 01-03 means January to March inclusive.

	STARLINGS	HOUSE SPARROWS
Months of control	<input type="text"/>	<input type="text"/>

7. If you have any further comments relating to this survey please record them in the box below.

Sorry, but we have never been involved with either species and thus have nothing to feed back to you.

We are most grateful for the time you taken to complete this questionnaire. Please return your form promptly to **Helen McKay at the Central Science Laboratory, Room 02F11, Sand Hutton, York, YO41 1LZ**

ALL REPLIES WILL BE TREATED IN THE STRICTEST CONFIDENCE

Appendix 11.4 Local Authority covering letter

SARAH JONES
SPECIES CONSERVATION POLICY OFFICER
EUROPEAN WILDLIFE DIVISION

DEPARTMENT FOR ENVIRONMENT,
FOOD AND RURAL AFFAIRS
TEMPLE QUAY HOUSE
ROOM 1/08
2 THE SQUARE
TEMPLE QUAY
BRISTOL
BS1 6EB

DIRECT LINE: 0117 3726236
DIVISIONAL ENQUIRIES: 0117 3728903
FAX: 0117 3728182
GTN CODE: 1371
E-MAIL: sarah.jones@defra.gsi.gov.uk

OUR REF: WLF 29/1/02

24 AUGUST 2001

Dear

STARLING AND HOUSE SPARROW RESEARCH - QUESTIONNAIRE INVESTIGATING PEST CONTROL

I am writing regarding the research, sponsored by DEFRA, into the declines of the starling and the house sparrow.

Recent research commissioned by The Department for the Environment, Food and Rural Affairs (DEFRA) has shown that the breeding population of starlings *Sturnus vulgaris* in farm and woodland areas has declined by over 50% in the period between 1973 and 1997. The decline has been especially acute in woodlands. A similar, though less severe, long-term decline in the house sparrow *Passer domesticus* population breeding on farmland has also been documented since the late 1970s. By contrast, relatively little is known about population trends for these birds in the urban and sub-urban areas that support the bulk of the overall population of each species.

The Department has let a comprehensive research project to investigate the long-term declines in two of Britain's most well known bird species. This will also embrace the parts of these populations that occur in urban and sub-urban areas, and any potential deterioration of conditions in winter that may be influencing breeding populations.

The research will assess the demographic and environmental factors that might be most influential in causing the declines in these species and conclude with clear guidance on the relative significance of these factors and with recommendations for any further research required.

The views of local authorities are crucial in determining whether starlings and/or house sparrows have proved to be a problem in their particular situation and whether this problem has required lethal control within the last 10 years. The questionnaire is brief, only taking about ten minutes to complete, and if accessing by e-mail can be viewed in tabulated or text only format.

On completion of the questionnaire it should be sent to Dr Helen McKay, Central Science Laboratory, Room 02F1 1, Sand Hutton, York, YO41 1LZ. E-mail responses may be sent direct to her e-mail account at h.mckay@csl.gov.uk

All replies will be treated in the strictest of confidence. If you wish to discuss either the research, or the questionnaire, then please contact either Helen on 01904 462 060, or myself.

I look forward to hearing from you.

Yours sincerely

SARAH JONES



12 CAUSES OF THE POPULATION DECLINES: SUMMARY AND RECOMMENDATIONS

Humphrey Q.P. Crick, Robert A. Robinson & Gavin M. Siriwardena
British Trust for Ornithology, The Nunnery, Thetford, Norfolk IP24 2PU.

Crick, H.Q.P., Robinson, R.A. & Siriwardena, G.M. (2002) Causes of the population declines: summary and recommendations. In H.Q.P. Crick, R.A. Robinson, G.F. Appleton, N.A. Clark & A.D. Rickard (eds) *Investigation into the causes of the decline of Starlings and House Sparrows in Great Britain*. BTO Research Report No 290, pp 265-292. DEFRA, Bristol.

This report has brought together a wide range of new information on the population dynamics of Starling *Sturnus vulgaris* and House Sparrow *Passer domesticus* in Britain. It has benefited not only from a thorough analysis of the long-term historical datasets held by the BTO, but also from analyses of an intensive study of each species and a large-scale questionnaire survey of the current extent of legal control exercised over the species in Britain.

Thus, in the preceding chapters, the factors that we have analysed and discussed include:

- Population size and long-term trends in abundance in different habitats (Chapters 2 and 3).
- Seasonal patterns in the use of gardens and the effects of winter weather (Chapter 4).
- Breeding productivity at both a broad, national scale (Chapters 6 and 9), and at a local scale, from two intensive long-term local studies (Chapters 5 and 8).
- Annual survival at both a national, and for the first time, at a regional scale (for Starling) for birds of different ages (Chapters 7 and 10).

We have also undertaken population modelling, using novel methods, to diagnose the relative importance of different demographic mechanisms underlying the population changes shown by Starling and House Sparrow (Chapters 7 and 10).

In this chapter, we synthesize the information from the preceding chapters to provide an overview of the British Starling and House Sparrow populations and their demography. We then use this information to provide:

- Guidance on the causes of the changes in population over the last forty years.
- An assessment of the significance and impact of legal control on the population dynamics of the two species.
- Recommendations for future research and for remedial activities that might be taken to help improve the population status of both species.

Throughout this chapter, summaries of the main results and recommendations for further action are highlighted in bold bullet points as an aid for the reader.

12.1 THE DECLINE OF THE STARLING: PATTERNS AND CAUSES

12.1.1 Breeding population size

We have, for the first time, rigorously quantified the size of the Starling population in Britain (Chapter 2). This amounted to some nine million birds in the late 1990s. These mostly occur in two broad habitat categories: farmland and around human habitation. Although the density of birds breeding on farmland (typically about 30 birds.km⁻²) is much lower than in human-associated habitats (180 birds.km⁻²), because farmland represents the major land-use in Britain, a significant proportion of the total population occurs there. Together, farmland, which supports 30% of the population, and human habitats, which supports 57%, hold the vast majority of the British breeding population.

- **The British breeding population of Starling is approximately 9 million.**
- **Farmland supports 30% of the British breeding population; urban/suburban habitats and rural gardens support 57% of the breeding population.**

12.1.2 Population trends in the breeding season

Analysis of the Common Birds Census (CBC) data show that, while populations have declined generally by 68% since 1962, declines have not been equal in all habitats. The greatest decline in CBC index has been in woodland, where the index has declined by 92% since 1965. This decline was already underway at the inception of the index series so, in reality, the total decline in woodland populations is likely to be even greater than this figure suggests. As discussed in Chapter 2, this is likely to reflect the fact that woodland represents a sub-optimal habitat for breeding Starlings but may reflect a decrease in the number of nest holes available. Although very young birds may feed arboreally on caterpillars for a short period immediately after fledging and, in the late summer, birds, particularly juveniles, will feed on fruiting trees, Starlings are primarily ground foragers, preferring to forage on pasture fields (Feare 1984). Thus, birds which breed in woodland will generally have to commute to suitable foraging areas, increasing their energy expenditure and exposing themselves to greater predation risk. Woodland seems to represent a 'buffer' habitat, into which the breeding population will expand, or from which it will contract, as it changes in size. This also suggests that, to some degree, the availability of nest sites on farmland may limit the numbers of birds that can breed there, at least at relatively high population densities.

Although the decline on farmland has been marked, it is less than that on woodland, the population declining by 66% since 1962. This decline, unlike that on woodland plots, has not been continuous. Rather, there were two periods of relatively rapid decline (1965-70 and 1979-91) with an intervening period when the population trend was largely stable. Even within farmland, population declines have shown habitat differences. Populations of Starlings breeding on farms with livestock-based systems have declined to a greater extent than those which breed on arable-based farms. The regional differences in CBC index values also reflect this, with declines being greatest in the south and west of Britain. This strongly suggests that changes in livestock farming have impacted on Starling populations and caused at least some of the population decline.

Population trends in birds breeding in urban and suburban habitats are largely unknown, although the Breeding Bird Survey (BBS) suggests that suburban/urban populations are currently declining, though to a lesser extent than in farmland habitats. An analysis of trends using the winter-based Garden Bird Feeding Survey (GBFS) suggests that there may be a decline in numbers. However, this is confounded by immigration from continental breeding populations, some of which are also known to have declined, and weather related dispersion of birds within Britain (see below for a full discussion of these factors).

- **The greatest declines in CBC index (92%) have been observed in woodland, but this probably represents sub-optimal habitat for Starling. Declines on farmland average out at 66%.**
- **Population declines on farmland are associated with livestock-based systems.**
- **Populations in suburban and urban areas are currently declining, but more slowly than in the wider countryside.**

12.1.3 Population trends in winter

In common with the breeding population, the number of Starlings present in Britain in winter has decreased. The GBFS indicates a 45% decline since 1970, with most of this occurring since 1985 (Chapter 2). The decline has been greater in suburban/urban gardens than in rural gardens. The only available information on winter farmland population trends in Starling numbers comes from studies of declining populations in Oxfordshire and Lincolnshire (Easterbrook 1999; Feare 1994). These

suggest that declines noted in gardens in winter may also be representative of population changes in the wider countryside.

The British wintering population of Starlings probably originates from around the Baltic, arriving in Britain from the Low Countries during November. Trends in the breeding populations are relatively poorly documented in these areas but there does appear to be some evidence for general population declines since the early 1980s (Chapter 2). Individuals from these populations also winter elsewhere in Europe and some will stop off *en route* to France and Iberia. This will affect the number of Starlings counted as wintering in Britain (Feare 1994).

The pattern of winter usage of gardens is further complicated by climatic considerations, at two scales. Winter temperatures in the breeding areas from which British winter immigrants originate are likely to increase markedly as the global climate warms (Parry 2000). This is likely to mean that fewer individuals will travel as far as Britain to winter, preferring to remain closer to their breeding grounds. Thus numbers of birds wintering in Britain are likely to decrease, independently of any changes in breeding populations. In Britain, the number of birds using gardens during the winter is also related to weather conditions (Chapter 4). In periods of severe weather, food resources become scarce and birds need to take advantage of other foraging opportunities. Individuals that would otherwise forage on 'natural' resources present in the wider countryside may congregate in gardens to forage on the 'artificial' food provided there. This is particularly evident in rural gardens where numbers were generally higher in the mid 1980s when winter temperatures were lower than in the 1970s or 1990s. The decline in Starling numbers in suburban gardens has been greater than that seen in rural gardens and the rise in winter numbers in the mid 1980s was also smaller. This suggests that the number of birds using urban and suburban gardens is less influenced by influxes of birds from the countryside during periods of adverse weather than the numbers in rural gardens.

Very little is known about the winter dispersal and habitat use of breeding Starlings in Britain, though virtually all remain in the country and most within a few tens of kilometres of where they breed (Feare in press). The wintering populations of immigrant Starlings in different areas of Britain originate from different breeding populations (Fliege 1984) and the habitat use of these immigrant birds whilst in Britain is unknown. Habitat use and its consequences for demography (particularly survival) is often density-dependent (Sutherland 1996), thus a knowledge of which habitats these birds use during their stay in Britain is necessary for a full understanding of over-winter survival patterns in the British breeding population. Knowing the relative importance of each habitat and how birds move between them is likely to be extremely important in understanding how to reverse the Starling population decline.

