British Trust for Ornithology

BTO Research Report No. 222

Changes in Lowland Grassland Management: Implications for Invertebrates & Birds

Authors
[1]Vickery, J.A., [3]Tallowin, J.T., [2]Feber, R.E., [1]Atkinson, P.W.,
[2]Asteraki, E.J., [1]Fuller, R.J. & [2]Brown, V.K.

[1]British Trust for Ornithology
[2]CABI Bioscience UK Centre
[3]Institute of Grassland and Environmental Research

A report by the British Trust for Ornithology under contract to
Ministry of Agriculture, Fisheries and Food

May 1999

British Trust for Ornithology, The Nunnery, Thetford, Norfolk, IP24 2PU
Registered Charity No. 216652

British Trust for Ornithology

Changes in Lowland Grassland Management: Implications for Invertebrates & Birds

BTO Research Report No. 222

Vickery, J.A., Tallowin, J.T., Feber, R.E., Atkinson, P.W., Asteraki, E.J., Fuller, R.J. & Brown, V.K.

Published in May 1999 by the British Trust for Ornithology
The Nunnery, Thetford, Norfolk, IP24 2PU, UK

ISBN 1-902576-14-4

CONTENTS

Page No.

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

Page No.

EXECUTIVE SUMMARY

1. Grasslands occupy over 50% of the agricultural land in Britain, which is a higher proportion than in most other European countries. Permanent and temporary grass accounts for *c.* 7 million of the 12 million hectares of crops and grass with a further *c.* 5 million ha of rough grazing. The extent of agricultural grassland in Britain decreases from around 60% of agricultural land in the west of the country to less than 15% in the east. Over 90% of the grassland has been agriculturally improved or semi-improved during the 20th Century. It is estimated that over 95% of semi-natural lowland grassland has been lost or declined in conservation value due to agricultural improvements. The remaining resource of semi-natural grasslands is now largely restricted to the west of the country.

2. In the last 25-30 years many common farmland birds have exhibited widespread population declines and range contractions in Britain. There is growing evidence to link these declines to agricultural intensification. To date research has focussed on arable systems despite the fact that changes in grassland systems have been at least as profound. This report focuses on lowland neutral grasslands and has three main components. First, British Trust for Ornithology (BTO) atlas data, on the distribution of breeding and wintering birds, and Institute of Terrestrial Ecology (ITE) Land Cover data have been used to identify bird species that are particularly strongly associated with grassland systems. Second, information on trends in grassland management practices, their impacts on sward structures and composition and grassland invertebrate fauna have been reviewed. Third, data derived from a number of existing studies of grassland birds have been used to evaluate the potential impact of these management practices on grassland birds.

3. Using breeding bird abundance and distribution data from the 1988-91 breeding bird atlas and wintering bird abundance data from the wintering atlas of 1981- 84, farmland birds could be classified into three main categories: arable specialists, mixed specialists and pastoral specialists. The latter were small insectivore species such as pipits, wagtails and chats and larger insectivores such as thrushes and waders. In winter most species (*c.* 74%) were most strongly associated with mixed landscapes. Although there are no widespread lowland farmland species that are confined to lowland grassland habitats in the breeding season, these areas do support a number of species of high conservation interest. A number of Biodiversity Action Plan species associated with mixed farming regions in winter and/or summer have shown recent population declines. Overall 12 out of 14 species identified as associated primarily with grassland areas are declining in numbers as indicated by the BTO Common Birds Census. The importance of pastoral areas, in terms of the number and diversity of birds they support indicates that changes in grassland management are likely to have had significant impacts of farmland bird populations.

4. Bird species associated with grassland derive, mainly, from four groups - wildfowl, rail, waders and songbirds (passerines). These groups differ considerably in their feeding and breeding requirements and their response to changes in grassland management will, therefore, also vary. Grassland tends to be more important for wildfowl (mainly geese) as winter feeding habitat, for rails (Corncrake) as breeding and feeding habitat in summer

and for waders and passerines as feeding and nesting habitat in the summer and feeding habitat in winter. With the exception of wintering wildfowl, that graze on herbage or take seeds, the species are all dependent on invertebrate prey particularly in the summer, but for many throughout the year.

5. Changes in grassland management that alter the botanical composition or structure of the sward will affect grassland birds directly, by altering the nesting and foraging quality of the habitat, or indirectly by altering the value of the habitat for the invertebrates on which most of these birds depend for food. Invertebrate communities associated with grassland vary widely in composition but groups of greatest significance, in terms of abundance, are the Nematoda, Annelida, Mollusca, Acari, Araneae, Insecta, Apterygota, Isopoda and Myriapoda. Invertebrate communities of extensively managed swards tend to be relatively complex, reflecting the varied habitat provided by diversity in sward structure and a well developed surface mat of decaying plant material.

6. Changes in grassland management practices in the UK since the 1940s have been largely aimed towards increasing production and predictability of output. Average use of fertiliser nitrogen has increased two to three fold. 86% of all agriculturally improved grassland now receives inorganic fertiliser and 48% receives organic (solid manure or liquid slurry) fertiliser. Highest inorganic fertiliser inputs are on fields cut for silage but not grazed (an average of 221 kg N ha^{-1}) and the lowest inputs are on fields mown for hay (90 kg N ha^{-1}). Dairy farms use, on average, twice as much fertiliser N than beef/sheep farms.

7. Addition of inorganic fertiliser N encourages growth of competitive species and results in the conversion of different grassland communities to one or other of the improved mesotrophic communities of the NVC namely the *Lolium perenne-Cynosurus cristatus* grassland or Perennial Rye-grass leys. Heavily fertilised and intensively managed swards are denser, faster growing, botanically much poorer and lacking in structural diversity compared with grasslands receiving low or no inorganic fertiliser or organic inputs. In general high inputs of organic and inorganic fertiliser appear to decrease numbers of invertebrates and change the faunal composition. Moderate to severe population reductions on fertilised compared to unfertilised grassland has been observed in Acari, Collembola, Diptera, Coleoptera, Orthoptera and Myriapoda. Earthworms show increased densities at low levels of fertiliser application but numbers decrease with higher fertiliser application levels.

8. Increased application of fertiliser N affects nest site and food availability for birds. Increased sward height reduces the availability of suitable nesting habitat for species such as Lapwing, that prefer short swards. Snipe and Redshank are likely to be adversely affected by changes in sward density towards structures that do not provide their nest site requirements. Fertiliser N use on grassland is that it can increase the nutritional value of the sward for grazing wildfowl. Fertilised swards can support much higher numbers of wintering geese, for example, than unfertilised pastures. However, food availability for many bird species that feed by probing the soil for invertebrates or pecking them from the surface of the soil or vegetation could be affected. Important prey such as earthworms, tipulid and chironomid larvae are not only less abundant in swards with high fertiliser application but they will also be much less accessible in tall dense swards.

Reductions in abundance and accessibility of invertebrates such as Diptera and Coleoptera will also reduce the quality of the grassland as foraging habitat for a number of passerines such as Yellow Wagtail and Meadow Pipit. Addition of farmyard manure, in contrast, may increase the abundance and availability of soil-dwelling invertebrates and hence benefit a range of passerines such as Starling and waders such as Golden Plover in winter.

9. Changes in pesticide inputs to grassland have not been substantial relative to changes in fertiliser inputs. Weeds and pests have, in general, been tolerated to a much greater extent on grasslands than in arable crops. The use of herbicides has been confined to the establishment phase of leys and for spot treatment of perennial weeds. The use of pesticide-based control measures has been restricted to pests such as leatherjackets and slugs. Overall pesticide use has been negligible compared with their use on arable land.

10. A switch from organochlorines to organophosphates for treating grassland pests has probably benefited the grassland invertebrate fauna as a whole since the former was very persistent and adversely affected most invertebrate groups. However organophosphates do have short-term impacts on non-target organisms such as carabid beetles and earthworms. Herbicides largely affect invertebrates through alterations in sward structure and composition. Phytophagous insects will be affected if their host plant is targeted by the herbicide and predatory insects such as spiders will be affected by changes in sward structure. Some anthelminthic products that control pests of livestock may have negative impacts on invertebrates. Residues of, for example ivermectin, in cattle dung reduce the number and variety of coprophagous insects in the dung such as flies and beetles.

11. Despite evidence for detrimental indirect effects of pesticides on birds in arable landscapes very little is known about the impact of pesticides on birds associated with grassland systems. Compared to the gross changes in sward management brought about by changes in fertiliser practice and grazing, indirect effects of pesticides may be relatively small in grassland. The negative effects of ivermectin on dung dwelling invertebrates may reduce food availability for passerines such as pipits and wagtails but there is almost no information available relating to this or to the impact of the wider use of pesticides on grassland birds.

12. The nature and extent of grazing has altered markedly in the last 40-50 years. Sheep numbers doubled between 1950 and 1990, with the main increase from 1975 to the late 1980s, and then declined by *c.* 10% in the following years. The beef herd has also increased in recent years but a marked decline in the dairy herd in the last 20 years has resulted in an overall reduction in cattle numbers. Overall, the live weight carried by grassland in 1997 differed by only 4% from that carried in 1980. These trends differ regionally across the UK, reflecting increased polarisation of arable and grassland systems; in general, overall stocking levels have decreased in eastern and increased in western counties. Intense grazing, especially by sheep, results in densely tillered swards of uniform structure. Intensive grazing also favours competitive species such as Perennial Rye-grass and White Clover or species with strongly developed defences against grazing such as thistle.

13. Grazing influences grassland invertebrates by altering the structure and species composition of the sward and the rate of organic matter return to the soil but impacts differ with respect to the timing and level of grazing. Selective grazing in extensive livestock systems can result in a structurally heterogenous sward and promote invertebrate diversity. High stocking rates reduce the numbers and biomass of phytophagous grassland invertebrates and hence the predatory species that depend upon them. Seasonal grazing, especially in autumn rather than spring, may be less deleterious to the invertebrate community in general than continuous grazing. Some soil and litter dwelling invertebrates are adversely affected by trampling and soil compaction may restrict the burrowing activity of earthworms. The addition of dung to grassland does provide habitat for a specialised component of the invertebrate fauna including coprophagous dung flies and beetles.

14. The timing, type of livestock and intensity of grazing are important factors determining the impact of grazing on grassland birds. Increased nest losses due to trampling by livestock is the main direct effect of more intensive grazing practices. This may be particularly important for ground nesting waders such as Redshank, Lapwing and Snipe. The uniform sward promoted under intensive grazing may also increase the detectability of nests to predators. Indirect effects relate mainly to changes in sward height and composition (see 7 in relation to increased fertiliser N). Short swards may increase nesting habitat availability for species such as Lapwing, that prefer short-swards, but reduce it for birds such as Snipe and Redshank that nest in taller vegetation. Moderate grazing may result in a structurally diverse sward with tussocks that can be valuable nesting habitats from sime waders. It will also provide the short swards preferred for foraging by many waders and passerines both in winter and summer and by grazing wildfowl in winter. However, since intense grazing reduces invertebrate abundance, foraging efficiency is only likely to increase under moderate grazing intensities. The most severe negative effects are likely to result from sheep, rather than cattle grazing, since the heterogenous sward produced by the latter may provide nesting habitat for a wider range of bird species and support a larger range and abundance of invertebrate prey. Also intense sheep grazing may create visually uniform swards against which clutches of ground nesting birds may be relatively conspicuous to predators.

15. Approximately 40% of enclosed grasslands in Britain are mown every year. Technical innovation and scientific improvements in the understanding of silage making since 1940s have resulted in a widespread replacement of hay with silage. In 1970 the ratio of hay to silage was 85:15, by the mid-1990s this ratio had changed to 30:70. The widespread shift to silage making has had a major impact on grassland structure and diversity. Silage is mown earlier and more frequently than hay and hence prevents most grass species flowering and setting seed. Frequently harvested sown grasses provide consistently higher quality forage than infrequently harvested permanent grassland. Hence re-seeding of cutting fields is widespread, particularly with species such as Perennial Rye-grass and *L.multiflorum*. Overall, intensive cutting tends to reduce the size and complexity of the sward, prolong the vegetative phase of grass growth and increase primary production.

16. The impact on grassland invertebrates of cutting and removing herbage is generally more detrimental than grazing. Although there is some recovery of invertebrate populations

between successive mowing events, the unselective nature of mowing produces a more homogenous sward than does grazing. Because many herbivorous invertebrates are associated with particular plant species or families, reductions in the floristic diversity of the sward will significantly reduce the abundance and diversity of the associated invertebrate community. Heteropteran species, for example, are affected by direct physical damage and the alteration of their food and shelter. As in the case of grazing, the timing of cutting in relation to the phenology of the species concerned is important in determining the impact of management. Cutting in summer seems to be generally more detrimental than spring and autumn for a range of species within, for example, the Araneae and Hemiptera. In addition, rolling of silage fields early in the year, to prevent contamination of silage with soil, can reduce populations of leatherjackets and slugs.

17. With respect to birds associated with grassland, the effects of cutting are similar to those of grazing. Cutting causes direct reduction in productivity of ground nesting species through mechanical destruction of nests and chicks. This increase in egg, chick and even adult mortality has been identified as the main cause of the decline of Corncrake populations in Britain and also has a severe impact on the productivity of waders and of some ground nesting passerines such as Skylark. The sward may provide a good physical feeding environment for many insectivorous waders and passerines but this advantage is likely to be out-weighed by the density of that sward, which may impede foraging, and the reduction in invertebrate abundance under intensive cutting. For some wintering wildfowl, however, management for silage may be beneficial resulting in the short, nutrient-rich swards that many of these species select.

18. Widescale drainage in 18th and 19th centuries led to *c.* 5 million ha of land being under-drained and many wetland areas were converted to arable land. There was an active period of drainage during the period 1940-1980, encouraged by grant aid, but since then the rate of drainage has fallen. Changes in soil hydrology result in alterations in plant communities either by creating unsuitable edaphic conditions for wetland plants or by enabling more intensive management e.g. earlier cutting and grazing. The height of the water table is of considerable importance in determining the abundance and composition of the invertebrate fauna in the top layers of the soil or plant litter. Invertebrates such as earthworms and tipulid and chironomid larvae become less abundant overall or burrow deeper in waterlogged soils.

19. Information relating to the impact of drainage on birds of neutral grasslands derives mainly from studies of lowland wet grasslands where drainage has had a highly detrimental effect on breeding populations of many birds, particularly waders. The broad mechanisms whereby neutral grassland birds will be affected are likely to be similar to those on lowland wet grasslands. Drainage will cause a reduction in the availability and accessibility of invertebrate prey and subsequent increases in the intensity with which the grassland, once drained, may be managed. Not only do the surface layers of dry soil support fewer key prey items for wader species but they are also much more difficult to probe and, hence, invertebrates present are less accessible to birds such as Lapwing and Snipe. A number of passerines, such as Yellow Wagtail, also select damp grassland areas to feed probably because these represent areas rich in invertebrates. In winter, waders such as Golden Plover and Lapwing will readily use dry grassland and arable land but may congregate on recently flooded grassland to feed on dead or dying earthworms that

suffer quite high mortality under regular and/or prolonged flooding. Many wildfowl favour damp grasslands in winter and species such as Shoveler, Teal, Pintail and Wigeon congregate on flooded meadows. Extensive flooding may reduce the availability of foraging habitat for some grazing geese but the intensive management that follows drainage is likely to favour many wintering wildfowl.

20. Quantitative data relating to the extent of re-seeding of grassland in Britain is relatively poor. An estimated 200,000 hectares of grassland are reseeded annually but *c.* 50% of swards are still at least 20 years old. In the earlier part of the century, grass seed mixes were complex with a range of forage herb species. Modern seed mixtures are relatively simple and this combined with better weed control and seed cleaning means that re-seeding will greatly reduce botanical diversity.

21. Re-seeding affects invertebrates through the disruption caused by cultivation and the shift to a less species-rich sward. Soil arthropods, particularly collembolans and mites, decline in abundance after cultivation of old pastures. Earthworms show short-term reduction in biomass but there is a rapid population recovery. As highlighted above (17), the reduction in species diversity of the sward will reduce the diversity, and probably also the abundance, of the invertebrates it supports.

22. Very little information exists relating to the impact of re-seeding on grassland birds. Older species-rich swards are likely to provide a greater range of feeding and nesting habitats and have been shown to be particularly favoured by wintering passerines Starling, Fieldfare and Redwing and waders such as Golden Plover and Lapwing. In contrast, many wintering wildfowl, such as Bewick's Swan and Barnacle Geese, prefer young grass leys probably because these provide higher quality forage than older pasture. There is also some evidence to suggest breeding Skylarks may prefer young (< 3 years old) grass leys.

23. On a national scale, intensive grassland management may benefit some grazing wildfowl species, but these species tend to be very localised in their winter distribution and utilise a relatively small proportion of grassland in the UK. Overall intensive modern grassland management practices appear to be very deleterious to the abundance and diversity of farmland bird species.

1. GENERAL INTRODUCTION

This review forms part of a wider project that aims to assess how changes in lowland grassland management in recent decades, typified by greatly increased inorganic fertiliser inputs and production of silage rather than hay, have affected biodiversity. Management of lowland grassland has been transformed in the last 50 years (Hopkins & Hopkins 1994), mainly through greater fertiliser inputs, re-seeding, the development of silage techniques, changes in stocking patterns and improved drainage. A very high proportion of lowland grassland is now managed intensively and there is considerable uniformity of management systems over large geographical areas. The biodiversity implications of these changes are likely to be substantial, but they have not been studied adequately. Research on the effects of post-war agricultural intensification on biodiversity have focused mainly on arable farmland, particularly cereals (e.g. Firbank *et al.* 1991, Greig-Smith *et al.* 1992).

The main aim of this project is to determine the extent to which changes in management in recent decades have affected communities of invertebrates and birds within managed grassland in the wider countryside. The focus is on grasslands that are now typical of large areas of lowland England; these are predominantly agriculturally-improved neutral grasslands. The broad aim of the work is to improve our understanding of the biodiversity implications of recent changes in management by linking changes in floristics and structure of vegetation with changes in invertebrate and bird communities. This review was undertaken in order to assess the extent of existing knowledge, identify gaps in that knowledge and generate some hypotheses that can then be tested by field data, collected in the following three years.

The review comprises three subsequent chapters. Chapter 2 provides a general description of the extent and nature of grassland in Britain and summarises key features of associated invertebrate and bird communities. Chapter 3 uses data on the distribution and abundance of breeding and wintering birds and land cover in Britain in an attempt to provide a quantitative definition of a grassland bird. The core of the review is contained in Chapter 4. This describes recent trends in grassland management practices, in terms of chemical inputs (fertiliser N, herbicides and insecticides) and physical management (cutting regimes, grazing regimes, drainage and re-seeding). Information from published literature is used to assess the impacts of these changes on the botanical and structural composition of the sward and on the invertebrates these swards support. This information, combined with that derived from specific studies on grassland birds, is then used to assess the potential impact of these changes on grassland bird populations in Britain. (Note: Latin names for all species mentioned in the text are given in Appendix 1.1 listed in alphabetical of common name).

2. LOWLAND GRASSLANDS: STATUS AND ASSOCIATED INVERTEBRATE AND BIRD COMMUNITIES

2.1 The Nature and Extent of Lowland Grasslands in the UK

Grasslands occupy a higher proportion of agricultural land in the UK than in most other European countries. Of a total area of *c.* 12 million hectares of crops and grass, nearly 7 million hectares consist of 'permanent' or 'temporary' grasslands (MAFF 1997). In addition there are some 5 million hectares of unenclosed 'rough grazing'. This heterogenous census category includes heather moor, bracken and Purple Moor Grass/Mat Grass/fescue grassland, and occurs mainly in the cool, wet uplands of the north and west; some of this is botanically and agronomically indistinguishable from permanent grassland (Hopkins & Hopkins 1994).

In the more westerly regions of the UK, such as north-west and south-west England and Ceredigion and Carmarthenshire, grasslands account for over 60% of the agricultural land (MAFF 1997). In contrast, in more eastern regions such as Cambridgeshire and Lincolnshire, for example, grassland now occupies less than 12% of the agricultural land area. The westerly grassland regions of the UK contain most of the lowland semi-natural grasslands. These are defined as communities of native grasses and dicotyledonous herbs, with few, if any, woody species, that have been largely created by agricultural practices not involving the regular use of inorganic fertilisers, herbicides or cultivation (Crofts & Jefferson 1994). Semi-natural grasslands have high nature conservation value in that they include some of the most diverse communities found in the UK and support a wide range of indigenous wildlife species (NCC 1989; van Dijk 1991; HMSO 1995). It has long been recognised that ancient calcareous grasslands have exceptional diversity (Tansley 1939; Rodwell 1992) but, more recently, it has been recognised that they are not unique in this respect. Agriculturally unimproved neutral grasslands, such as Crested Dog's Tail-Black Knapweed (MG5) grassland (Rodwell 1992), can also have exceptionally species-rich communities (Jefferson & Robertson 1996; Gibson 1998).