- **Information on winter population trends contained in the GBFS data is confounded by patterns of winter dispersal of birds within Britain and from overseas.**
- **The numbers of Starlings using suburban/urban gardens in winter are less affected by influxes from the wider countryside than those in rural gardens.**
- **The number of birds using rural gardens has not shown a marked long-term decline, but rather appears to be related to climatic conditions.**
- **Understanding dispersal within Britain of the British breeding and continental breeding populations, and how these interact, is essential to effectively plan action targeted at reversing the decline in the British breeding population.**

12.1.4 Demographic Processes

In resident bird populations, such as that of the British breeding population of Starlings, two main processes will influence the population trend: the production of fledged young, and the survival of free flying birds (Lack 1954).

12.1.4.1 Productivity

Breeding productivity was quantified by using the archives of the Nest Record Scheme (NRS, Chapter 6), which can be used to assess the success of individual breeding attempts. The breeding performance of Starlings has increased over the last forty years. This is similar to the situation in many other declining passerines (Siriwardena *et al.* 2000a; Baillie *et al.* 2001). In general, increased temperatures and longer growing seasons caused by global climate change mean that birds can lay eggs earlier (Crick *et al.* 1997, Crick & Sparks 1999) and may have greater quantities of available invertebrate food to feed to their young. Such a pattern may also represent a density-dependent response to a reduction in numbers, and this is discussed below.

Although there was relatively little difference in breeding productivity on individual farms of different types, productivity was higher in the West and South West of Britain, where pastoral farming tends to predominate, and lowest in the South East where densities were highest and declines greatest. Breeding performance was also greater in rural compared to suburban gardens, and in suburban gardens compared to urban gardens. Thus, as has been found in other studies (Tiainen *et al.* 1989; Bruun 2002), productivity tends to be higher in more rural, particularly more pastoral, areas.

The NRS can only be used to look at the number of fledgling birds produced in each nesting attempt. Productivity summed across the entire season is more important for population dynamics. Although no national data are available, we used a long-running local study to address this (Chapter 5). This study ran from 1975 to 1997 at a suburban colony in Surrey, which included the major period of decline in the national population index (CBC) and some years immediately preceding the decline, when the CBC index was largely stable. Unlike the national population, numbers at this colony remained largely stable until 1991, when they fell to about one third of their former numbers. Although the number of birds fledged from each nest varied significantly from year to year, there was no overall trend in productivity, nor any discernible difference in the years immediately preceding or following 1991.

In this local study, the proportion of birds laying second clutches varied annually, being largely dependent on the date of laying of the first clutch. There did not appear to be a systematic temporal trend in either of these variables. The mean period between laying of the first and second clutches (the inter-clutch interval) also varied between years, but showed no long-term temporal trend. In general, the inter-clutch interval reflects the degree of environmental stress that laying birds face during the breeding period. The implication from this study is that it has not increased.

- **Breeding performance (per nesting attempt) has increased during the period under investigation.**
- **There were differences in productivity between regions and habitats: productivity was lowest in the South East and in urban gardens.**
- **Results from a local study in suburban southern England suggested that the number of nesting attempts each year has not changed.**

12.1.4.2 Survival

Survival was quantified using reports of dead birds which had been ringed as part of the National Ringing Scheme (Chapter 7). We estimated survival during the period immediately following fledging (which lasted 44 days) as 37.7%, that over the first winter as 39.0% and annual adult survival as 67.1%. Thus, birds were much less likely to survive their first year (only 15% would) than any subsequent year. These estimates are comparable to other similar sized birds, such as the Song Thrush *Turdus philomelos* (R.A. Robinson, unpubl.), and other passerines in general (Siriwardena *et al.* 1998b).

Although, over the long-term, survival of birds over the first winter is broadly what might be expected of a passerine of this size, it has not been constant. In particular, it declined markedly through the 1980s, from 50% in 1980 to just 31% in 1991. Survival increased subsequently to around 45%.

The decline in survival rates nationwide coincided with the major period of decline in the CBC index, which showed some evidence of levelling off subsequently, possibly in response to the increase in first-year survival rates at that time. Although adult survival rates were also higher during this later period, the pre-eminence of first-year survival rates was indicated by population modelling (Chapter 7). Thus, factors that affect the over-winter survival of first year birds are almost certainly responsible for the decline in population size. Note, though, that the 'over-winter' period is very broadly defined here, running from August through to the following May. The important source of mortality may be happening at any point in this period. This will be discussed further below.

The regional population models constructed in Chapter 7 show that first-year survival rates differed between regions. Whilst there has been little overall trend in the survival of first-year birds in Eastern England, survival rates in Western and Northern England tended to be lower during the periods of population decline in those regions. Adult survival rates, though variable, did not differ much between the regions, but seemed to be the most likely driver of the population decline in Eastern England. On the basis of national analyses of survival rates, the declines in many farmland bird species can be attributed to changes in first-year survival (Siriwardena *et al.* 1998b). The results presented here are particularly interesting, since they suggest that species' demography may vary regionally and hence conservation measures may need to be regionally targeted.

- **Changes in survival rates of first-year birds coincide with changes in the breeding population, as measured by CBC.**
- **Estimates of, and trends in, first-year survival differ regionally in Britain, with first-year survival in the North and West of Britain being lower during periods of population decline, while adult survival was lower during population declines in the East.**

12.1.5 Population Dynamics

The results of these analyses clearly demonstrate that the recent population decline (1979-91) in the British breeding population is related to changes in survival (Chapter 7). Not only has productivity apparently increased over the last twenty years, annual changes in productivity do not reproduce the pattern of observed population change in the CBC index. In support of the national pattern, the long-term study of the Worplesdon Starling colony carried out by CSL indicated that recruitment into the population was more important than productivity in determining the decline in that population. This conclusion also agrees with that of Aebischer *et al.* (in press), who suggested that changes in survival were required in order to reverse the Starling population trend and help meet the government's Public Service Agreement (PSA) target on farmland bird populations. In fact, these analyses expand on that conclusion, since they suggest that first-year survival, in particular, is the critical factor.

A major, and innovative, result of this study has been the construction of regional models of Starling population dynamics. Even though these models push the boundaries of what is possible, given the available data, they do reveal some very interesting results. Although changes in survival have driven the population decline, the stage of the life-cycle at which the critical period of mortality occurs appears to differ between the largely arable South and East and the more pastoral North and West of the country. These differences in survival are likely to reflect differences in habitat use, particularly by juveniles. In autumn, when first-year birds disperse from their natal area, possibly as a result of exclusion by adult birds (Feare 1984), they are found in a wide range of agricultural and non-agricultural habitats, including grazed hill pasture, salt marsh, orchards and a wide variety of urban and suburban habitats; whereas adults tend to remain in the same area (Cramp & Perrins 1994). Most of these supplemental habitats are likely to be more common, and possibly of higher quality, in the South East of Britain; grazed hill pasture contains relatively few soil invertebrates, for example

(Coulson 1962). The greater decline in survival in Western Britain may thus be a result of a shortage of habitat into which juveniles can disperse; for example, upland afforestation may have reduced habitat availability. In order to increase juvenile survival, extensive creation or re-instatement of 'good' habitat would be required, particularly in Northern and Western Britain. Such changes need not be expensive or intrusive to farming systems (Curry 2002). It must also be noted that the amount of data available, for both the ring-recovery and, particularly, the productivity part of these regional analyses was barely adequate and that information on the relative quality of different habitats in each region is needed to confirm these conclusions.

A critical factor we have not taken into account explicitly is density-dependence in demographic rates. The presence of density-dependence will affect both the diagnosis of population declines (Green 1999) and potential remedial action that could be undertaken to manipulate the population levels of species (Newton 1998; Aebischer *et al.* in press). The premise underlying density-dependence is simple (Newton 1998); as survival or productivity declines below the level that the environment can currently support, there will be fewer individuals competing for limiting resources, thus the decline will tend to slow as individuals have higher per-capita survival or reproductive success. Note, this only occurs if resources are limiting. Although density-dependence is important in determining population dynamics, it is extremely difficult to measure in free-living populations (Holyoak & Baillie 1996a,b).

Although it is hard to quantify, it is likely that both survival rates and breeding productivity of Starlings are density-dependent. Both brood size and survival, particularly first-year survival, have increased through the 1990s, following the major period of population decline. Thus, the cessation and subsequent increase in survival during the 1990s should not be taken as evidence that the environmental stress factor causing the decline in survival has ceased to be present; it may reflect purely internal population processes.

Aebischer *et al.* (in press) estimated the increase in survival rates of adult and first-year birds required to reverse the Starling population trend in order to meet the PSA target of reversing the decline in the farmland wildbird indicator by 2020, under some simple model assumptions. Under conditions of no density-dependence, they suggested that a 6% increase above their estimated average survival rates for the period 1990 to 2000 would be required. However, the required increase needed to be much greater when the survival rate was modelled as being density dependent; the increase required being proportional to the strength of density-dependence. In fact, this analysis has shown that Starling survival rates are currently somewhat higher than they suggest are required to reverse the population decline under the assumption of no density dependence. The estimates of survival presented here for the period when the CBC index was largely stable (1972-79) suggests that the strength of density-dependence may actually be in the middle of the range that they considered. Thus, in reality, the increases in survival rates required to reverse the population decline are likely to be in the higher part of the range they consider necessary.

- **Changes in first-year survival, particularly in Northern and Western Britain, have been a major driver of the population decline; however, changes in adult survival may also have contributed. Changes in productivity have not contributed to the population decline.**
- **Survival rates and breeding productivity of Starlings, and other species, are likely to be density-dependent, although to an unknown degree. This needs to be considered when setting targets for ameliorating population declines.**
- **Encouragement of nest recording and ringing (and the subsequent recovery) of Starlings would greatly aid the construction of regional Integrated Population Models with which to measure the efficacy of remedial actions. This applies more generally to all species, since future conservation challenges are usually unknown.**

12.1.6 Starlings on farmland

On farmland, Starlings are very much birds of pastoral systems; the BBS shows that densities are currently approximately 2.5 times as great in pastoral compared to arable habitat. This largely reflects their foraging preferences; prey densities tend to be higher in pasture fields, particularly those which are undisturbed by cultivation (Whitehead *et al.* 1995; Bruun 2002). The key features of pastoral systems for biodiversity in general and species in particular are not as well understood as for arable systems (Vickery *et al.* 2001). However, we briefly outline the major features of pastoral habitats and their management that are likely to be important for Starlings and how they may have affected their population status.

The main prey of Starlings are soil and ground-dwelling invertebrates, particularly leatherjackets (tipulid larvae) and earthworms, although they take a wide range of other taxa and some plant material (seeds), particularly in autumn and winter (Kluijver 1933; Tinbergen 1981). There is little information published on population trends in tipulids, which are the major prey of Starlings; but numbers are quite variable from year to year and there is little evidence for a decline in numbers (Wilson *et al.* 1999). Tipulid numbers are monitored as one of the core measures in the Environmental Change Network (Lane 1997). Soil sample cores have been taken in April and September and data are available for 1993-2000. Over the six lowland sites (Alice Holt, Bucks; Drayton, Northants; Hillsborough, N.I.; North Wyke, Devon; Rothamsted, Herts. and Wytham, Oxon.), there has been no temporal trend in tipulid numbers recorded. However, analysis of the longer-term annual leatherjacket survey organised by the Agricultural Development and Advisory Service (ADAS) (e.g. Blackshaw 1983) would be particularly informative in this regard. For example, these surveys show that leatherjacket numbers are negatively correlated with warm, dry autumns (Blackshaw & Coll 1999), the frequency of which is likely to increase in the UK due to global climate change (Hulme *et al.* 2002).

The number of soil invertebrates is affected markedly by the frequency of cultivation, with biomass being higher in fields where soil disturbance is minimal (Paoletti 1999). In general, soil cultivation reduces the number of invertebrates present. Consequently, invertebrate densities tend to be highest on permanent pasture fields, rather than on temporary grass leys (Wilson *et al.* 1999; Vickery *et al.* 2001) and Starlings prefer to forage in this habitat (Whitehead *et al.* 1995; Wilson *et al.* 1996). The density of birds recorded by the BBS is also greater on unimproved grass (36.7 km⁻², average across all regions) than on improved grass (29.9 km⁻²). These categories, however, are broadly defined and will include habitat of varying quality. For example, the CBC shows that Starling abundance tends to be lower in areas where rough grazing predominates which, because of lower soil fertility levels, will have fewer soil invertebrates (Coulson 1962).

The area of pasture in England & Wales has decreased by 10% since 1970 (DEFRA statistics), with the decrease in temporary grass (down by 348,000ha) being much greater than the decrease in the area of permanent pasture (down by 137,000ha). The total area decline, however, tells us little and differences in definition of grassland type complicate this comparison. Some knowledge of the spatial patterning of this change would be required to fully ascertain how important this loss of habitat is in driving the population decline.

On grassland, Starlings often forage in association with livestock, particularly cattle (Feare 1984). Grazing by livestock, especially sheep, can lead to very dense swards, where stocking densities are high. Cattle, being larger and less selective in their foraging, create a more heterogeneous sward in which Starlings can forage more easily (Vickery *et al.* 2001). Although the number of sheep on pasture has increased (Fuller & Gough 1999), the size of the cattle herd in Britain has decreased by 18% since 1970, with most of this decrease occurring since 1980 (DEFRA statistics). The decrease has been restricted to the dairy herd, which made up 70% of the total cattle herd in 1980; numbers of beef cattle have increased slightly. The timing of grazing is also likely to be relevant, with autumn grazing likely to be less deleterious to invertebrate numbers than spring grazing, although the impact on leatherjackets specifically is unclear (Vickery *et al.* 2001).

Summary

In a quest for increased yields, the nature and quantity of inputs into farming systems have changed in both arable and pastoral systems, although the changes have been greatest in arable systems (Vickery *et al.* 2001; Robinson & Sutherland 2002). Farmland is now increasingly fertilised with synthetic fertilisers rather than organic fertilisers, such as manure. Although the increased use of synthetic fertilisers will decrease the amount of organic matter in the soil, moderate levels of fertilisation, which promotes plant biomass, will generally increase the overall number of soil invertebrates present, though there seems to be little effect on leatherjacket numbers (Linzell & Madge 1986; Paoletti 1999). Numbers and diversity of other insects taken by Starlings, however, may decrease and very high levels of fertilization can also decrease soil invertebrate numbers (Edwards & Lofty 1975; Fenner & Palmer 1998).

The indirect effects of fertiliser use will generally be unfavourable to the Starling. Fertiliser use tends to promote taller, denser swards, in which Starlings will have greater difficulty foraging, and is also likely to be associated with increased levels of grazing and/or mowing. The commonest tipulids of agricultural land, such as *Tipula paludosa*, feed on a wide range of plants and are able to persist at relatively high densities in improved grassland, which could explain why populations of Starling are declining less in this habitat than in others.

One consequence of increased fertiliser application has been an increase in the area used for silage production, at the expense of hay-fields (Chamberlain *et al.* 2000). In the 1970s, hay and silage production occurred at a ratio of 85:15. The invention of the 'big round baler' in the 1980s meant that silage production became feasible in marginal areas, where permanent silos were not economically justifiable (Vickery *et al.* 2001). The ratio of hay to silage production is now about 10:90. Silage fields are cut more frequently, which leads to a general reduction in organic matter and hence soil invertebrate biomass, although there may be a temporary flush of invertebrates following cutting (Vickery *et al.* 2001). Silage fields are also often heavy rolled early in the season, to prevent *Clostridium* poisoning of the crop, which leads to a marked decline in leatherjacket numbers (Clements & Cook 1996).

The amount of pesticide applied on farmland has increased dramatically. The total area sprayed with insecticides, for example, has increased approximately ten-fold since 1970 (Robinson & Sutherland 2002). Although this increase has been greatest on arable land, there has been a marked increase in the amount applied to pasture fields too, though the relative amounts are much smaller (Vickery *et al.* 2001). The application of such chemicals will generally target those organisms that cause economically significant amounts of damage, such as leatherjackets, wireworms and molluscs. Carbamates, which are often used on grass and are also particularly toxic to earthworms. Thus the major invertebrate prey of Starlings are likely to be disproportionately affected by current regimes of pesticide applications. However, experiments during the breeding season suggest they may be able to find alternative food sources at this time, as breeding success was not unduly affected (Fletcher *et al.* 1992).

Perhaps more important than the increase in use of insecticides has been the increased use of anthelmintics, particularly Ivermectin, in livestock (McCracken 1993). Although Starlings rely predominantly on subterranean invertebrates, they turn to surface-dwelling invertebrates if these are scarce or unavailable due to drought or hard frost (Feare 1984). Starlings will also utilise other food sources, including invertebrates from dung at such times. The importance of this source of food for Starlings has not been established but, if it is important, depletion through the advent of Ivermectin is likely to impact on the survival of individual birds, especially at times when sub-surface prey is unavailable and birds are likely to be generally stressed.

Starlings frequently forage around cattle feeding stations, where they may take significant amounts of food, particularly cereal grains (Feare & Wadsworth 1981; Feare 1984). It is often the most dominant birds (primarily adult males) that use this food source, other individuals continuing to forage on grassland. The tendency to keep cattle indoors may have reduced foraging opportunities for Starlings.

Similarly, Starlings often forage on outdoor pig farms (Feare 1994). The number of pigs kept in Britain has also decreased, by about 500,000 or 7.5% since 1981 (DEFRA statistics), which may also have reduced foraging opportunities.

- **There has been a general intensification in the management of grassland which may have impacted on Starlings. This is likely to have reduced both the number of foraging opportunities and prey density.**

12.1.7 Starlings in towns

Relatively little is known about Starlings, or many other species, in towns and cities. People will perhaps be most familiar with the spectacular urban roosts, sometimes numbering in excess of a million birds, as they wheel around stands of large trees in the darkening skies. There can be few more evocative sights. However, these urban roosts are a relatively recent phenomenon, and the number of roosts was increasing in the 1950s and 1960s (Potts 1967). Part of the increase may result from an expanding population, but may simply arise because birds are taking advantage of sheltered roost sites and a reduction in harassment from predators (Feare 1984). However, the number of urban roosts has declined since the early 1980s, with major roosts, such as those in London, Leeds and Bristol no longer existing (C.J. Feare pers. comm.). There is some, largely anecdotal, evidence that these roosts seem to be used largely by resident birds, rather than continental immigrants (e.g. Potts 1967), but this needs to be confirmed with large scale ringing studies.

The BBS recorded very high densities of birds occurring in suburban areas during the breeding season, certainly much higher than in farmland areas. A major finding of this report is just how important suburban and urban habitats are for Starlings. For breeding, Starlings require a suitable cavity to nest in with some short grass fields close to the nest; adults rarely forage more than 500m from the nest (Feare 1984). Such opportunities must be widespread in many towns and cities, although the quality of the urban and suburban habitats in terms of food provisioning for nestlings is unknown. Nesting attempts in urban and suburban areas tended to produce fewer young than those in more rural situations. This seemed to be related more to differences in clutch sizes and hatching success than to chicks dying in the nest (Chapter 6). A further consideration is the extent to which non-breeders are present in the population. Many Starlings may not breed every year (Chapter 5), but the relative frequency of this in different habitats is unknown.

Lawns, parks and sports fields must provide an attractive alternative foraging habitat to their preferred pasture fields. Although large numbers of Starlings can frequently be seen foraging in these areas, their quality, in terms of the food resources available, remains unquantified. Also unknown is the extent to which Starlings use these resources. Potts (1967) noted some largely anecdotal evidence that roosts in urban areas generally receive relatively few continental immigrants. Chapter 4 showed that the influx of birds into suburban areas during periods of severe weather in winter was much less than for rural areas, which again suggests that continental immigrants, which will be much more mobile than resident birds and hence more likely to make cold weather movements, may use urban and suburban areas to a lesser extent. For the moment, though, this must be regarded as largely speculative.

- **The dynamics and resource use of urban Starling populations are poorly known.**
- **Further work is needed to determine the food availability for and resource use of urban and suburban Starlings.**

12.1.8 Conclusions and recommendations

In order to understand the causes of a population decline, and to plan effective measures to ameliorate the decline, one needs to understand the demography of the species concerned. For the Starling, this consists of three components: productivity, survival and migration/dispersal. For the British breeding

Summary

population, dispersal is likely to be negligible at a national level since the bulk of the population remains within the country. Adult dispersal between breeding seasons tends to be low, but juveniles will disperse much more widely in their first autumn. Mortality of juvenile Starlings is higher than adults (as for almost all other passerines) and changes in this are likely to have been a major driver of the population decline. Mortality is likely to be highest when birds are moving between habitats; mortality at other times of year may be relatively low (e.g. Sillett & Holmes 2002). Further research into juvenile dispersal and habitat use would be informative in understanding reasons for the population decline. Particular attention should be paid to differences between Eastern and Western Britain, since the survival of juvenile birds seems to differ between the two regions.

This report clearly shows that changes in survival have driven the population decline. On farmland, these changes are likely to have resulted from decreased foraging opportunities. There seem to be two major categories of foraging opportunities for Starling: foraging on soil invertebrates in pasture fields and foraging around livestock. Assessment of the relative importance of these is hampered by a lack of quantitative data on prey availability. Long-term data on leatherjacket abundance are potentially available from the ADAS annual leatherjacket survey (e.g. Blackshaw 1983) and from the ECN network. An analysis of these data in relation to the Starling decline and, in particular, the regional and habitat differences in population trend, could determine whether recent changes in pastoral farming practice have reduced food supplies sufficiently to have caused the Starling population decline.

During the non-breeding period, the number of individuals that a habitat can support is largely determined by the available food resources. This, in turn, is largely determined by a few key foraging parameters: the rate at which food is encountered, the handling time of an individual item, the strength of aggregation and the density of prey at which further searching becomes unprofitable (Sutherland & Anderson 1993). Models of individual behaviour which incorporate these parameters have proved extremely successful in determining and predicting population size in a diverse range of bird species (Sutherland 1996; Bradbury *et al.* 2001; Gill *et al.* 2001). This approach is also being used in two current DEFRA contracts exploring the declines in farmland seed-eating birds. Much of the information required to parameterise these models is already available (e.g. Whitehead *et al.* 1995, 1996). Constructing such behaviour-based models would determine the extent to which changes in agricultural management in pasture farmland are likely to impact on Starling survival.