A substantial proportion of the total area of lowland semi-natural grasslands has been lost, or has undergone a marked decline in its nature conservation value, during the 20th century (van Dijk 1991). In the UK the loss has principally been due to drainage and agricultural improvement (NCC 1989; Hopkins & Hopkins 1994). In the period from the 1940s to the early 1980s there was a degree of political consensus on countryside management. Successive governments encouraged the intensification of agriculture through guaranteed prices and capital grants, and farmers were provided with a free advisory service in turn supported by a large, production-oriented, research service. A radical change occurred during the 1980s, when most of the arguments for increasing agricultural production gradually fell away and mainstream British politics underwent a progressive 'greening'. The 1981 Wildlife and Countryside Act heralded a change in emphasis in terms of encouraging conservation, and several contentious issues during the period, including debates over the future of the Somerset Levels and the Halvergate Marshes (O'Riordan 1985), focussed attention upon grassland loss. The introduction of milk quotas in 1984 removed a major incentive to further increases in production, and the 1986 Agriculture Act imposed a duty for agriculture ministers to balance the needs of farming with conservation and enjoyment of the countryside, and gave ministers powers to establish Environmentally Sensitive Areas.

However, despite these changes of policy and outlook, the loss of grassland continued. Fuller (1987) reported an approximate 2% per annum loss of semi-natural grasslands between 1930 and 1984, but in some areas this may have risen to 10% in the 1980s due to a combination of agricultural intensification, inappropriate management and neglect (Devon Wildlife Trust 1990; Porley & Ulf-Hansen 1991). Ironically, the reasons for this increased rate of loss would appear to relate to government policy. Many dairy farmers responded to milk quotas by intensifying their management of grassland, to reduce expenditure on bought feed-stuff. Falling incomes from other livestock enterprises, and anticipation of a quota system on cattle and sheep numbers, were countered by increasing stocking rates and intensification of grassland management. This increased intensification of management was associated with considerable changes to the infrastructure of grassland landscapes in Britain. The greatest rates of hedgerow loss in Britain were in the 1960s and 1970s (O'Connor & Shrubb 1986) but even during the 1980s approximately 20,000 km of hedges alone were lost in the pastoral area of Britain and the total length of fences increased by over 30,000 km (Barr *et al.* 1993). Loss of hedges, together with changes in the type of field boundary, were associated with significant loss of species in the pastoral landscapes. The study by Barr *et al.* (1993) indicated that the potential of hedges and field boundaries to provide a reservoir of species for future recolonisation of grasslands had declined during their study period.

The extent of the loss of semi-natural grasslands was highlighted by Fuller (1987) who estimated that in 1984 unimproved grassland occupied only 3% of the area that it had covered in 1930 in England and Wales. More recently it has been estimated that less than 200,000 ha of lowland semi-natural grassland now remain in the UK (HMSO 1995). Drastic losses have been suffered by all the broad categories of semi-natural grassland that are found in the UK namely, calcareous, neutral and acidic grasslands. By the early 1990s Crofts and Jefferson (1994) estimated that the total extent of semi-natural neutral grasslands, which are found on moist mineral soils of pH between 5 and 6.5, probably amounted to less than 11,000 ha. Lowland wet grasslands, defined as permanent grasslands that are periodically waterlogged (Jefferson & Grice 1998), are estimated to occupy approximately 220,000 ha of land in England, much of which is now probably agriculturally improved (Dargie 1993; Jefferson & Grice 1998). The total area of agriculturally unimproved, semi-natural wet neutral grasslands is estimated to be less than 10,000 ha in England (Jefferson & Robertson 1996). Most of which is in the south west (Dargie 1993).

The distribution maps presented in Rodwell (1991, 1992) provide a general guide to the spatial distribution of different grassland communities in the UK (excluding Northern Ireland). However, these maps should be used with caution, as they are unlikely to reflect the complete distribution of these communities.

2.2 Invertebrate Groups Associated with Grassland

Invertebrate communities associated with grassland can be very variable in composition, but they do have certain characteristic features that derive from the general nature of the grassland habitat (summarised by Curry, 1994). The simplicity of the structure of grassland compared to a multi-structured habitat such as woodland, for example, results in a correspondingly lower range of invertebrate species. A high proportion of grassland invertebrates are specifically adapted for feeding on grasses, or have other adaptations appropriate to the predominantly vertical structure of the habitat. Although above-ground communities may be simpler in grasslands, grassland soils tend to have higher and more evenly distributed organic matter levels than woodland soils, and this is reflected in a correspondingly richer soil fauna (Curry 1994). In all types of grassland, the vast bulk of the invertebrate biomass (70-90%) occurs below ground and decomposers are the dominant trophic group.

The invertebrate groups of greatest significance in grassland are the Nematoda, Annelida, Mollusca, Acari, Araneae, Insecta, Apterygota, Isopoda and Myriapoda. Most of these invertebrates have a wide range of distribution, and the size and composition of the community will be determined by local habitat factors such as the botanical composition and structure of the sward, weather and climate, physical and chemical properties of the soil, and topographical features. A number of these habitat factors will be modified by the management practices applied to the grassland, which will further affect their invertebrate communities.

Within grasslands, certain general responses of invertebrate communities to increasing the intensity of management can be identified (Curry 1994). The invertebrate communities of extensively managed grasslands tend to be complex, reflecting the varied habitat provided by a relatively complex vegetational structure and mixture of plant species, and a well-developed surface mat of decaying plant material. In contrast, the communities of intensively managed grasslands tend to be simpler in structure and to be dominated by species that can tolerate disturbance and are adapted to exploit the greater productivity of managed swards. However, this broad generalisation is the result of a complexity of effects of different management practices, both at and within different levels of the community.

2.3 Importance of Invertebrate Groups to Birds

Invertebrates comprise an important component of the diet of a number of grassland birds. Diet may vary seasonally, and the importance of invertebrates in the diet often increases during the breeding season, with nestlings frequently being fed an entirely invertebrate diet (Wilson *et al.* 1996a). The majority of bird species associated with grassland habitats derive from four main groups: waders, wildfowl, songbirds or passerines, and rails (see below 4.1.3). Invertebrates are not important in the diet of species within all these groups, though the use made by birds of invertebrates differs between them. In general wildfowl, such as ducks, swans and geese, are largely herbivorous as adults and invertebrate prey is less important within this group of species than for waders, passerines and rails. In addition to these four groups of birds, a number of gull species utilise grassland for feeding. In winter, Black-headed Gulls often come onto flooded grassland and Greater Black-backed Gulls and Lesser Black-backed Gulls and Common Gulls also feed on grassland at this time of year. As well as feeding directly, largely on insects and earthworms (Cramp & Simmons 1983), Black-headed Gulls also kleptoparasitise other grassland birds, especially Lapwing and Golden Plover (Barnard & Thompson 1985). However, in general, very little is known about the use gull species make of grassland and, for the purposes of this review, we will focus on the four groups of birds traditionally recognised as grassland species. Information on diet for these species is taken from a review by Wilson *et al.* (1996a). It should be noted that the following is, by necessity, an extremely general account of diet. Relative usage of prey items will vary with habitat and region.

The diet of waders, such as Lapwing and Curlew, consists mostly of invertebrates which are taken both from the ground surface and the vegetation, and by probing in soft substrates. Both species are primarily diurnal feeders and take mainly Mollusca, Annelida, Arachnida, Orthoptera, Hymenoptera, Colepotera and the larvae of Diptera. The most important dietary items include slugs (Stylommatophora), earthworms (Oligochaeta), spiders (Araneae), leatherjackets, ants and their pupae and the adults and larvae of ground beetles, weevils, click beetles, dung beetles and chafers (Scarabaeidae), jewel beetles (Buprestridae) and darkling beetles (Tenebrionidae).

Many passerines are primarily insectivorous in both winter and summer. Species such as Meadow Pipit, Pied Wagtail, Yellow Wagtail, Whinchat and Wheatear take a very wide range of soft and hard-bodied invertebrates from the ground surface, vegetation and, in the case of wagtails, in the air. The most important invertebrate foods for these species are within the Hemiptera, Diptera, Hymenoptera and Coleoptera, with spiders and caterpillars also important in the diet of Meadow Pipit. Meadow Pipits and Yellow Wagtails take very small insects within the Hemiptera including aphids, psyllids, and scale bugs. Within the Diptera, crane-flies, fruit flies, dung-flies, midges and blow-flies and a wide range of other dipteran taxa are also frequently taken. Sawflies, ichneumon wasps and ants are the most important hymenopteran components and ground beetles, weevils, leaf beetles and rove beetles are the most important beetle prey.

Other passerines, particularly buntings and some finches, such as Cirl Bunting and Yellowhammer, are graminivorous outside the breeding season, but switch to a partially invertebrate diet during the breeding season and feed their nestlings almost entirely on invertebrates. The species feed mostly on the ground, but will sometimes forage in low bushes, especially when gleaning invertebrates during the breeding season. These species take a wide taxonomic range of invertebrates, with springtails (Collembola), grasshoppers (Orthoptera), caterpillars, weevils, rove beetles, crane-flies and bush-crickets being among the most important components. Nestling diet is almost entirely invertebrate in origin, including adult and larval Lepidoptera, beetles, adult Diptera, sawflies, spiders and Orthoptera. Similarly, Skylarks feed on seeds and green plant material in winter but dependent young are fed invertebrates. This species tends to take small prey items from a very wide range of taxa including Arachnida, Hemiptera, Diptera, Hymenoptera and Coleoptera. Amongst these, the most important components of the diet are spiders, bugs and aphids, adult and larval crane-flies, soldier-flies, hoverflies, hymenopteran larvae, especially of sawflies, ground beetles, weevils, leaf beetles and click beetles.

2.4 Birds Associated with Grassland

Four main groups of birds can be identified as associated with grassland habitats - waders, wildfowl, songbirds or passerines and rails. These groups/species differ significantly in their feeding and breeding requirements and their response to changes in grassland management practices will, therefore, also differ between species. We consider each group of birds separately within the relevant sections of the following Chapter and provide a short overview of the species concerned in this introductory section.

Eight species of breeding waders are associated with grasslands in Europe: Oystercatcher, Black-tailed Godwit, Curlew, Redshank, Lapwing, Snipe, Dunlin and Ruff. Throughout the UK, Lapwing, Redshank and Snipe are the most common breeding waders on grassland. Dunlin does not regularly occur in this habitat in the UK away from Hebridean machairs. Black-tailed Godwit and Ruff have very small populations and occur mainly on reserves managed specifically for lowland wet grassland. Oystercatcher is more characteristic of northern grasslands (Fuller *et al.* 1986) but is currently increasing, especially in eastern England. Curlew is characteristic of northern and western grasslands though it has probably declined (Fuller 1995). Of the eight species of waders only three will use well-drained neutral grassland: Oystercatcher, Curlew and Lapwing. The other species require wet habitats to breed.

Pasture is an important feeding area for several species of wader in winter. Golden Plover and Lapwing, which winter in the UK in internationally important numbers (Cranswick *et al.* 1997), select permanent pasture for feeding in many, but not all, areas (Lister 1964; Fuller & Youngman 1979; Fuller & Lloyd 1981; Milsom *et al.* 1985; Gregory 1987; Fuller 1988; Tucker 1992; Gillings & Fuller 1998). In coastal areas, small numbers of Curlew and other waders use agricultural pastures (Milsom *et al.* 1998) and, in spring, the Icelandic race of Black-tailed Godwit move from estuaries to feed and fatten up on permanent grass before returning to the breeding areas (J. Gill pers. comm.). Pastoral areas such as the Ouse Washes and Nene Washes are important staging posts for these populations.