The situation in winter is complicated by the presence of immigrants from the continent. These come from a number of breeding populations, mainly those breeding near the Baltic Sea (Fliege 1984; Feare in press). Although the number of these immigrants is unknown, as are changes in numbers, they are likely to be at least as numerous as the breeding population (Potts 1967; Feare in press). During the winter, Starlings are relatively mobile and can exploit a wide range of food sources. Consequently, their survival is not depressed by severe weather as it is for many other species (Dunnet 1956; Taitt 1973). It thus seems unlikely that changes in food supply during the winter period are critical factors within the population decline. Their prey is likely to be scarcest in the autumn, when adult craneflies have emerged from their larval stages and are laying eggs. In this regard, it is interesting to note that when the population was at its highest in the 1960s, large numbers of birds fed in cherry orchards during the summer (Feare 1984). These birds were mostly juveniles, which have a tendency to feed more arboreally than adults, perhaps because they are sub-dominant and excluded from preferred pasture habitats by adults.

The major change in the farming landscape over the last twenty years has been the increased specialisation in farming systems, both at a farm unit and at a landscape scale (Robinson *et al.* 2001; Robinson & Sutherland 2002). Arable farming has largely become concentrated in Eastern Britain, with pastoral farming predominating in the West. This decreased habitat diversity is likely to be the root cause of many of the widespread declines in biodiversity seen in recent years (e.g. Krebs *et al.* 1999; Robinson & Sutherland 2002). These results suggest that increasing the amount of pastoral farming in arable areas should increase Starling numbers. This can be tested by comparing the increase in the number of breeding Starlings in response to small increases in the amount of pastoral

habitat, using data from the BBS in an analysis analogous to that of Robinson *et al.* (2001). This shows that in arable landscapes, where pastoral habitat is generally scarce, increased amounts of grassland do indeed produce a significant increase in Starling numbers. In pastoral landscapes, where grassland is generally common, the increase is much less marked and statistically non-significant; mixed landscapes were intermediate (Table 12.1.8).

It should be noted that this analysis considered grassland habitat as a whole, with no distinction being made with regard to habitat quality. Sympathetically managed grassland habitat would be likely to produce much greater increases in Starling numbers than those detailed here. In a comprehensive review, Aebischer *et al.* (in press) considered the features of pastoral management that would be most likely to improve Starling numbers. In essence, these were the planting of grass pockets, management for a short, sparse sward structure and provision of winter stubbles. Encouraging minimum tillage might also have beneficial effects, but this was seen as of secondary importance. The results presented here support these recommendations.

Table 12.1.8 Interaction between the extent of pasture available locally and regionally. The slopes of the relationship (coefficients of a Poisson log-linear regression, with 1 standard error) between bird numbers and pasture habitat (in a 1km square) in grass, mixed and arable landscapes. The χ^2 value tests for significant differences between the slopes (*i.e.* the interaction term of the regression model). Asterisks indicate significance: * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$. See Robinson *et al.* (2001) for full details of the analytical method.

	Grass (n=517)	Mixed (n=512)	Arable (n=329)
Slope	0.037 (0.040)	0.056(0.028)*	0.18(0.05)***

$$\chi^2 = 15.56, p = 0.0014$$

Although the population decline has been largely driven by changes in survival, it seems likely that the population breeding on farmland may have been limited by the numbers of nest sites. When the population was highest there were large numbers of birds breeding in woodland, presumably commuting to farmland to forage (Chapter 2). This population started to decline earlier and has declined faster than the farmland population, classic indicators of a buffer habitat (Brown 1969; Gill *et al.* 2001). Providing extra nesting-sites within good areas of farmland may have the potential to increase the size of the breeding population in these areas, but this requires that sufficient foraging resources are available to support the increased numbers. This could be done through the provision of suitable nestboxes, primarily in areas close to suitable foraging habitat. Bruun (2002) provided nestboxes in his farmland study area in Southern Sweden and found a good number were occupied, also suggesting a limiting number of nest-sites in his study area. In a similar vein, Aebischer *et al.* (in press) recommended planting of hedgerow trees, which would increase the availability of nest-sites for Starlings in the longer term. Thus, although breeding productivity is not the cause of the decline, provision of extra nesting opportunities has the potential to help reverse it. Careful monitoring would be needed to ensure this was actually the case and birds were not simply moving from other sites.

- **The population decline in the wider countryside has been caused by changes in survival, particularly first-year survival. This is likely to be related to supplies of available food in the autumn.**

To identify the environmental factors behind this decline and to help reverse it and thereby meet the PSA farmland bird target, we recommend that the following actions should be considered:

- **Undertake a survey to determine differences in juvenile dispersal and habitat use in Eastern and Western Britain.**
- **Undertake a survey to determine where birds from urban and suburban populations forage, and the quality of those habitats.**
- **Analysis of the long-term ADAS leatherjacket survey results to assess potential**

- **changes in food availability for Starlings foraging on farmland.**
- **Construction of behaviour-based models to assess the impact of prey availability on Starling population size.**
- **Assessment of the importance of livestock feeding stations as a food resource and the impacts of changes in animal husbandry.**
- **Use of agri-environment schemes to encourage the inclusion of pockets of grassland habitat in arable areas to help reverse the Starling decline.**
- **Studies of recruitment to urban/suburban starling populations are needed, to discover whether they are self-sustaining, or whether they depend on immigration from elsewhere for their maintenance, and if so, to investigate the range from which birds immigrate.**
- **Provision of extra nest-sites, in the form of nestboxes, as a potential means to reverse the observed decline of the Starling. However, any such scheme should be closely monitored to ensure its efficacy.**

12.2 THE DECLINE OF THE HOUSE SPARROW: PATTERNS AND CAUSES

12.2.1 Breeding population size

This study provides a population estimate of *c.* 13 million House Sparrows in Britain during the breeding season during the late 1990s. This is the first such estimate based on a properly stratified random sample of all major habitats, including urban and suburban habitats. Previous estimates have been based on small and potentially unrepresentative sample plots, or have used information from the CBC, which only covers lowland farmland and woodland habitats concentrated more towards the South and East of Britain. Given that House Sparrow populations are likely to contain a certain proportion of non-breeding birds (Anderson 1990; Summers-Smith 1988, 1999) the number of breeding pairs is likely to number around six million. The analysis of population trends shows that declines in abundance of between 50 and 60% have occurred in both the wider countryside and in suburban/urban habitats. This suggests that, in the early 1970s, before the current decline began, the breeding population of House Sparrows was between 12 and 15 million breeding pairs.

The BBS is also able to provide estimates of the proportions of the population in each major habitat and region. (It should be noted that House Sparrows usually occur near buildings, but the habitats are those in the wider context around the 200m transect section surveyed as part of the BBS.) Some 63% of breeding House Sparrows occur in human habitats, 18% on unimproved and improved grass, and only 10% in arable farmland. Thus, human habitats and particularly suburban areas, which alone contain 35% of the population, are of major significance for the House Sparrow. This is shown particularly by the densities of breeding birds in different habitats: *c.* 320km⁻² in rural and suburban human habitats; 220km⁻² in urban areas; but only 45km⁻² in pastoral habitats and 25km⁻² in arable farmland.

Regionally, just over a half of British House Sparrows occur in East Anglia, Central East and southern England. This, then, is the key region for the species and may link to its likely origins in warm, dry areas of the Middle East (Summers-Smith 1988). Densities within pastoral habitats tended to increase from South East to North West, but showed no such trend in arable farmland or human habitats (suburban or urban areas and rural gardens).

House Sparrows can be difficult to count, because they are not strictly territorial and often occur in small mobile flocks that fly to dense cover if disturbed, where exact numbers of calling birds can be difficult to estimate (Churcher & Lawton 1987). Counts in urban and suburban areas are also likely to miss a proportion of birds because of difficulty in gaining access to gardens or in observing the back of buildings (e.g. Bland 1998). Furthermore, House Sparrows appear to be distributed patchily within the urban and suburban environment and more information is needed about this spatial patterning. Thus, although the BBS can produce a better population estimate than previous ones

because of its sampling design, its surveyors are likely to miss a proportion of the population due to the species' colonial behaviour and due to the structure of the suburban/urban environment. Also, the BBS analytical methodology makes assumptions about the independence of bird registrations and of smooth changes in detectability with distance that are unlikely to apply to counts of House Sparrow in suburban/urban environments. Thus a targeted survey of House Sparrows should aim to take such factors into account.

During the early part of the breeding season, male House Sparrows defend their nest sites by sitting and calling from near their entrances almost continuously (Summers-Smith 1988) and are readily identifiable by non-specialist birdwatchers. It would therefore be desirable to design a special survey to establish the fine-scale patterning of population densities in different suburban and urban habitats where the BBS methodology may be less efficient at counting House Sparrows than for other less colonial and more strictly territorial species.

- **The British breeding population of House Sparrows is around 6 million pairs, having fallen from between 12 to 15 million pairs in the early 1970s.**
- **Just over half of British House Sparrows occur in southern and central-eastern England.**
- **About 60% of House Sparrows occur in towns, villages and rural gardens, with over half of these in suburban areas.**
- **Because of difficulties in counting urban and suburban populations due to the species' colonial habits and difficult physical structure of the habitat, there is a need to undertake a specific national survey to establish the fine-scale patterning of population density estimates for House Sparrow in these habitats.**

12.2.2 Population trends.

Long-term trends in House Sparrow abundance in the breeding season have only been monitored in the wider countryside, in essentially lowland areas by the CBC since 1976. Overall, the size of the population in these areas has fallen by 53%, and by 46% in farmland alone. The declines have been greatest and are still continuing in East England (90%) and South East England (65%), but have shown some signs of recovery in the West (only 50% decline) and have shown fluctuations, with no overall decline in South West England and North Britain (Chapter 3). The declines have also been greatest in arable farmland, less steep in pastoral farmland and least steep on mixed farmland.

Given the essentially sedentary nature of House Sparrows and their high densities in garden habitats, the population trends recorded from gardens in winter by the GBFS provide probably the best long-term monitoring record of the major part of the House Sparrow population. Numbers have fallen more rapidly in suburban and urban gardens (60%) than in rural gardens (48%), but with declines all starting in the early 1980s. The declines started earlier (in the late 1970s) in the wider countryside, as measured by the CBC, indicating that its suitability declined sooner than suburban and urban habitats. However, the smaller decline in rural gardens, combined with their high densities there, suggests that this habitat is perhaps most preferred.

The BBS, which samples a wider geographical area and broader range of habitats than the CBC, confirms that between 1994 and 2000, populations have declined in the South East, especially in the species' strongholds in suburban and urban habitats, but have been generally increased in Scottish farmland (both arable and pastoral) and in Welsh towns (urban and suburban). The reasons for such marked differences in population trends between regions and habitats are unclear and suggest the need for some intensive comparative research, particularly with respect to the possible causal factors that are discussed in later sections of this chapter.

Contrasts that would be particularly valuable to investigate include:

- House Sparrows in rural, suburban and urban gardens.
 - Urban and suburban House Sparrows in Wales (population increasing) and in South East England (population decreasing).
 - House Sparrows in arable and pastoral farming in Scotland (population increasing) and in South East England (population decreasing).
- **Since the 1970s, House Sparrow populations have declined most in South East England and least in Scotland and Wales, where they are currently increasing.**
 - **Population declines began earlier in farmland than in gardens and in towns, but declines have been greatest in suburban and urban gardens. Rural gardens may be the most favoured habitat for the species.**
 - **Comparative studies of House Sparrows in specific regions and habitats of contrasting current population change are needed to elucidate the causal factors behind these differences.**

12.2.3 Seasonality in the use of gardens

The analysis of seasonality of garden use by House Sparrows shows some marked changes since the 1970s (Chapter 4). In general, the timing of peak numbers of House Sparrows in gardens has advanced from late December to mid October, with the advance being more marked in suburban gardens than rural ones. Also, House Sparrows move into gardens in the pastoral West and South West of the country earlier than in the more arable East.

The number of cereal grains, weed seeds and soil invertebrates available to birds on farmland has decreased markedly in recent decades (Donald 1998; Ewald & Aebischer 1999; Robinson & Sutherland 2002). Consequently, gardens are likely to have become a relatively more important source of winter food for birds in the wider countryside (Cannon 2000). However, the patterns of change in seasonality must also reflect the changes in abundance and densities of House Sparrows within a local area. Thus the mid winter peak that occurred in the early 1970s has disappeared entirely, with peak numbers now occurring in the autumn (around October). In rural gardens, the number of birds present appears to change very little through the winter, whereas in suburban gardens the timing of the peak has just shifted earlier. Although House Sparrows are largely sedentary, there is clearly increased flocking in gardens in the winter months, which could reflect an influx of birds into gardens from adjacent areas, or simply birds in adjacent gardens banding together. This no longer seems to be happening in rural gardens, suggesting individual colonies have become increasingly isolated, with little movement between (previously adjacent) colonies; the distribution of suburban colonies may be more continuous.

The differences in timing of arrival of birds in gardens in pastoral and arable areas may reflect differences in the relative abundance of food in the surrounding countryside. Thus, birds in pastoral areas, where grain and weed seeds will be generally scarce on farmland, gather in gardens much earlier in the winter than do those in arable areas. Similarly, the mid-winter peak in rural gardens, where individuals can feed on farmland concurrently, occurs much later than in suburban gardens, where such alternative foraging opportunities will not be available to a species that does not wander far. The relatively small number of House Sparrows that occurs in rural gardens during winter compared to the summer months, may reflect a greater proportion of birds foraging in alternative ('better') habitats, or simply that the density of birds on farmland tends to be lower than that in suburban areas, there thus being a smaller pool of individuals in the "catchment" area of a rural garden.

These results suggest that there is still much to be discovered about how House Sparrows change their use of different foraging areas near their colonies over the course of a year. Understanding how birds use different habitats in winter and how this relates to breeding distribution will be critical in understanding why the population has declined and hence in determining remedial action. Such information requires the development of locally-based colour-marking studies, possibly combined with radio-tracking studies, to document the use of different habitats by House Sparrows through their annual cycle.

- **The pattern of occurrence of House Sparrows in gardens has changed over the last 30 years. This change is consistent with a decrease in food resources in the wider countryside.**
- **There is a need for locally-based colour-marking studies to determine the patterns of habitat usage in space and time by colonies of House Sparrows in different rural, suburban and urban situations.**

12.2.4 Demographic processes

Population regulation arises from the balance between productivity and mortality, and between emigration and immigration (Lack 1954). At the broad geographical scale, House Sparrows are essentially sedentary (Summers-Smith & Thomas in press), although juveniles can disperse over distances of up to 20 km and adults may move up to 2 km to find abundant food sources in flocks in the autumn. Thus, within the broad geographical scales considered here, the main demographic processes that need to be considered are productivity and survival.

- **Dispersal rates are very limited for House Sparrow, so the main demographic processes behind population declines are some combination of changes in productivity and survival.**

12.2.4.1 Productivity

The analysis of NRCs shows that House Sparrow breeding performance has tended to increase over the past 40 years, particularly since the mid 1980s, and that this has occurred in all regions. However, average breeding performance is lowest and is improving least rapidly in the parts of the country, the South East and South West, or declining in habitats (arable farmland) where the population declines have been the most rapid over both the long- and short-term. The improvement in breeding performance in the North and West may be a factor influencing the recent population increases in Scotland and Wales. Samples of nest records were insufficient to investigate this further, but comparative studies of breeding success in areas of population increase and decrease would be valuable in helping to understand the mechanisms behind these differences in breeding performance and their influence on abundance.

There seems to be little difference in breeding performance between farmland habitats of differing types. This seems to fit with the lack of a response of House Sparrow abundance to the addition of small areas of arable land within pastoral landscapes (Robinson *et al.* 2001). However, the declines in breeding performance in arable habitats might be a contributory factor to the low and declining population densities in this habitat. Breeding performance is higher on farmland than in urban/suburban habitats. In addition there is a large difference in nest failure rates between suburban gardens (32%) and urban and rural gardens (each 15%). Breeding performance appears to be increasing in urban areas, but not in suburban areas where populations are falling most rapidly. The reasons behind the differences in breeding performance in these habitats need further investigation because the lack of a density dependent increase in breeding performance in response to falling numbers in suburban areas may be reinforcing the population decline there.

Summary

An important finding of this study is that breeding performance is positively correlated with population growth rate measured on all CBC monitoring sites but is negatively correlated with population growth rates in suburban GBFS gardens. These results suggest that breeding performance may have had a role in determining the pattern of population changes in the wider countryside, but not in suburban gardens. Thus although poor breeding performance in suburban areas may be contributing to the population declines, changes in other demographic factors are also playing a key role.

- **Breeding performance per nesting attempt has increased over the past 40 years in all regions.**
- **Breeding performance may have had a role in determining the pattern of population changes since 1975 in the wider countryside, but not in suburban gardens.**
- **Increases in breeding performance have been least rapid in South East England, where populations have declined most rapidly, and most rapid in the North and West, where some populations have increased.**
- **Breeding performance does not differ between farmland habitats, but is higher there than in urban and suburban habitats.**
- **The high nest failure rates and lack of any density dependent improvement in breeding performance in suburban areas, where populations are declining most rapidly, might be reinforcing the population declines there.**
- **Comparative studies of breeding success in areas of population increase and decrease would be valuable in helping to understand the mechanisms behind these differences in breeding performance.**

12.2.4.2 Survival

The survival rates of adult House Sparrows tended to rise during the 1970s to a peak in the early 1980s, then fall in the 1980s and early 1990s, before showing some signs of improvement at the end of the 1990s (Chapter 10). The survival rates of House Sparrows in their first year of life showed a general trend of improvement from the mid-1970s to early 1990s, before falling back again in the latter half of the 1990s.

Siriwardena *et al.* (1999) suggested that a fall in adult and/or first-year survival rates was likely to have driven the population decline in the wider countryside in the 1970s, but were unable to produce independently varying estimates of survival rates for adults and first-year birds. We were able to produce separate survival estimates for adults and first-years in both the pre-decline period from 1965 to 1975 and when populations were declining rapidly on CBC plots, between 1980 and 1983. These showed that annual first-year survival was 0.53, compared with 0.30 in the period of rapid decline; whereas the figures for adult survival were 0.58 and 0.61, respectively. Thus, it appears that changes in first-year survival are most likely to have driven the population decline. Their partial recovery in survival in the late 1980s has probably helped to halt the decline, but a corresponding fall in adult survival (to 0.45) may have acted to cancel out this improvement.

Evidence from a number of sources suggests that adult mortality rates are highest in the breeding season (Summers-Smith & Thomas in press; Summers-Smith 1959, 1988). Heij & Moeliker (1990), in an intensive study of the disappearance rates of colour-marked birds in the Netherlands, found that 50% of adult mortality occurred during the breeding season. As an investigation of one source of mortality, they undertook regular standardised counts along a road in their study plot and found that the peak in deaths due to traffic occurred in the breeding season. They suggested that adults had to “work blindly” to raise their chicks and thereby increased their exposure to mortality risks.

Hegner & Wingfield (1990) showed that House Sparrows are unusual among small passerines in demonstrating increased reproductive hormone levels (luteneizing hormone and testosterone) from November, earlier than the normal spring rise in other species. This, they suggested, was due to the

competition for suitable nesting sites and the need for males to start defending them from late winter, which must increase the period of potential stress for these birds considerably. Certainly the reports of non-breeding “surplus” populations in past studies (Anderson 1990; Summers-Smith 1988), and evidence of competitive nest site niche expansion between House and Tree Sparrows *Passer montanus* (Cordero 1993), would suggest that good quality nest site shortage might be a factor that would necessitate House Sparrows establishing site occupancy early.

Churcher and Lawton (1987) investigated the importance of cat *Felis catus* predation in a rural village in Bedfordshire and found that 16% of the prey brought in by the cat population in the village was House Sparrows. At least 30% of the House Sparrow mortality during the year was due to cat predation and possibly double that figure (given that cats may only bring back about 50% of captures to houses). In particular, one can calculate from their paper that, given the population in the village of 340 House Sparrows (i.e. 170 pairs), and given that 43 adults were killed by cats from May to August, then this source of mortality may affect up to 25% of breeding pairs in the village. Cat predation is also likely to account for a large proportion of the juvenile mortality in the village. The analysis of ringing recoveries shows that 41% are due to domestic predators (Summers-Smith & Thomas in press). Although for most species this would be a serious over-estimate, it is likely for House Sparrows, given their commensal nature with Man, that this is a more reasonable reflection of the importance of this mortality factor.

Under normal circumstances, House Sparrows are amongst the most cautious of foragers, as experimental manipulation of the distance between artificial bird feeders to cover showed that they would not fly to feeders even as close as 2.5 m from cover (Cowie & Simons 1991). Such a response in this case is likely to be to avoid predation by aerial predators, particularly Sparrowhawks *Accipiter nisus*. In an early study by Tinbergen (1946) in the Netherlands, it was demonstrated that House Sparrows were taken at a marginally higher rate than that expected by chance, given their relative abundance in the region. Sanderson (1996) noted that Sparrowhawk predation might have been a contributory factor in the recent decline of House Sparrows in Kensington Gardens in London (which have been censused periodically since 1925). House Sparrow was one of the main prey items (38 were counted) at a nest in 1996. However, he considered that Sparrowhawk predation is unlikely to be a main cause of the decline in the Gardens. The likelihood that Sparrowhawks might have influenced House Sparrow populations has also been discounted by Summers-Smith (1999) and Dott & Brown (2000). Newton (1986), in a general review of the impacts of Sparrowhawk predation suggests that it acts mainly to change the seasonal pattern of mortality and reduce the post-breeding peak without effecting a decline in breeding numbers of its prey. Thomson *et al.* (1998) demonstrated that between-year changes in the abundance of a wide range of bird species on CBC plots were not related to the presence or absence of Sparrowhawks on the census plots. Unfortunately, this study did not include House Sparrow, and it would be a useful exercise to repeat this type of analysis for House Sparrow and to perhaps to undertake a similar study using data from GBFS gardens.

The importance of failure rates of nests at the chick stage, found from the analysis of NRCs and th population modelling work (Chapter 10), supports the suggestion that adult mortality during the breeding season is high due to high work rates or the need to forage in risky situations. Although in the event of death by one or other parent the other parent may successfully rear a brood, it is also quite likely to stimulate the other parent to abandon the brood and seek a replacement clutch (Summers-Smith 1963). The chance of a lone parent succeeding in rearing a brood is only high if the death of the other parent occurs late in the breeding cycle (Summers-Smith 1988).