Grasslands also support a range of breeding and wintering wildfowl, although these species are primarily associated with lowland wet grasslands which tend to be more important as wintering rather than breeding sites. Important species associated with lowland wet grasslands in winter and/or summer include Bewick's Swan and Whooper Swan, Barnacle Goose and Greenlandic and European White-fronted Goose, Shoveler, Garganey, Wigeon, Gadwall, Teal and Pintail.

A range of passerines are associated with grassland habitats although very few depend exclusively on such areas (see Chapter 3). During the breeding season, lowland agricultural grassland is important for a number of species, e.g. Chough, Skylark, Cirl Bunting, Yellowhammer, Meadow Pipit and Yellow Wagtail. Although, of these, only the Chough is entirely dependent on particular grassland types. Other species, such as Wheatear and Whinchat, although now almost entirely restricted to upland areas, were once more widely distributed on grassland in lowland Britain. In winter, the number of passerine species which use grassland increases; thrushes, Starlings and some larks and buntings forage in agricultural grasslands at this time of year.

One species of rail, Corncrake, is also associated with grasslands. It is a species typical of low-input farming and used to be widespread across the agricultural landscape of lowland Britain. However, Corncrake has exhibited a major population decline and severe range contraction since the early 1900s and is now restricted to west and north-west Scotland with strongholds in a number of Hebridean islands (Green 1995). The adult birds breed in species-rich hay fields, and tall marshland vegetation is important as spring cover (Green 1986).

2.5 The Importance of Hedgerows

Although the focus of this review is on management of the grassland crop itself, rather than field boundaries, field boundary characteristics are extremely important in determining the potential use of fields by birds (Clarke *et al.* 1997). For this reason, brief consideration is made here of the way in which field boundaries, particularly hedges, have changed historically, and the broad effects these changes may have on bird communities associated with grassland.

The importance of hedgerows for a large proportion of the British avifauna has been highlighted in a number of reviews of habitat use by birds in farmland. For example, in a study by Lack (1992), 27 species of bird, out of a total of 55 under consideration, routinely used hedges for nesting and feeding. In a second study, O'Connor *et al.* (1987) showed bird density to increase with hedgerow density, with *c.* 50% (24 of 57) of species considered occurring in higher numbers on farms where field boundary density was greater. Fuller *et al.* (1997) showed the density of hedgerows to be one of the most important predictors of species density of birds within lowland English farmland. Sensitively managed hedges and hedge bottom vegetation provide a range of resources for many birds including nest sites, song perches, food supplies and protection from predators (Barr *et al.* 1995).

There are some species, notably Skylark (Schlapfer 1988; Fuller *et al.* 1997; Wilson *et al.* 1997; Chamberlain & Gregory 1999) and Lapwing (Milsom *et al.* 1985) that avoid hedgerows and tend to be associated with large fields. In general however, bird species richness increases with the size and species richness of the hedgerow (Parish *et al.* 1994) although different bird species often require different structures during the breeding season (Green *et al.* 1994; MacDonald & Johnson 1995) and the management of hedgerows can also influence their value to birds. For example, management of the hedge itself, particularly trimming, will affect berry abundance (Maudsley *et al.* 1997) and one study (Sparks & Martin 1999) suggests berry production on hedges unmanaged for 10 years considerably exceeds that of managed hedgerows. The production of berries is of particular importance for some birds, with shrubs such as Hawthorn, Blackthorn, Dog rose and Bramble, and climbers such as Bryony acting as key food resources for birds especially in winter (Snow & Snow 1988).

Some hedgerow tree or shrub species also support a wide range of invertebrates, some of which are important as prey for farmland birds. Hawthorn, for example, has about 230 species of phytophagous insects and mites associated with it (Duffey *et al.* 1974). Tall, wide and dense hedges tend to support richer invertebrate communities than gappy hedges or hedges subject to severe mechanical trimming (Dowdeswell 1987; Dennis & Fry 1992; Morris & Webb 1987). Hedge bottoms also have an abundant ground fauna which includes important bird food items such as ground beetles, spiders and harvestmen (Opiliones) all of which benefit from a dense, structurally complex herbaceous flora in the hedge base.

3. THE ASSOCIATION OF BREEDING AND WINTERING FARMLAND BIRDS WITH PASTORAL FARMING SYSTEMS

3.1 Introduction

In the last 25-30 years many common farmland birds have exhibited widespread population declines and range contractions both in Britain and abroad (Tucker & Heath 1994; Fuller *et al.* 1995; Siriwardena *et al.* 1998). Growing evidence now exists to link these declines to changes in farm management practices associated with agricultural intensification (e.g. Potts 1986; O'Connor & Shrubb 1986; Evans 1997; Wilson *et al.* 1997). However the majority of recent relevant research has focussed almost entirely on arable farming systems despite the fact that changes in grassland systems have been at least as profound. Management and production of lowland grassland in Britain has been transformed during the last 50 years, achieved mainly through greater fertiliser inputs, changes in fertiliser practice (a switch from farmyard manure to inorganic compounds and slurry), reseeding, the development of silage techniques and widespread efficient drainage (Hopkins & Hopkins 1994). Furthermore, stocking patterns have altered substantially because numbers of livestock, especially sheep, have increased markedly since the mid-1970s (Fuller 1996; Fuller & Gough in press). Changes in management have occurred extensively throughout the lowlands so that now a very high proportion of grassland is managed intensively and there is considerable uniformity of management systems over large geographical areas. Farming systems in general have also become polarised geographically in Britain with arable landscapes concentrated in the south and east and pastoral landscapes in the north and west. This has greatly reduced regional landscape diversity.

Intensification of grassland management has been broadly linked to declines in floristic species richness in lowland grassland (Fuller 1987) and increases in stocking densities on grazed grassland have been shown to have major effects on the invertebrate communities they support (Gibson *et al.* 1992; Brown 1993). There is also some evidence that grassland invertebrates have declined in response to increased fertiliser usage (Van Wingerden *et al.* 1992). Intensification of grassland has probably played an important role in the recent declines of farmland birds but the mechanisms are poorly known. Most previous work on grassland birds in Britain has focused on localised types of grassland such as grazing marshes or coastal grassland (Smith 1983; Vickery *et al.* 1997; Milsom *et al.* 1998) or the autecology of rare species such as Corncrake (Tyler *et al.* 1998).

Before reviewing the possible effects of changes in grassland management in Britain on bird populations it is important first to define what is meant by a grassland bird. Farmland birds in general have been defined by Gibbons *et al.* (1993) as those species which depend mainly on fields for food, although they may nest in woods or hedges. Pain *et al.* (1997) considered the distribution of six declining species of bird known to depend on extensive pastoral systems but to date there have been no attempts to provide a quantitative definition of a grassland bird.

In this chapter we relate bird atlas data detailing the distribution and abundance of farmland birds in summer (Gibbons *et al.* 1993) and winter (Lack 1986) to ITE Land Cover data in order to identify birds as associated with pastoral, mixed or arable farming. Our aim is to provide a broad classification of farmland bird communities in general and to identify those species most strongly associated with grassland systems in particular.

3.2 Methods

Source of bird data

Breeding bird abundance and distribution data were taken *from The New Atlas of Breeding Birds in Britain and Ireland: 1988-1991* (Gibbons *et al.* 1993). The atlas data are based on the 10 km National Grid squares and up to 25, 2 x 2 km tetrads were visited in each 10 km square over the three year period and the presence or absence of all bird species was recorded. (Direct counts of some species, such as colony nesting seabirds, were also recorded but none concerned species dealt with here.)

If areas with a mix of arable and pastoral land are important for some species then the scale at which the data are arranged is likely to be important. The data collected for the atlas allows analysis at several different levels but for the purposes of this analysis we consider bird distribution at the tetrad level. At the 10 km level is possible that apparently 'mixed' farming areas within the square could be a series of either predominately arable or predominately pastoral farms rather than a true mixed-farming landscape and a higher degree of precision was desirable. Analyses were therefore performed by modelling the probability of occurrence of each bird species at the 2 x 2 km (tetrad) level based on the presence or absence of a particular species in each tetrad surveyed.

Data on winter bird abundance were taken from the BTO's *Atlas of Wintering Birds* (Lack 1986). These data were collected over the three years in the winters of 1981/82 to 1983/84. The data are organised on a 10 km square level and the abundance of birds was measured as the number of birds seen in a six hour day in each surveyed 10 km National Grid square (see Lack 1986 for detailed methodology). Tetrad data for winter birds were unavailable.

Species selection

Many bird species in Britain use farmland to a greater or lesser degree. To investigate the importance of grassland habitats for 'farmland' birds we have taken a general approach to species selection but we consider their distribution within agricultural landscapes only (see below). Many species are found in a variety of habitats and through the selection of study areas which are in landscapes which are predominantly agricultural, we are confident that, at least for breeding birds at the tetrad level, we are dealing with those populations that occur in a farming landscape.

For guidance as to the species to consider, we have used species that Gibbons *et al.* (1993) define as farmland species, namely, those species which feed in open farmland, although they may nest in woods or hedges. Additional species defined by Lock (1998) as being associated with farmland in the south-west of England were added and species such as Blue and Great Tit, Dunnock, Robin and Swallow were included as a large proportion of their populations occur on farmland. The probability of occurrence in a tetrad was modelled for 60 species in total.

In winter, a similar selection procedure was employed to select species as being associated with farmland (Lack 1986). A total of 57 species was selected, including those used in the breeding season analyses but excluding summer migrants. The list also included species found on farmland in winter by Wilson *et al.* (1996b). We have also added other species that use farmland in winter such as such as Hen Harrier, Merlin, Short-eared Owl, and Golden Plover which breed in upland or marginal upland areas, continental migrants such as Blackbird, Song Thrush, Redwing and Fieldfare and wildfowl such as swans and Wigeon.

Definition of study area

This analysis is restricted to lowland farmland in England and Wales and selection of squares was based on agricultural statistics data from the MAFF June 1988 Parish summaries (collated by the University of Edinburgh data library) as a basis for selection of areas. The selection of areas to be considered in this study was made according to the amount of land under cultivation in each 10 km National Grid square. Squares were included if they contained a cover of grassland, crops or rough grazing greater than 50% of the total area (Figure 3.1). This effectively excluded coastal squares, 'upland' squares and those which were predominately sub-urban. A total of 1,084 squares were selected and used for the analysis of breeding and wintering bird data.