Further studies of the importance of different mortality factors during the breeding season would be valuable and could involve intensive studies of radio-tagged birds or more extensive studies of colour-marked birds, in which the timing of disappearance could be recorded by local volunteer observers. The study of Churcher & Lawton (1987) needs to be replicated to establish its generality and it would be valuable to initiate standardised road-kill monitoring schemes, particularly in urban areas, to establish the importance of this mortality factor. Ideally, these studies should be placed within the

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context of known population sizes of House Sparrows, established by a standardised censusing technique.

- **A fall in the survival rate of House Sparrows in their first year of life is likely to have caused the decline in abundance in the mid-1970s.**
- **House Sparrows suffer greatest mortality during the breeding season when adult birds appear to incur greater risks due to the needs of nesting and young birds are vulnerable when just out of the nest.**
- **The broader significance of a range of potentially important mortality factors need to be established by a combination of intensive and extensive studies using radio-tagging, colour-marking and recording of mortality within local populations of known size.**

12.2.5 Population modelling

The population modelling work carried out under this project (Chapter 10) allows an assessment of which of the demographic factors discussed above appears to have driven the patterns of population changes shown by the census schemes.

Our population models demonstrated that changes in breeding performance rather than in survival rates was the best candidate as a driver of the population changes shown on CBC plots since 1975. Variation in chick-stage failure rates appeared to provide the best explanation for the population changes, but reasonably good fits were also obtained when egg-stage failure rates and hatching success were allowed to vary in the model. Changes in clutch size, post-fledging survival and numbers of broods per pair per year were unlikely to have played an important role in driving changes (i.e. in helping to halt the decline) in the abundance of House Sparrows since 1975.

Although it could not be modelled except in the context of a block model (using blocks of years instead of annual variation), variation in first-year survival provided a model that also showed a reasonable match to the changes in abundance measured by the CBC. Thus this, too, is a candidate for helping to drive the population changes of House Sparrow over the past 25 years. Changes in adult survival provided only a poor fit in a similar model, so changes in this demographic factor seem unlikely to be implicated in their decline.

As described above, evidence from survival rates from ringing recoveries and nest record data prior to 1975 suggested that declines in the survival rates of first-year birds caused the population decline in the 1970s, but our modelling work shows that improvements in breeding performance (and possibly in first-year survival) have slowed or halted the population decline since 1994. It is possible that the improvements in breeding performance and first-year survival are a density-dependent response to reduced abundance. However, it should be noted that adult survival has not responded in this manner, having declined in a way that might be helping to inhibit recovery. In addition, the results of the modelling exercise suggested that post-fledging survival and/or the numbers of broods (encapsulated by the parameter p in the population models) have also declined in recent years, suggesting that these, too, may also be factors that could currently be inhibiting recovery.

The existence of different demographic mechanisms affecting the changes in abundance of a species at different periods is an unusual finding. It suggests that remedial conservation action can be attempted by altering a key demographic rate other than the one that caused the decline.

Given that first-year survival has not recovered to pre-1975 levels and that adult survival shows little sign of increasing in response to declining population levels, it is likely that some of the factor(s) that caused the decline in survival, and hence led to population decline, are still affecting House Sparrows. In addition, new factors might have come into play affecting adult survival, post-fledging survival and the numbers of breeding attempts so as to inhibit recovery. However, the intensive study at Oxford (Chapter 8) suggests that numbers of breeding attempts have not changed between the 1960s and

1990s. Thus, the search for mechanisms to increase the abundance of House Sparrows should concentrate on factors affecting adult and post-fledging survival.

Breeding performance per nesting attempt has already responded positively to the population decline in most areas, but it would be interesting to attempt to manipulate adult survival rates and chick food supplies experimentally by providing suitable food sources that were relatively risk-free for foraging parents. Such work would be particularly valuable in suburban gardens in the South East, which holds 10% of Britain's House Sparrows, and where breeding performance is relatively poor and has not shown a density-dependent response to declining abundance. Such experimental work would need to be preceded by the comparative research suggested above, that would investigate the mechanisms behind differences in nesting success between suburban areas of differing population trend.

- **The population decline of House Sparrows in the 1970s appears to have been caused by a decline in first-year survival rates.**
- **The decline in the wider countryside was slowed or halted by a combination of increased breeding performance, most likely through declines in failure rates of nests at the chick stage, and increased first-year survival rates.**
- **Recovery of the population appears to be inhibited by a decline in adult and (probably) post-fledging survival rates.**
- **Declines in gardens are still occurring, particularly in suburban areas. Breeding performance is not only poor in suburban areas but has not responded in a density-dependent manner to strong declines in abundance over the past 20 years. This may be exacerbating the declines and experimental provision of food resources that reduce mortality risk to parents would be useful to explore as a potentially practical means of reversing population declines in this important habitat.**

12.2.6 House Sparrows in farmland

Although farmland is the major component of the British landscape, forming 75% of the land surface, only about a third of House Sparrows inhabit this habitat. Their densities are almost an order of magnitude lower than in towns or rural gardens, and the densities in arable habitats are nearly half that in pastoral areas. House Sparrows used to occur at very high densities in arable farmland, where they were serious pests of cereal crops and crop stores (Summers-Smith 1963). Now, it appears that arable farmland is a poor habitat for House Sparrows, such that small pockets of arable habitat in pastoral landscapes does not cause any increase in numbers of House Sparrows (Robinson *et al.* 2001) compared to areas of purely pastoral habitat. Many seed-eating species appear to benefit from the presence of stubbles and spring-sown cereals (Siriwardena *et al.* 2000c), but Robinson *et al.* also showed that House Sparrows in the late 1990s did not show any response, in terms of population densities, to their addition to the landscape. The analysis of breeding performance presented here also showed little difference between nesting success in pastoral, arable or mixed farming and no significant trends except for a slight improvement on mixed farmland.

Changes and intensification of agricultural practices since the 1970s have resulted in reductions in invertebrate and seed availability on farmland with consequences for bird populations living in farmland (Wilson *et al.* 1999; Chamberlain *et al.* 2000; Vickery *et al.* 2001; Robinson & Sutherland 2002; Benton *et al.* in press). This has occurred through a loss of seed-rich habitat and also a decline in the number of seeds available, both because there are fewer weeds and because harvesting is much more efficient than previously. As farms have increased in size, there will have been a decline in the numbers of farmyards as foraging sites and the loss of stockyards in the now predominantly arable East of the country may also have reduced foraging opportunities for House Sparrows. Cereal, and other crop, seeds are increasingly sown with seed-dressings, which is likely to decrease the palatability of the seed to birds (e.g. Green 1980). Improvements in grain storage post-harvest in response to stricter hygiene laws will be another lost foraging opportunity. With the decrease in

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spring sowing of cereals, the availability of sown cereal has become concentrated in the autumn, further reducing food resources throughout the winter. Summers-Smith (1999) has asked the question; why don't House Sparrows concentrate on fields of ripening cereal crops as they did in earlier decades? Experiments on the palatability of new varieties of cereal crops to House Sparrows would be valuable in this respect. The loss of autumn and winter food supplies may well be a driving force behind the declines in survival rates that led to the population decline in the 1970s.

Populations associated with rural dwellings appear to have declined recently to a lesser extent than other habitats, with only arable dominated East Anglia showing a marked, but non-significant, decline in rural habitats. This probably reflects the mix of habitats present, with buildings present for nesting, gardens for foraging on insects and fields to provide a source of grain. Although there is no published data, it is likely that declines in the amount of cereal grain available to sparrows have been greatest in arable areas, where farmers are most likely to invest in the latest, most efficient machinery and storage, which may account for the greater decline in East Anglia. Studies of the use of available habitats by House Sparrows around rural gardens, by a combination of regular counts in different areas, the recording of the locations of colour-ringed birds, and intensive radio-tracking studies over diurnal and seasonal cycles would be very valuable in elucidating the factors that have led to population declines. Such studies should be comparative, and take place in regions with contrasting population trends.

It is interesting that population declines in farmland have been least steep in pastoral areas. Little is known about the foraging behaviour of House Sparrows in pastoral areas, but analyses have suggested that certain aspects of breeding performance are related to stocking rates: brood sizes tended to increase with more cows and sheep, but failure rates appeared to increase too. Areas where high stocking rates occur may be indicative of more intensive pasture management and more intensive livestock husbandry practices. There have been widespread changes in grassland management in Britain in recent decades (Vickery *et al.* 1999). These have resulted in a considerable uniformity of management to increase yields, with the replacement of hay with silage, and increased fertiliser treatments that have negative impacts on invertebrate abundance (Wilson *et al.* 1999). Silage, with its earlier and more frequent cuts, will provide fewer seeds for granivores, such as sparrows. The declines in invertebrate numbers would also be detrimental for House Sparrows at the chick-feeding stage and may limit their productivity. Although greater livestock numbers might increase the availability of spilt grain and livestock feed, intensive livestock husbandry might be associated with more careful control of livestock food provisioning to avoid spoiling and hence loss to House Sparrows and other animals (see Chapter 11). This would decrease the food supplies available during the breeding season and thereby tend to limit breeding success. The influence of pastoral land management and livestock husbandry on food availability for House Sparrows is an area that requires more intensive research.

The relationship between House Sparrow populations on farmland and those in towns is unclear. It is known that suburban birds used to disperse locally into the surrounding countryside to feed in flocks on ripening grain and in farmyards (Summers-Smith 1963, 1988). Heij & Moeliker (1990) found that, in the Netherlands, the density of House Sparrows in suburban areas was almost twice that in rural areas. Birds in rural areas (particularly juveniles) foraged over a much larger area than their suburban counterparts and consequently had a higher mortality (road traffic mortality formed a significant component). Heij & Moeliker argued that rural populations were supported by immigration from suburban areas. From this we might predict that the BBS should show populations in suburban areas to be declining less than those in farmland or rural gardens; in fact, this is only true for three of the ten regions for farmland and only in Wales for rural gardens (Chapter 3). In addition, although it is true that the population declines on CBC plots started earlier than on GBFS plots, the declines on GBFS plots coincided with a period of relative stability in the CBC index, instead of an accelerating decline, which is what we might expect if gardens were no longer able to "export" birds to the surrounding farmland.

Thus, of the possible factors that might have detrimentally affected House Sparrow survival on farmland, it seems that loss of seed resources in both pastoral and arable systems and loss of spilt grain around farm buildings and livestock feeding areas are likely to be particularly important. Thus, the provision of waste grain, or tailings, as a supplementary food source by farmers is likely to enhance House Sparrow survival and productivity at minimal cost. However, methods will need to be devised to avoid the potential problems that could arise from associated rodent infestation. The effects of reduced immigration from garden populations cannot be definitively ruled out and it would be possible to develop a project involving volunteer ringers and House Sparrow enthusiasts to use colour ringing studies to investigate the local dispersal of House Sparrows.