For analyses at the tetrad level, the ITE Land Cover dataset was used to calculate the amount of each tetrad under cultivation. As the aim of the analysis is to consider bird distribution trends in predominantly agricultural landscapes, only tetrads within the former sample of 1,084 10 km squares with a percentage cover of farmland greater than 75% were included. Other suitable tetrads were available outside these 10 km squares but were excluded as they were not deemed to be in a wider farming landscape. It should be noted that under this Land Cover classification the grassland category also includes recreational grassland. However, tetrads considered all contained at least 75% farmland cover and the proportion of recreational grassland was therefore small relative to agricultural grassland.

3.3 Statistical Analysis

Analyses were performed using generalised linear models constructed in the SAS GENMOD procedure (SAS 1986). These analysed model bird data (relative abundance or probability of occurrence as appropriate) as a continuous function of the arable:pasture ratio with a binomial error distribution with a logit link function (for tetrad breeding bird analyses) or with a Poisson error distribution and log link function (for winter bird atlas 10 km count data). To allow for quadratic relationships between bird abundance/occurrence, the square of the proportion of land under pastoral agriculture was also entered. The polarisation of geographical distribution of the different farming landscapes has already been highlighted and in order to avoid spurious relationships with geographical location, the easting and northing of the square or tetrad was also entered in the model for widespread species. Models were constructed using a step-forward approach. First a model just with easting, northing and intercept was constructed. The proportion of pasture was added and the model recalculated. Finally, the proportion of pasture squared was added. Each additional parameter was accepted if significant and if an analysis of deviance between models showed a significantly improved fit.

Once models had been constructed each species was attributed to a particular landscape type (subsequently taken as the preferred landscape) using the probability of occurrence or estimated count. Arable farming landscapes were taken to be those squares with <25% pasture/rough grass, pastoral landscapes >75% pasture/rough grassland and mixed farming landscapes were taken to be in between. For breeding birds, the preferred landscape type was taken to be the one in which the species was most likely to occur. Some species showed no particular association with any of the landscape types whilst some showed associations with two landscape types. In order to refine the classification associated habitats were taken to be those where the maximum probability of occurrence in that type was less than 10% different from the preferred landscape type. A similar procedure was carried out for the winter analyses, although an additional associated landscape type was taken to be those types where the abundance of birds was <25% different from the preferred landscape type. This was due to the greater variation in the winter count data compared with the presence/absence breeding bird dataset.

3.4 Results

Breeding birds

Table 3.1 describes the model fits; model parameters and goodness of fit criterion appear in Appendix 3.1. As expected, the geographical location of the square or tetrad was highly significant for most species. Based on the criteria applied, the majority (44) of the 60 species are associated with one or two of the three landscape types and only 16 show an even distribution across all habitats (Table 3.1). Only two species, Long-eared Owl and Woodlark were solely associated with mixed farming and the remainder are either widespread or associated with predominately arable or pastoral landscapes.

Amongst the larger family groups, gamebirds, finches and buntings tend to be associated with predominantly arable or arable/mixed habitats and chats, thrushes and waders and, to a lesser extent, pipits and wagtails, tend to be associated with pastoral or pastoral and mixed landscapes (Table 3.2). The reasons for this apparent separation between species groups may be related to a species' diet during the breeding season. All species, apart from the raptors and owls, are known to feed on both invertebrate and plant material, the extent of which varies between the breeding and non-breeding season (Wilson *et al.* 1996a). It is possible to divide up the species into five groups based on the major components of their diet. Each species was assigned to one of five categories: carnivores, insectivores, species which require invertebrates & seeds, pure granivores, and those that eat both seeds and plant material (Table 3.3). Pastoral or pastoral/mixed landscapes tend to be preferred by insectivores, i.e. chats, wagtails, pipits, Swallow, Wren and also lowland breeding waders. Species that depend upon seeds (the cardueline finches and the three pigeon species) or both seeds and invertebrates (other finches, buntings and larks) tend to be more abundant in arable or arable/mixed areas.

Overall, raptors and owls did not show a particular affinity for one particular landscape type. Small mammal specialists occurred in each landscape type (these include Long-eared Owl, Kestrel and Barn Owl) whereas species whose diet contains insectivorous food, such as Hobby and Little Owl, were associated with mixed-farming areas. The Buzzard was the only raptor associated with pastoral areas, presumably due to higher populations of rabbits, which are a major component of Buzzard diet.

Birds in winter

Landscape preferences in winter are different to those seen in summer (Table 3.4). The majority of birds (35 out of 57 species, 61.4%) were most abundant in mixed farming landscapes, followed by arable (14 species, 24.5%) and pastoral (four species, 7%). The ratio of arable to pastoral land was not significant for Wigeon, Meadow Pipit, Starling and Long-eared Owl and models including just intercept, easting and northing were the best fit for these. The proportion of species associated with mixed farming habitats is much higher in winter than during the breeding season and, at the 25% difference level, only two species were associated with purely pastoral and eight with arable areas. Only five species are widespread across all types of farming landscapes at the 25% level. These results suggest that diverse habitats, created by mixed farming, may be more important to birds in winter than in summer.

When broken down by families, the distribution of families across the different farming landscape types is even for most groups although game-birds, pigeons and wildfowl tend to be associated with arable and mixed areas, and tits with pastoral areas (Table 3.5). For seed-eating species, as with the breeding season data, the general pattern was of larger numbers in arable and mixed-farming areas rather than in predominately pastoral systems (Table 3.6). Insectivores tended to be more abundant in mixed and pastoral areas as they were in the breeding season.

Herbivores such as the wildfowl tended to occur in greater numbers in arable and mixed landscapes. The two wild swan species showed very strong preferences for arable areas although grassland is known to be important for these two species in winter (Rees *et al.* 1997; Rees 1990). Mute Swans were more widespread, occurring in arable and pastoral habitats. Wigeon, a common species on inland pasture, did not show any significant relationship between abundance and either geographical location or the proportion of pasture in the 10 km square, perhaps due to the clumped nature of its distribution.

Seasonal differences in bird distribution

Species associated with arable areas in the breeding season tended to show similar preferences in winter. In contrast, very few species were associated with pastoral areas in winter and those that were breeding in predominantly pastoral areas tended to be associated with mixed-farming habitats in winter, suggesting a local redistribution may be taking place.

Most seed-eating species show similar patterns of abundance in winter as in the breeding season. However, the Corn Bunting, typically a bird of arable landscapes in summer, is found in higher numbers in areas with up to 25% cover of pasture in winter suggesting that this species may undergo small scale movements in winter and that mixed farming is important for this species in winter. This partial migration may be a feature of several species of farmland passerine which breed in solitary pairs and winter in flocks. Yellowhammer, the one seed-eating species typical of mixed farmland in summer, is more abundant in mixed farming areas in winter and very few occur in predominately pastoral areas. Cirl Bunting showed a completely different association in winter to that in summer but this may be a result of the limited data available for this species and the different geographical scales upon which the data were collected (see discussion).

Species such as Linnet, Skylark and Reed Bunting were most abundant in arable areas during the breeding season but also occur in pastoral areas, albeit in lower numbers. However, during the winter months these species were virtually absent in pastoral areas. Reed Bunting and Skylark are migrants or partial migrants (Cramp *et al.* 1988; Cramp & Perrins 1994), suggesting a redistribution between summer and winter. Whether these records refer to the British-breeding population, an influx of winter migrants or a mix of the two is unknown for most species. Many of these seed-eating farmland birds are species of conservation concern and have undergone declines over the past 30 years (Siriwardena *et al.* 1998), although the more widespread species, Goldfinch and Linnet, have undergone recent increases (Crick *et al.* 1998).

The Stock Dove, which is mainly sedentary, shows a similar pattern of abundance between seasons. Woodpigeons, which were common and widespread in the breeding season, show a strong preference for arable and mixed areas in winter where winter sown cereal crops, clover leys and oil-seed rape are important food sources (Murton 1965). Very few are found in predominantly pastoral areas. The larger numbers in the east of the country may also reflect the large autumn influx of continental migrants to the east coast.

In winter, as with the breeding season analyses, insectivorous species such as the thrushes, Pied Wagtail, Common and Black-headed Gull, Lapwing, Snipe, Little Owl and the corvids all showed much higher abundance in mixed farming areas or areas which are predominantly pastoral. This finding was predicted by O'Connor & Shrubb (1986) and highlights the importance of grassland areas in the winter period. However, two insectivorous species, Golden Plover and Starling do not follow this trend and occur in greatest numbers in arable areas. Starlings, however, do tend to be widespread whereas the model for Golden Plover shows a very strong association with arable areas. Meadow Pipit and Stonechat, which were strongly associated with pastoral areas in summer, were most abundant in mixed farming areas in winter but their abundance was less than 25% different in arable and pastoral landscape types.

Several species which breed across all farming landscape types were, in winter, more abundant in one or two landscape types. Woodpigeon, Kestrel, Blackbird and Starling were associated with arable and arable/mixed habitats in winter whereas species such as Chaffinch, Robin and Rook were associated with mixed or pastoral habitats.

3.5 Discussion

The analyses presented here result in a broad classification of birds into three main categories; in summer 13 species were classed as arable, 14 as mixed and 12 as pastoral. Species associated with pastoral landscapes were small insectivores such as pipits, wagtails and chats and larger insectivores such as thrushes and waders. In contrast, seed-eaters such as gamebirds, finches and buntings were associated with arable landscapes whilst raptors showed little affinity for any one landscape type. The landscape preferences in winter differed from those observed in summer. In winter, most species (*c*.74%) were associated with mixed farming landscapes. Only two species, Cirl Bunting and Buzzard, were associated with pastoral landscapes and only eight, Bewick's and Whooper Swans, Pheasant, Red-legged Partridge, Pink-footed Goose, Hen Harrier, Merlin and Golden Plover, were associated with arable landscapes. Within the species associated with mixed farming, insectivores such as thrushes, Pied Wagtail, Lapwing, Snipe and Little Owl tended towards the pastoral mixed regimes.

Interpretation of the model fits

Three issues need to be addressed when interpreting the model outputs. First, the summer and winter models estimate different parameters. The breeding season analysis models the probability of occurrence in a tetrad, whereas winter models estimate abundance. Therefore, comparisons between seasons for individual species need to be treated with caution as distribution and abundance are not necessarily linked (Chamberlain *et al.* 1999). Second, the summer and winter data are at different spatial and time scales; tetrad and 10 km squares respectively. This difference may have confound the results. However, analyses of summer data at 10 km square did show similar patterns (Atkinson unpubl data) and tetrad level analyses were used to avoid losing information. As well as the difference in spatial scale between the summer and winter atlas data, there is also a difference in the time of data collection. The winter atlas data having been collected *c.* 10 years before the summer atlas data. It is possible that distributions may have changed over this time and that winter distributions were more widespread in the early 1980s, prior to the major population declines, than the 1990s.