- **Arable farmland now appears to be a least favoured habitat for House Sparrows in Britain, despite their previous pest status earlier in the 20th Century.**
- **Changes in agricultural practice have probably decreased the availability of autumn and winter seed supplies for House Sparrows, as for other granivores, but House Sparrows are likely to have been strongly affected by stricter hygiene rules governing the storage of crops. The provision of tailings by farmers, as a supplementary food source, has the potential to increase survival and productivity of House Sparrows in the rural environment.**
- **Rural dwellings still support high densities of House Sparrows and studies of the seasonal use of available habitats by House Sparrows around rural gardens would be valuable in understanding the factors that promote high population densities.**
- **The influence of pastoral land management and livestock husbandry on food availability for nesting House Sparrows is an area that requires more intensive research.**
- **The effects of reduced immigration from garden populations cannot be definitively ruled out as a factor in the decline of House Sparrows on farmland. A colour-ringing project would readily allow an assessment of the potential importance of the local dispersal of House Sparrows between rural habitats.**

12.2.7 House Sparrows in towns

One of the major results of this report is to establish the significance of the urban and suburban habitat for the British House Sparrow population. The declines in the populations in this habitat, particularly in the South and East of England, have had the greatest impact on total population size in Britain. Evidence presented here and by other local studies shows that population changes may differ between towns in different areas. Thus there are declines in London (Sanderson 1996), Edinburgh (Dott & Brown 2000) and Dublin (Prowse 2002), but the last study reports no declines in Manchester. The BBS shows that, while urban and suburban populations in Wales appear to be increasing, those in the South East and West Midlands have decreased significantly.

The national analysis of the demographic causes of the decline in House Sparrow abundance strongly suggests that changes in first-year survival rates drove the decline in the mid 1970s. Unfortunately, sample sizes were insufficient to permit the calculation of survival rates in urban and suburban habitats alone, but nest record data for suburban and urban habitats suggest that breeding performance per nesting attempt did not decline at that time. Thus, the demographic factor responsible for declines in these habitats is likely to be a decline in survival, as it was for the wider countryside, although a decline in the number of nesting attempts per pair per year is also a potential factor that may have been influential.

A number of hypotheses have been suggested for the population declines in towns (Summers-Smith 1999; Dott & Brown 2000; Prowse 2002) and these are discussed below.

Predation by cats and Sparrowhawks has been discussed above (12.2.4.2) and could be a factor in suburban and urban situations as cat-ownership has risen and Sparrowhawks have colonised urban areas (Newton 1986). Suggestions for potential studies to elucidate this issue are provided above.

Lack of nest sites has been proposed as a possible factor, as house roof spaces have become increasingly sealed off to avoid ingress by nesting birds. House Sparrows nest in a variety of holes and crevices in buildings, trees, earth-banks and even in the foundations of larger nests, such as those of the Corvidae (Snow & Perrins 1998). They can also build free-standing nests, often in thick bushes or trees. It has been suggested that modern buildings may contain fewer nest sites for birds, and that those in old buildings may be being destroyed (Moss 2001). In support of this, the Bristol survey (J. Tully & R. Bland *in litt.*) found a negative correlation between House Sparrow numbers and the extent to which loft insulation had been installed in houses ($r = -0.56$, $n = 35$, $P < 0.001$). This may result in fewer nesting opportunities and there may also be a possibility of adverse respiratory effects from airborne fibreglass on breeding birds or their chicks. On the other hand, although they present no quantitative data, both Dott & Brown (2000) and Prowse (2002) thought that the number of nesting opportunities had not changed significantly, although there had been large declines in House Sparrow numbers.

Loss of food supplies has been suggested as an explanation for urban House Sparrow declines in two contexts. Urban streets may be cleaner than previously, extending a trend begun in the first part of the 20th Century, when the replacement of horse-drawn vehicles with motor vehicles led to the first large reduction in House Sparrow numbers (Bergtold 1921; Rand 1956; Summers-Smith 1963, 1988). The loss of “brown field” sites is likely as city development plans infill and the loss of such sites might be important, as they are likely to support large numbers of “weeds”. The seeds might provide a higher quality food source than the household and other scraps that are otherwise available to urban House Sparrows. Urban expansion may now also mean that cereal fields are now outwith the daily and seasonal ambit of many urban House Sparrows, since their foraging ranges are extremely restricted.

Dröscher (1992) reported that the House Sparrow had become a rarity in West Berlin, but remained relatively common in East Berlin, which might reflect a general lack of development under the former communist regime. East Berlin has since undergone massive redevelopment so it would be interesting to discover if these differences still exist. A survey of House Sparrow numbers in Bristol, (J. Tully & R. Bland *in litt.*) in the winter of 2000/01 showed a strong correlation with the degree of social deprivation between city electoral wards ($r = 0.61$, $n = 35$, $P < 0.001$). Sparrows were largely absent from the wealthy suburbs and most dense in the post-war overspill housing estates. However, social deprivation is likely to be confounded with the prevalence of roof insulation mentioned above and the two effects cannot be separated in their analysis. A similar distribution pattern is evident in Norwich (Paston 2001). Studies to explore the seasonal pattern of food use by House Sparrows and the potential importance of “waste ground” as a source of weed seeds are needed.

Over the lifetime of the GBFS there have been marked increase in both the prevalence of garden bird feeding and in the quantity and range of foodstuffs provided (Cannon 2000). However, the number of House Sparrows using gardens did not increase in response to this, even in the pre-decline period. It is possible that a greater decline would have been seen had these extra resources not been available, or that the newer types of food being provided by house-owners, such as black sunflower seeds, might not be as suitable for House Sparrows as they are for other birds feeding in gardens. The relative use of different food-stuffs provided in gardens by House Sparrows and any relationships with breeding success would be valuable information that could be collected very cost-effectively by a carefully designed experimental study involving volunteer birdwatchers in their gardens.

The availability of invertebrate food used to feed chicks in the nest has been proposed as a possible explanation for urban population declines (Bower 1999; Summers-Smith 1999). In the first few days after hatching, chicks are fed almost exclusively on a protein-rich diet of invertebrates, which is then supplemented increasingly with vegetable food as the chicks get older (Summers-Smith 1988). Key prey types fed to chicks are aphids (Aphidoidea), weevils (Curculionidae), grasshoppers (Orthoptera)

and caterpillars (Lepidoptera). Bower (1999) studied a small population of House sparrows in Hamburg and found that all first broods (in April) failed to produce any fledged young, which he ascribed to the lack of invertebrates at that time. If this was a general problem in Britain, then we would have expected to have been able to detect declines in the productivity from the nest record data; however, breeding performance has actually improved in urban situations, although it has not improved in suburban habitats.

Pollution is a factor that could affect House Sparrows both as a result of immediate toxicity and indirectly through effects on their food supplies. One possible source of pollution is lead-free petrol, which has increased in usage markedly over the past 15 years in response to the impact of leaded petrol on air quality in built-up areas (Barnaby 1983; Achten *et al.* 2001). However, this fuel contains volatile organic compounds as lead substitutes, particularly benzene and methyl *tert*-butyl ether (MTBE). It has been hypothesized that MTBE, or one of its by-products, might affect the abundance of aphids that House Sparrows feed to their chicks in the first few days after hatching (Mitschke *et al.* 2000; Moss 2001). While urban populations of House Sparrow in South East England (primarily London) do seem to be declining more rapidly than suburban or rural populations (Table 3.4.1.1), this is not true of other species, such as tits, which also feed on aphids (Noble *et al.* 2001; Prowse 2002). It is also unclear why Welsh urban populations should be apparently unaffected and why Tully & Bland (*in litt.*) found no correlation between aerial benzene levels (which are likely to be correlated with those of MTBE) and House Sparrow numbers at the local level within Bristol.

Dott & Brown (2000) could find little direct evidence for any particular factor driving the population declines of House Sparrows in Edinburgh and suggested that pollution remained an unexplored potential factor. Certainly, it would be valuable to relate House Sparrow numbers, recorded by GBW and BBS, to measurements of air pollution taken routinely in cities around Britain to explore whether there is any relationship between the two. An initial exploratory analysis is currently planned, under the APRIL (Air Pollution Research in London) umbrella.

Disease is a largely unexplored factor in bird population dynamics, due to the difficulty of studying levels of infection without the use of invasive techniques and to the expense of laboratory identification of pathogens. Diseased birds may be difficult to find because debilitated birds may die away from sources of infection. It would seem unlikely that intra-specific disease transmission has increased, since the incidence of large flocks of House Sparrows foraging in gardens has decreased (see Chapter 4). However, the incidence of cross-species disease transmission may have increased as the total number of birds of all species concentrated on garden bird feeders has increased (Hartup *et al.* 2001). Summers-Smith (*in litt.*) has reviewed available evidence of disease outbreaks in House Sparrow populations and noted local epidemics and population declines in Shetland in 1926; in New Brunswick in 1980 attributed to Salmonellosis; in several New Zealand towns in 2000 also attributed to Salmonellosis. He also notes that House Sparrows are susceptible to conjunctivitis transmitted from House Finches *Carpodacus mexicanus* in Eastern USA and that it has been reported as a carrier of West Nile Virus disease, which can cause death in birds. Such outbreaks are characterised by a prevalence of corpses being found by the public. However, it remains a possibility that House Sparrows are susceptible to some sort of disease transmission, potentially via unhygienic garden feeding stations, and this should be explored by taking samples from bird tables and from birds feeding at them. However, this mechanism would require House Sparrows to be particularly susceptible to disease compared with other birds that commonly use bird feeders.

In conclusion, there is an urgent need to gather more information about how House Sparrows use the urban and suburban environment and to investigate the fine-scale habitat associations of the species. Some work has begun with respect to green spaces in London, with the BTO's London Birds Project (Gough & Chamberlain 2002), but research needs to be targeted at suburban and urban gardens as well. The most cost-effective way to gather such information at a national level would be to develop a volunteer-based survey in gardens. Such a survey should also gather information on the fine-scale habitat features of gardens and buildings that might affect House Sparrow numbers. Surveys of House Sparrow populations in different urban centres would allow investigation of the broader

significance of the correlations between House Sparrow populations and information gathered by local authorities, such as social deprivation and the presence of roof insulation found by the Bristol study. Targeted habitat recording as part of such a survey (as is being undertaken as part of the BBS and London Birds Project) would be important if we are to investigate the impact of habitat features in the areas surrounding gardens.

- **The population declines of urban House Sparrows are likely to be due to declines in survival rates, and possibly through declines in the numbers of breeding attempts per pair per year, rather than any impacts on other aspects of the breeding performance of nesting birds.**
- **The strongly contrasting fortunes of House Sparrows in different urban centres urgently need investigation by comparative studies and surveys of House Sparrow populations.**
- **These studies should be designed to allow a national evaluation of the impact of differences in broad-scale habitat and environmental features of the urban environment as well as in the fine-scale characteristics of gardens.**
- **Potential factors that could have led to the declines of House Sparrows in urban situations include predation (by domestic cats and Sparrowhawks); loss of sources of weed seeds (through loss of “waste ground”); changes in the suitability of food provided at garden feeding stations; air quality (pollution); disease transmission (via bird feeding stations); loss of nest sites (possibly due to house renovation).**

12.2.8 Conclusion and recommendations

It is clear that the main demographic factor that has caused the decline of House Sparrows is the decline in survival rates of birds in their first year, although we cannot rule out declines in the numbers of breeding attempts in suburban and urban habitats. In addition, declines in survival rates of adult birds and the lack of improvement in breeding performance in suburban areas (as has occurred in urban areas) have probably contributed to the continuing declines and have tended to inhibit any recovery. However, it should be noted that this study has shown how different demographic rates have had major influences at different phases of the population trajectory. Thus, remedial actions to improve the population status do not necessarily have to reverse declines in first-year survival rates, but could seek to improve other demographic factors.