A third major problem is that of model fits and the problem of over- and under-dispersion. A measure of dispersion can be taken by dividing the deviance of the model by the number of degrees of freedom; this should be close to a value of 1. In the breeding season, where the response variable is binomially distributed (i.e. present or absent), this was achieved for the majority of species that are reasonably common. For those which are rare, such as Montagu's Harrier, Stone Curlew etc., fits were poor. Conversely in winter, overdispersion tends to be a problem as many species move around in flocks and counts tend to either be zero or large. This is particularly true for species such as the small gulls, Starling, wildfowl, and finches/buntings. Species which tend to occur either singly or in small flocks such as, for example, Kestrel, Barn Owl, Song Thrush, Bullfinch and Stonechat do not suffer this problem to the same extent. The model fits where overdispersion is a problem needed to be inspected closely but in the majority of cases the landscape type does exert a major influence on the abundance of these species, even though other factors may also be important.

The problem of overdispersion in winter could not be overcome because alternative analytical approaches are confounded by different factors. Firstly, the use of presence/absence at a 10 km level, is too crude a measure of bird distribution. This is because most species are widely distributed at this large scale, and so would be recorded as present in almost all 10 km squares with subsequent loss of much of the spatial variation in the data. Similarly, a second approach, namely the removal of zero values, inherently invalidates the models as the Poisson distribution allows zero values. An alternative distribution in the model could be used but Poisson distribution is the most appropriate for count data.

Finally, three points need to be made relating to the habitats, and habitat associations, considered in the analyses. First, habitats other than fields are, of course, extremely important for farmland birds and the results of these analyses may be a reflection of certain non-crop habitat characteristics of arable, mixed or pastoral farms. For example, Fuller *et al.* (1997) showed that structural elements of landscapes, especially density of hedgerows, woodland and ponds, were more frequent predictors of bird densities than the relative amounts of arable and grassland. Farmland contains areas of semi-natural habitats such as woodland, ponds, marshes and bog. The amount of these depends on the intensity of farmland management and is likely to vary between pure arable, mixed or pure pastoral farming. Extremely intensive arable or pastoral farming may have fewer of these non-crop habitats and the importance of this landscape type for birds may reflect the value of non-crop as well as, or rather than, cropped habitats. Second, due to the precision of the ITE land cover data, this analysis is not restricted entirely to agricultural swards but also semi-natural grasslands. Thus species such as Stone Curlew, Nightjar and Tree Pipit, although grassland birds, are not species of agricultural landscapes but tend to be found on heaths or rough grassland, and recently felled woodland with areas of open ground are important for the latter two species (Gibbons *et al.* 1993).

Trends in overall distribution and abundance of breeding grassland birds

This analysis has, for the first time, attempted to quantitatively categorise bird species with respect to the lowland farming landscapes with which they are associated. The models fitted to the breeding and wintering atlas data have highlighted the importance of both arable and pastoral habitats for farmland birds in both summer and winter. In summer, birds tend to be associated with one or other landscape type whereas in winter the majority of birds are most abundant in mixed farming, i.e. arable and pastoral areas.

No common lowland farmland species are exclusively dependent on lowland grassland habitats during the breeding season as most grassland specialists are now very rare or extinct in lowland Britain. One exception is the Chough which, although relatively rare in Britain, is a grassland specialist. Changes in agricultural practice and general intensification of grasslands have been blamed for the decline in Corncrake, Red-backed Shrike and Wryneck in lowland Britain (O'Connor & Shrubb 1986; Gibbons *et al.* 1993). Small insectivorous species, such as Wheatear and Whinchat, which were formerly found in lowland grassland habitats, are also now largely absent and confined to other habitats (Sharrock 1976; Gibbons *et al.* 1993). For the Wheatear, deterioration of grassland quality and invasion of scrub in many downland areas during the agricultural depression of the 1920 and 1930s, the subsequent ploughing up of grasslands during the Second World War and the recent intensification of agricultural grasslands have caused a large reduction in breeding numbers in lowland Britain (Gibbons *et al.* 1993). The reduction in the intensity of rabbit grazing due to the introduction of myxomatosis in the 1950s has also reduced the extent of short close-cropped rough grass on common land and downland required by Wheatears for foraging (Marchant *et al.* 1992). In lowland Britain, Whinchats were associated with rank unimproved grass in agricultural areas, particularly hay meadows (Sharrock 1976; Fuller & Glue 1977). However, with myxomatosis, much suitable habitat in downland became covered with dense scrub and the subsequent intensification and the increased use of herbicides and fertilisers (which increase the density of the sward) on farmland have reduced the quality of agricultural land as a feeding and nesting habitat for Whinchats (O'Connor & Shrubb 1986; Marchant *et al.* 1992). Stonechats were once widely associated with lowland habitats such as coastal or lowland heaths and commons and other areas with scrub. During and since the Second World War, the conversion of neglected pastures, heaths and rough grassland/scrub have contributed to the decline in Stonechat populations and fragmentation of inland habitats have led to a predominantly southerly coastal distribution where it is less susceptible to cold winters (Sharrock 1976; Marchant *et al.* 1992).

Pastoral areas do still support a range of species of high conservation concern, particularly the lowland grassland breeding waders, though these have become increasingly scarce especially in western Britain. The number of breeding Lapwing, for example, has decreased by approximately 50% in the 11 years between 1987 and 1998 and there has been a marked retraction of range in Wales and south-western England. Reasons suggested for this decline include changes in land management, including the loss of rough grassland due to conversion to intensively managed agricultural swards, the drainage of lowland wet grassland and the loss of mixed farming (Wilson *et al.* in prep).

Two common pastoral species, Meadow Pipit and Pied Wagtail, are distributed across the whole of Britain but, in agricultural regions, are more likely to occur in pastoral areas. Pied Wagtails are reported to prefer mixed farmland (O'Connor & Shrubb 1986), especially those with riparian areas, but this analysis suggests that grassland areas are more important in the wider countryside. Meadow Pipit numbers have declined since 1980 and in southern England this has been blamed on the conversion of grassland to arable land and the loss of marginal land to afforestation (Marchant *et al.* 1992). It is also possible that intensive grazing has resulted in grassland becoming unsuitable as nesting habitat for Meadow Pipits either as a result of changes in sward structure or increased risk of trampling (Fuller & Gough in press). However, the sudden drop in the CBC index since 1980 suggests that habitat loss, although important on a local scale, is not driving the national decline and other factors, perhaps climatic, are driving the decrease (Marchant *et al.* 1992).

The only raptor species associated with pastoral areas is the Buzzard and this association probably reflects both the distribution of their main prey, the rabbit, and also the degree to which raptor populations have been persecuted. Buzzards were once widespread across central and eastern England but by the first half of the 20th century, only a relic population remained in the west of England, Wales and Scotland (Gibbons *et al.* 1993). Populations have recovered since then but in lowland areas Buzzards are restricted to the west of Britain. Reduction in rabbit numbers through myxomatosis, and the conversion of grassland to arable land which will reduce rabbit numbers further, are probable causes of the continued absence of Buzzards in central and eastern England, although persecution may still be a problem in these areas (Marchant *et al.* 1992; Gibbons *et al.* 1993).

One surprising result of this analysis is the association of Yellow Wagtail with arable landscapes. In previous literature looking at large scale distribution of breeding birds (e.g. Sharrock 1976; Gibbons *et al.* 1993; Marchant *et al.* 1992). Yellow Wagtails have been associated with lowland flood meadows, grazing marsh and damp grasslands. Drainage, grassland improvement and conversion of grassland to arable land are blamed for declines in this species (Gibbons *et al.* 1993; Marchant *et al.* 1992). Birds have a higher breeding success in drained cereals (O'Connor & Shrubb 1986; Gibbons *et al.* 1993) and, in the Netherlands over 50% of the breeding population occurs in cereals where breeding densities tend to be higher than in grasslands. This analysis suggests that breeding in arable land in lowland England and Wales is more widespread than previously thought. Although this analysis does not provide information on any differences in abundance, in tetrads which are >75% farmland, Yellow Wagtails were approximately four times more likely to occur in arable rather than pastoral areas.

Although no birds were associated exclusively with pastoral areas throughout the year a number of bird species of high conservation concern were associated with mixed landscapes in winter and/or summer. These include Biodiversity Action Plan species such as Bullfinch and Tree Sparrow (summer and winter), Corn Bunting, Linnet, Grey Partridge and Song Thrush (summer only) and as well as species for which serious declines have only recently been identified, such as Lapwing (summer and winter) and Yellowhammer (summer and winter). Furthermore, CBC data for long term population trends of common British birds suggest that of the 12 species identified as being grassland specialists, only two are not showing indications of a decline since 1965; Pied Wagtails are stable and Buzzard numbers are increasing (Crick *et al.* 1997). Thus despite that fact that, to date, most research on farmland birds has focussed on arable habitats many of them also use grassland, especially in winter. This bias may reflect the fact that most studies have been carried out in the breeding season. Winter ecology remains a key information gap for many BAP farmland birds and in this context more information concerning the use these, and other, species make of grassland is clearly important.

4. GRASSLAND MANAGEMENT PRACTICES AND THEIR EFFECTS ON BOTANICAL COMPOSITION AND SWARD STRUCTURE, INVERTEBRATES AND BIRDS

4.1 General Introduction

The previous chapters have considered the nature and extent of grasslands, particularly neutral grasslands, in Britain, and the plant, invertebrate and bird communities associated with them. In this chapter we review the potential impacts of recent changes in management practices within grassland systems on plant and invertebrate communities, and on the grassland birds which they support. We consider changes in chemical management (fertiliser and pesticide) and physical management (livestock and cutting regimes, drainage, ploughing and reseeding of grasslands). We summarise the historical trends of each particular practice and then review available information on the impacts on botanical and invertebrate composition and breeding and wintering birds.

4.2 Use of Fertiliser on Grassland

4.2.1 Recent changes in grassland fertilisation practice

Since World War 2, the average use of fertiliser nitrogen (N) on grassland has trebled (Hopkins & Hopkins 1994). Amounts of fertiliser nitrogen applied to grassland reached their peak in the mid 1980s with an average input of *c.* 160 kg N ha^{-1} (ADAS/FMA 1992). Ley grasslands received on average *c.* 200 kg N ha^{-1} whereas 40% of grassland that was over 20 years old received either none or less than 50 kg N ha^{-1}. Since the mid 1980s there has been a net decline in overall fertiliser nitrogen use on grassland to *c.* 142 kg N ha^{-1} (MAFF/FMA/Scottish Office 1997). Nevertheless, these recent estimates indicate that fertiliser nitrogen inputs are two- to three-fold greater than the amounts applied to grassland in the 1940s. By 1997, it was estimated that some 86% of all grassland in the UK received fertiliser nitrogen (MAFF/FMA/Scottish Office 1997). Across all types of grassland farms, grass under five years old received, on average, *c.* 168 kg N ha^{-1} and grass fields of five or more years in age received *c.* 132 kg N ha^{-1} in 1997. The average nitrogen input on fields cut for silage but not grazed was *c.* 221 kg N ha^{-1}, for fields cut for silage and grazed 178 kg N ha^{-1}, whereas fields mown for hay received *c.* 90 kg N ha^{-1}. Grazed-only fields received an average of 123 kg N ha^{-1} (MAFF/FMA/Scottish Office 1997). Dairy farms used more than twice the amount of fertiliser N than beef/sheep farms. On sites with good grass-growing conditions, herbage yield responses (up to 300 kg N ha^{-1}) are *c.* 15-20 kg dry matter per kg of fertiliser N (Hopkins *et al.* 1990; Tallowin *et al.* 1990). Losses in utilization prevent such responses from being fully reflected in additional livestock production. Additional grass from fertiliser N is usually cheaper than purchased feeds. Other inorganic fertiliser inputs include phosphorus (P) and potassium (K), applied on *c.* 67% of grassland at average rates of 15 kg P/ha and 45 kg K/ha. Each year about 10% of grassland receives lime (CaO) (MAFF/FMA/Scottish Office 1997).

In addition to inorganic fertiliser inputs, much agriculturally improved grassland also receives applications of organic fertiliser in the form of either solid manure and/or liquid slurry. Approximately 31 million tonnes of solid animal manure and about 37 million tonnes of liquid slurries are collected annually from housed livestock (cattle, pigs, poultry and sheep) systems and subsequently spread on farmland (B. Chambers, K. Smith and B. Pain, unpublished data). In addition, approximately 45 million tonnes of excreta are deposited on fields grazed by animals kept indoors. Chambers, Smith and Pain (unpublished data) estimated that the average annual amount of nutrients applied to land (grassland and arable) that receives manure, in the form of solid manure and liquid slurries, is equivalent to 170 kg N ha^{-1}, 30 kg P ha^{-1} and 90 kg K ha^{-1}. It is also estimated that about 48% of grassland (2.3 million ha) receive manures annually. This figure accords with grassland survey information collected by Hopkins *et al.* (1985) which found that about 40% of grassland received these organic manures (solid manures liquid slurries) in most years. A further 29% received organic manures in some years. Their survey also showed that 51% of one to eight year old swards received organic manure, whereas only 27% of old grass, over 20 year old swards, were manured. Regular use of organic manure was also associated with fields being mown every year. As these surveys were conducted in the 1980s there is a need for more up-to-date survey information on manure usage on grassland, particularly with regard to the proportions and nutrient contents of solid manure and liquid slurries that are applied.

4.2.2 Impact on botanical composition and sward structure

Our understanding of the effects of fertilisers on botanical diversity of grasslands in the UK is far from complete, particularly with regard to interactions between nutrient addition and other management practices such as grazing or cutting (Smith 1994). It is now generally recognised that the addition of inorganic fertiliser nitrogen encourages the growth of competitive species and results in the loss or decline of slower growing species (Mountford *et al.* 1993, 1994; Kirkham *et al.* 1996). Whereas, as Smith (1994) pointed out, the periodic addition of organic fertiliser in the form of farmyard manure appears to be compatible with the maintenance of some species-rich meadow communities. The widespread and intensive use of inorganic fertilisers has been associated with the conversion of different grassland communities to one or other of the improved mesotrophic communities of the NVC, namely the *Lolium perenne-Cynosurus cristatus* (MG6) grassland or *Lolium perenne* (MG7) leys (Rodwell 1992) throughout the UK. The considerable extent of Perennial Rye-grass dominated swards within the grassland landscape of the UK has been documented in surveys by Forbes *et al.* (1980), Hopkins *et al.* (1985) and Hopkins and Wainwright (1989).

The observation by Smith (1994) that the existence of some species-rich grassland has been associated with organic fertiliser use emphasises the fact that a total lack of fertiliser input may, lead to a loss of nature conservation interests. The importance of maintaining a low to moderate level of fertility for many semi-natural neutral/mesotrophic grasslands of high nature conservation value is now widely recognised (Crofts & Jefferson 1994). However, definition of what constitutes a sustainable input of nutrients for different types of grassland is urgently needed.

Soil phosphorus availability appears to have a major role in controlling grassland biodiversity (Marrs 1993; Janssens *et al.* 1998). Kirkham *et al.* (1996) found that inorganic phosphorus fertiliser application with potassium was more important than inorganic nitrogen application in influencing botanical change in a species-rich *Cynosurus cristatus-Centaurea nigra* (MG5) grassland. High inputs of these two nutrients, together with lack of grazing, dramatically reduced botanical diversity and changed the community towards one with affinities to agriculturally improved MG6 grassland. Studies by Janssens *et al.* (1998) demonstrated that very low soil phosphorus availability is necessary for the existence of most natural and semi-natural grasslands of nature conservation value in northern Europe. A legacy of post World War 2 fertiliser practices has been that over 80% of grasslands in the UK have received phosphatic fertiliser inputs (ADAS/FMA 1992; MAFF/FMA/Scottish Office 1997) and on many soils the enhanced status of this nutrient could severely impede restoration of botanical diversity (Marrs 1993), even if the intensity of grassland management was reduced.

Lime, although not strictly a fertiliser, is applied to maintain soil pH at around 5.5-6.0, the range at which responses to other fertilisers are optimised and the main sown species are likely to persist (Cromack *et al.* 1970). Knowledge of the effects of lime application to grasslands has been largely derived from the results of the Park Grass Experiment (PGE) at Rothamsted (Warren & Johnson 1964; Williams 1978; Dodd *et al.* 1994). The PGE results indicate that, providing no other macronutrients are applied, lime additions of 2.0 to 2.5 tonnes CaO (equivalent) /ha to *Cynosurus cristatus-Centaurea nigra* (MG5) grassland (Rodwell 1992) at four yearly intervals can maintain high forb cover in the Meadow Vetchling (MG5a) sub-community and the Lady's Bedstraw (MG5b) sub-community. A limitation of the PGE data is that the plots were managed by cutting only and therefore not representative of the effects of lime on cut and grazed, or grazed only, neutral grassland, and on grassland in other geographical locations in Britain. On the PGE, where soil acidification occurred due to inorganic fertiliser applications, more acidophilic species and in particular grasses, such as Yorkshire Fog, became dominant (Warren & Johnson 1964). Elsewhere lime applications have undoubtedly reduced many acid grassland communities and enhanced plant species diversity. For example, classic experiments on Fescue-Bent spp. and Purple Moor Grass-dominated swards at Llety Hill in Mid-Wales showed that lime resulted in the development of diverse swards with lowland grass and forb species (Jones 1967).

With the cessation of subsidy payments to farmers for the application of lime in 1976 there is some evidence that soil acidity of grasslands has, as a consequence, increased within the UK (Skinner *et al.* 1992; Skinner 1997), which could have implications both for botanical (Tallowin 1998) and, in turn, invertebrate diversity. It is possible that this increase in soil acidity has been caused or exacerbated by increased atmospheric deposition of SO_x, NO_x and NH_x (Van Breeman *et al.* 1983).

4.2.3 Impact on invertebrate communities

The impact of inorganic fertilisers on grassland invertebrates can be very variable, depending upon the species and their habitat but, in general, the effects of fertilisers on grassland invertebrates are brought about largely through their effects on the vegetation. Fertiliser application causes an increase in net primary production and changes the sward composition, usually resulting in an overall decrease in plant species diversity (see 4.2.2). Fertiliser application can, however, also cause an increase in nutrient content of the vegetation, which will significantly affect its quality as a food source for invertebrate herbivores. In practice, the effect of subsequent differences in sward composition, on invertebrate communities, is a combination of differing plant species richness and plant architecture; in many cases, the structural complexity associated with botanical diversity may be more important than plant species richness *per se* in productive grasslands.

Fertiliser application may have contrasting effects on invertebrate populations, with abundance and species richness reacting in different ways. Morris (1992) showed that more species of Auchenorrhyncha were found in unfertilised grass plots compared to fertilised plots, but population densities have been found to be higher on fertilised than unfertilised areas (Sedlacek *et al.* 1988). Leafhopper (Cicadellidae) species react in a similar way; additions of NPK fertiliser to grass plots reduced leafhopper species diversity by disproportionately increasing the total number of individuals. Other studies have shown planthoppers (Delphacids) to be more abundant on N fertilised plots, but higher abundances of leafhoppers were found on unfertilised plots (Byers & Jung 1979; Prestidge 1982). McNeill (1973) identified the availability of high-N feeding sites, at a time when the general level of grass is low, as an important factor influencing larval mortality and fecundity in the mirid bug.

Other invertebrate groups have been shown to suffer following fertiliser application. Moderate to severe reductions in populations of Acari, Collembola, Diptera, Coleoptera and Myriopoda were reported by Edwards and Lofty (1975) in permanent pasture receiving 144 kg N/ha/year, compared with unfertilised pasture. Van wingerden *et al.* (1992) showed grasshoppers, to react strongly to increasing fertiliser level, resulting in a decrease in their species richness, as well as in overall density of individuals.

The overall effects of fertiliser application may differ within any one invertebrate group according to the levels and types applied. For example, earthworms have been shown to benefit from moderate applications of nitrogenous fertilisers, but, conversely, numbers can be reduced at higher rates of application (Zajonc 1975; Edwards & Lofty 1975, 1982). Nuutinen *et al.* (1998) found a positive relationship between total numbers of earthworms and the amount of soluble soil phosphorous, while other studies have demonstrated that large doses of sulphate of ammonia can be toxic to earthworms in acid soils (Satchell 1955; Edwards 1977, 1983). Although some groups of invertebrates, for example, leatherjackets and nematodes, have not been shown to be affected by fertiliser application (Linzell & Madge 1986), in general, additions of inorganic fertiliser, phosphorous, potassium and lime, as well as N, seem to decrease numbers of invertebrates as a whole and change the faunal composition (Fenner & Palmer 1998).

The effects of organic and inorganic fertilisers in terms of nutrient enrichment may be comparable but, in addition, organic fertilisers provide extra food for the decomposer communities. Grassland soil invertebrate populations generally benefit from applications of organic manures but responses can be variable depending on the species and the type of amendment (Marshall 1977). Earthworm populations have been found to increase in response to moderate applications of farmyard manure and slurry (Zajonc 1975; Curry 1976; Dinden *et al.* 1977; Cotton & Curry 1980a, b; Edwards & Lofty 1982; Standen 1984; Unwin & Lewis 1986). However, adverse effects on earthworm populations following heavy applications of slurry have also been reported and populations may not recover if the applications are repeated (Curry 1976; Cotton & Curry 1980b; Andersen 1980). Curry (1976) found that earthworm populations took up to 14 months to recover from one heavy application of cattle slurry in terms of biomass, but community composition still differed from untreated plots. Other invertebrates are also affected by application of organic manures. Lower populations of Collembola have been reported in pig or cattle slurry-treated plots than in those receiving mineral fertiliser only (Curry 1994). Similarly, plots treated with cattle slurry had significantly reduced densities of Acari and Collembola (Bolger & Curry 1980). Changes in species composition and lower species richness of nematode populations were found following application of cattle slurry to soils (Dmowska & Kozlowska 1988).