Although farmland supports considerably lower densities of House Sparrows than urban and suburban areas, the large geographical extent of farmland habitat means that research and conservation work needs to be carried out in both major habitats. In particular, there is a need for:

- **Comparative studies of House Sparrows in specific regions and habitats of contrasting current population change to elucidate the causal factors behind these differences; the reasons for apparently preferred status of rural gardens need to be established.**
- **The influence of pastoral land management and livestock husbandry on food availability for nesting House Sparrows is an area that requires more intensive research.**
- **The effects of reduced immigration from garden populations cannot be definitively ruled out as a factor in the decline of House Sparrows on farmland. A colour-ringing project would readily allow an assessment of the potential importance of the local dispersal of House Sparrows between rural and other habitats.**
- **It is likely that the provision of tailings as a supplementary food source by farmers has the capacity to improve survival and productivity of House Sparrows in the rural environment.**

We know relatively little about House Sparrows in the urban and suburban environment and there is an urgent need to undertake a number of studies and surveys to establish baseline figures and bird-habitat relations:

- **Comparative studies and surveys of House Sparrow populations in suburban and urban areas are required to allow a national evaluation of the impact of differences in broad-scale habitat and environmental features of the suburban and urban environment as well as in the fine-scale characteristics of gardens and other features.**
- **Comparative studies of breeding success in areas of population increase and decrease are needed to investigate why there is an apparent lack of a density-dependent response to declining abundance in suburban habitats.**

More detailed studies are needed to explore the significance of specific factors affecting survival rates and breeding performance should be explored in habitats and regions of differing population trend:

- **Use a combination of intensive and extensive studies using radio-tagging, colour-marking and recording of mortality within local populations of known size.**
- **Since breeding performance is poor in suburban areas and has not responded in a density dependent manner to strong declines in abundance over the past 20 years, experimental provision of food resources that reduce mortality risk to parents would be useful for exploring a potentially practical means of reversing population declines in this important habitat.**
- **Potential factors that could have led to the declines of House Sparrows in urban situations include predation (by domestic cats and Sparrowhawks); loss of sources of weed seeds (through loss of “waste ground”); changes in the suitability of food provided at garden feeding stations; air quality (pollution); disease transmission (via bird feeding stations). The potential importance of these factors should be investigated by targeted studies, which could take advantage of the large network of volunteer birdwatchers.**

12.3 THE POTENTIAL IMPACT OF LEGAL CONTROL

The questionnaire survey of land-owners and occupiers and of Local Authorities provided essential information on the extent of current legal control activities, although it should be noted that the response rate was lower than expected (probably due to the outbreak of Foot-and-Mouth disease). However, the follow-up survey of a sample of non-respondents provided useful information that helped in the interpretation of the survey.

The vast majority of owner/occupier respondents (97%) and all Local Authority respondents undertook no lethal control. Contact with a sample of non-respondents suggest that they did not undertake lethal control, so it is reasonable to estimate that 74,000 (between 17,000 and 164,000) Starlings and 16,000 (1,000 to 45,000) House Sparrows were killed in the survey year (2001). Numbers estimated to have been killed were similar to those reported for the periods one to five years ago and six to ten years ago. Estimates for the period more than ten years ago were higher. Although culling occurred in all months of the year, control of Starlings was higher in the pre-breeding season and of House Sparrows during the breeding season. This means that a proportion of culling of Starlings will be of immigrant birds from northern Europe and Scandinavia. However, culling of House Sparrows in the breeding season will impact on breeding adults and on their productivity and is likely to have a more significant effect (at least locally) than culling later on in the year when mortality is more likely to be of juveniles. Culling of juveniles is likely to act in a “compensatory” manner (mortality due to culling replacing some of the mortality which would have occurred naturally), through density-dependence, to reduce mortality due to other causes subsequently.

Summary

In comparison with the national population estimates calculated as part of this project, the numbers culled each year are small. The estimates of breeding population size are likely to be seasonal minima because they reflect population size of breeding adults before the addition of young birds. Even so, and assuming that all Starlings culled are part of the British breeding population, then the proportions of each population culled are:

- For Starling, assuming a population of 9 million birds, approximately 0.8% (with a range of 0.2% to 1.8%) are culled per year, at current levels.
- For House Sparrow, assuming a population of 13 million birds, approximately 0.1% (with a range of 0.008% to 0.3%) are culled per year, at current levels.

Our estimates of annual adult survival are *c.* 0.69 for Starling and 0.50 for House Sparrow. Even using these estimates, which would assume that no first-year birds are culled, the proportion of the annual mortality that culling represents is very small. Culling represents 3% (with a range of 0.6% to 6%) of annual adult mortality for Starlings and 0.2% (with a range of 0.01% to 0.6%) of annual adult mortality for House Sparrows. The impact on the national House Sparrow population is thus negligible. Given that a substantial proportion of Starlings culled will be immigrants or resident first-year birds (which have a lower survival rate than adults), then the impact on the national Starling population is likely to be negligible also. Furthermore, it is highly likely that some of this increased mortality due to culling will be compensated for by decreased mortality due to other factors, probably at some other stage of the life-cycle.

Neither species appears to be a widespread or serious problem; only 3% of owner/occupiers reported Starling damage so severe that farm income was affected (0.5% for House Sparrows), and 5% of responding Local Authorities reported Starling problems so severe that budgets were affected. No Local Authorities had problems with House Sparrows. Over ten years ago perceived problems were more widespread, with greater percentages of owner/occupiers and Local Authorities reporting damage. The survey obtained some crude estimates of the value of damage inflicted by the species: land-owners/occupiers who reported damage valued this at *c.* £1000 per annum; Local Authorities who reported damage valued this as £1000 p.a. for fouling of public areas, £750 p.a. for concerns over public health and £500 p.a. for damage to property.

The majority of farms using lethal control also used non-lethal methods. Of these, exclusion nets appeared to be the most effective and shooting and auditory scarers the least effective. Removal of spilt grain was also moderately effective against House Sparrows. The most common technique used by Local Authorities was auditory scaring which was perceived to be partially effective. Thus the levels of damage inflicted by these species appear to be relatively small, even at the level of an individual farm and lethal control is generally considered less effective than other non-lethal measures (although a small percentage of respondents to the owner/occupier questionnaire did consider that lethal control was effective).

The partial effectiveness of non-lethal methods reported in Chapter 11 implies that they are likely to have some effect on the local populations of Starlings and House Sparrows. It has been postulated that the reduction in the availability of livestock foodstuffs and grain stores by more careful handling procedures and more secure storage facilities on farms may have played a part in the decline of House Sparrows and (less so) of Starlings. However, about 80% of land-owner/occupier respondents to the questionnaire reported that they undertook no special lethal or non-lethal actions to control Starling or House Sparrow numbers. It is likely that this might under-report the use of more secure grain storage, as this is a general requirement for farmers under existing guidelines of best agricultural practice. Other non-lethal methods such as scaring techniques, used particularly by Local Authorities, may have an effect on survival, but these methods are more likely to just move the birds from one area to another, where control methods are not used.

- **Owner/occupiers were estimated to have killed 74,000 Starlings and 16,000 House Sparrows in 2001.**
- **No local authorities reported lethal control of either species.**
- **Lethal legal control of House Sparrows and Starlings is likely to have a negligible impact on national population levels.**
- **In general lethal control was considered ineffective when compared to non-lethal control.**

12.4 RECOMMENDATIONS FOR FURTHER ACTION

One of the key aims of this project was to investigate the trends in abundance, breeding performance and survival of Starlings and House Sparrows in Great Britain, in relation to environmental factors and legal control activity. The other key aim was to provide clear guidance to the Department of Environment, Food and Rural Affairs on the likely causes of the declines and identify further research that would aid the understanding of these causes.

A detailed summary review of the work carried out under this report is provided above, but in Table 12.4.1 below we summarise:

- What we know about the most likely causes of the declines.
- What research is still needed to identify targeted actions to reverse the declines.
- What actions can be identified now that are likely to help reverse the declines.

Table 12.4.1 Summary of the most important factors underlying the declines of Starling and House Sparrow, the key areas where research is required and suggestions for actions that can be undertaken to reverse the declines.

	Starling	House Sparrow
Reasons for decline	<ul style="list-style-type: none"> Primarily changes in first-year survival First-year survival most important in north and west Britain Adult survival more important in eastern Britain Decline in food sources and available habitat 	<ul style="list-style-type: none"> Declines in first-year survival, compounded by subsequent declines in adult and post-fledging survival. Poor levels of breeding performance in suburban areas Declines in food sources in autumn on farmland
Research needed to identify future actions to reverse declines	<ul style="list-style-type: none"> Studies to quantify importance and quality of urban and suburban foraging habitats Targeted ringing to determine dispersal between habitats, particularly of first-year birds, and winter movements in Britain by British and continental breeding populations Use of behaviourally based models to predict effects of farm management on food supply and hence population size 	<ul style="list-style-type: none"> Specific national survey of urban and suburban populations to identify fine-scale habitat use. Targeted local studies, using colour-ringing and radio-tracking to identify seasonal patterns of habitat usage and identification of mortality patterns in areas of contrasting current population change. Targeted studies to identify the relative importance of potential key mortality factors including predation; food availability in urban and suburban habitats; air quality; pollution; disease transmission. Experimental provision of nest boxes to investigate the potential importance of loss of nest sites.
Actions identified to reverse declines	<ul style="list-style-type: none"> Provision of extra grassland habitat in arable areas Management of grassland for short, sparse swards Provision of extra nest sites on farmland; this needs careful monitoring. 	<ul style="list-style-type: none"> Provision of tailings as a supplementary food source near farm buildings. State of knowledge of mortality factors and food sources in urban and suburban areas are still too uncertain to identify specific actions

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ABBREVIATIONS

ADAS	Agricultural Development and Advisory Service
ANOVA	Analysis of Variance
asl	above sea level
BBS	Breeding Bird Survey
BTO	British Trust for Ornithology
CBC	Common Bird Census
CJS	Cormack-Jolly-Seber (model of survival)
CS	Clutch size
CSL	Central Science Laboratory
DEFRA	Department for the Environment, Food and Rural Affairs
DISTANCE	Abundance estimation software
DSR	Daily Survival Rate
EFR	Nest Failure Rate (Egg stage)
FPA	Fledglings per nesting attempt
GAM	Generalised additive models
GAIM	Software to fit generalised additive models
GBFS	Garden Bird Feeding Survey
GBW	Garden BirdWatch
GENMOD	Procedure within SAS to fit generalised linear models
GLM	Generalised linear models
HS	Hatching success
JNCC	Joint Nature Conservation Committee
LRT	Likelihood Ratio Test
MA	Methyl anthranilate
MAFF	Ministry of Agriculture, Food and Fisheries
MARK	Survival rate estimation software
MTBE	Methyl tert.-butyl ether
NAG	Numerical Algorithms Group
NFR	Nest Failure Rate (Nestling Stage)
NRC	Nest Record Cards
NRS	Nest Record Scheme
PMR	Population Multiplication Rate
PSA	Public Service Agreement
RSPB	The Royal Society for the Protection of Birds
SAS	Statistical analysis software
SF	Step Farm, Farringdon, Oxfordshire
UF	University Farm, Oxford