The application of lime to grasslands to maintain soil pH at around 5.5-6.0 affects the plant species composition of the grassland (see 4.2.2), which in turn may affect invertebrate communities. For example, Sanderson (1993) found that soil pH indirectly affected Hemiptera due to the changes in vegetation composition. Direct effects of soil pH can be found with the soil fauna, for example the number and weight of earthworms are positively correlated with soil pH (Standen 1984).

4.2.4 Impact on bird communities

Interactions between the use of inorganic fertiliser and cutting or grazing frequency/intensity have important effects on the biomass, density and composition of the grass sward (see section 4.2.2). Heavily fertilised swards tend to grow faster, be species-poor and, due to an interaction with increased management intensity, have a much higher sward density in comparison to low- or no-input pasture (Bunce *et al.* 1998). The major indirect effects of increases in N input on birds are brought about through alteration of the value of the habitat for nesting and feeding. This may be effected through structural changes in vegetation or by alterations of the food resources (invertebrates and seeds).The direct effects arise from the fact that, once fertilised, farming operations such as grazing and mowing usually take place earlier in the season, often leading to greatly increased nest loss as a result of trampling or destruction by farm machinery.

For waders, the main impact of increased inputs of nitrogen fertiliser is the resulting rapid change in sward height in the spring which alters their foraging efficiency and the availability of suitable nesting cover. Different species of wader breeding on grassland show distinct preferences for certain sward heights. For example, on the Somerset levels, highest densities of breeding Lapwing were in areas with a vegetation height of 10-15 cm in mid-May, whereas breeding Snipe and Redshank preferred taller swards of 15-20 cm (Green 1986). The wader species associated with grasslands feed almost entirely on invertebrates, by probing the soil or pecking prey from the surface of the soil or vegetation. A change in sward height is likely to influence the accessibility of these prey. Many important prey items, such as earthworms, tipulid and chironomid larvae are associated primarily with the top layers of soil or plant litter and plant bases (Ward 1994). These will be less accessible in a tall dense sward particularly for a bird such as the Lapwing which detects prey visually and then runs to capture it. The chicks of Lapwing, in particular, may have difficulty foraging in dense grass (Redfern 1982). Snipe, on the other hand, probe many times in the same place and walk relatively infrequently; they might be expected to be somewhat less affected by vegetation height or density (Green 1986). In addition to affecting accessibility of invertebrates, increased use of inorganic fertiliser can also reduce invertebrate numbers and alter species composition (Fenner & Palmer 1998; Siepel 1990; see also section 4.2.3). The impact varies markedly with the level of input, for example, density of earthworms may be enhanced at low levels of input of nitrogenous fertilisers but reduced at higher rates of application but, overall, high levels of inorganic fertiliser do seem to reduce the abundance of invertebrates and hence the quality of grassland as foraging habitat (section 4.2.3).

Changes in sward height also alter the suitability of nesting habitat for ground waders. For larger waders, which often attempt to drive off potential predators, good visibility and early detection may be of more value than cover, and they often nest in short vegetation. Lapwing, for example, select small patches of short sward even when breeding in hay meadows (Nairn *et al.* 1988). In April, when Lapwing start to nest, silage grass with large N inputs (typically >200 kg N ha^{-1}) is too high for nesting compared with hay meadows, where inorganic fertiliser inputs are lower (typically 90 kg ha^{-1} for hay) and the sward is shorter (Shrubb & Lack 1991). However, many smaller waders, such as Snipe, rely on concealment and require tussocky areas for breeding

(Green 1986). In the Shannon Callows, for example, Snipe nested in low tussocky sedges or in taller vegetation dominated by Reed Canary Grass (Nairn *et al.* 1988). This is also true of some larger waders such as Curlew which often prefer to nest in taller vegetation in hay meadows and tussocky pasture (Nairn *et al.* 1988). However, many of these birds are likely to avoid uniform dense swards, such as those maintained under silage production, for nesting.

In addition to, or possibly as a result of, nitrogen input altering the nesting and feeding quality of grassland, it may also cause a shift in the timing of breeding of some waders. Beinteima *et al.* (1985) show that, over the past century, there has been a large-scale shift in the timing of breeding in grassland waders in the Netherlands. Lapwing, Oystercatcher, Black-tailed Godwit, Ruff, Snipe and Redshank now breed between one to two weeks earlier than in the early 1900s. This has been attributed to increased use of inorganic fertilisers and the higher soil temperatures due to improved drainage, leading to conditions becoming suitable for nesting and feeding earlier in the year. Whether this change in breeding time is of benefit to waders is unknown. There is no evidence that adult moult starts earlier and therefore the potential breeding season is extended; however, chicks appearing two weeks earlier than normal may face unsuitable conditions, as a result of the breeding season becoming 'mistimed' with respect to food availability or weather, and chick mortality may increase.

There have been very few studies considering the impact of changes in nitrogen inputs on passerines. However, it seems likely that reduction in numbers and accessibility of invertebrates associated with increased fertiliser use may also have negative impacts on a number of passerines. Reductions in the abundance of invertebrates, such as Diptera, Coleoptera, Orthoptera and Auchenorrhyncha, will reduce the quality of grassland as foraging habitat (section 4.2.3). In addition, as for waders, increases in sward height associated with increased fertiliser use may reduce accessibility of prey. Many grassland passerines are ground feeders and prefer short swards for foraging. Changes in breeding numbers of Yellow Wagtail, which feed largely in short vegetation, have been attributed to alteration in management resulting in tall and dense swards (Cramp *et al.* 1988). Similarly, Wheatear also take invertebrate prey from the surface of short vegetation and only breed in habitats where areas of short vegetation or bare ground are available close to the nest site (Cramp 1988). Skylarks, which feed by pecking prey from the soil surface or leaves, Meadow Pipits, which feed exclusively on the ground and Starlings which feed largely on the ground, all tend to select open areas of low vegetation cover for foraging and show a preference for shorter vegetation (Cramp 1988; Cramp & Perrins 1994; Feare 1984; Wilson *et al.* 1997; Schon 1999). In addition to impacts on the invertebrate food resource, high fertiliser inputs reduce botanical diversity (see section 4.2.2) and this is likely to have also reduced seed availability for birds such as Linnet, Turtle Dove and a number of bunting species both in summer and winter.

A study of field use in winter by insectivorous birds in the Vale of Aylesbury found that frequent addition of farmland manure on permanent grassland was positively associated with numbers of Lapwing, Starling, Fieldfare and Redwing using the study fields (Tucker 1992). It was also shown that addition of manure to arable land was correlated with the density of soil-dwelling invertebrates but had no effect on invertebrate numbers in pasture. Although manure did not appear to increase the densities of soil-dwelling invertebrates in pasture it may have made these more available to the birds by bringing them closer to the surface (Scullion & Ramshaw 1987; Tucker 1992). Other studies have found that the addition of organic fertiliser can increase earthworm densities in grassland (section 4.2.3). High inputs of slurry and inorganic fertiliser may reduce earthworm densities (section 4.2.3) and may be expected to reduce available food resources for ground-feeding birds in winter. Fertiliser regimes may also affect sward height and density in winter with detrimental consequences for species that require relatively short swards for feeding e.g. Golden Plover and Lapwing (Milsom *et al.* 1985 & 1998).

The addition of nitrogen fertiliser strongly influences the selection of feeding sites by many species of wintering wildfowl (and to a lesser extent waders) through altering nitrogen content and species richness of the sward, and sward height. For grazing wildfowl the most important effect of fertiliser application is the subsequent increase in the nitrogen content of the forage itself. Specific management of grassland for geese often involves fertiliser application in autumn when the major impact is not to alter sward height but to raise protein levels in the grass itself and hence increase its quality for grazing geese (Vickery & Gill 1999). Fertiliser application has been shown to increase the attractiveness of grass swards for Pink-footed Geese (Fuchs & Patterson unpublished data, cited in Vickery & Gill 1999), White-fronted Geese (Owen 1971) and Brent Geese (Vickery *et al.* 1994; Riddington *et al.* 1997). These preferences have been related to a higher live:dead biomass ratio in grass and higher protein levels in fertilised grass swards (Drent & Prins 1987; Lane 1994). Changes in sward composition may also be important. Many species of geese, including Pink-footed, Barnacle and Brent, select improved grassland and feed on White Clover, Perennial Rye-grass and, to a lesser extent, Creeping Bent and Red Fescue. Species such as Yorkshire Fog and Meadow Barley are avoided (Vickery & Gill 1999). High nitrogen inputs favour many of the grass species selected by geese and fertiliser application may benefit these birds. Sward height is also a key factor influencing foraging efficiency of these species in winter (Vickery & Gill 1999). However, the cutting and grazing regime in summer and autumn, rather than fertiliser input, is likely to be much more important in determining sward height at this time. This is considered under sections on grazing and cutting (4.4.4 and 4.5.4).

Although fertiliser-related changes in sward height are likely to be important in determining the suitability of grassland as feeding and nesting habitat for birds, major impacts of nitrogen also arise indirectly as a result of the increased intensity of grassland management associated with increased N inputs. In particular, fertilised grassland tends to be grazed and/or mown earlier in the season and grazed more intensively or mown more frequently. The impacts of both these changes are considered in detail in sections 4.4.4 and 4.5.4. In brief, such changes are probably most severe for ground nesting waders and passerines although little is known about the latter in this respect. Among waders, late-breeding species such as Redshank are the most vulnerable, in terms of destruction of nests and nesting habitats, since both species prefer taller grass than earlier nesting species such as Lapwing and Oystercatcher. Although these impacts are considered elsewhere it is important to note that they are intricately linked to, and therefore should be considered as part of, the effects of increased fertiliser input. Potentially, the overall effects on breeding productivity and ultimately bird population size can be extremely severe.

4.3 Weed, Pest and Livestock Disease Control - Effects of Pesticides

4.3.1 Trends in pesticide use

Weeds and pests have generally been tolerated more on grassland than on arable crops. Consequently, the use of herbicides has been confined mainly to the establishment phase of leys, or for spot-treatment of perennial weeds or bracken. In general, it is probable that the impact of herbicides in grassland areas has been greater during the arable phase of ley- arable rotations. A large array of approved herbicide agents and formulations has been introduced for use on grassland over the past 50 years, for selective and non-selective use, and for contact, translocation or pre-emergence action (Frame *et al.* 1995). Reports by the Pesticide Usage Survey Group (Thomas & Garthwaite 1994; Garthwaite *et al.* 1998) indicate that there has been a marked increase in the area of grassland treated with agrochemicals between 1989 and 1997. However, it still appears to be the case that the use of agrochemicals for pest or weed control on permanent pastures is negligible compared with the arable sector of agriculture.

In general, clearly visible damage to swards due to pest and disease attacks is rare; instead, their insidious damage to roots and herbage is usually undetected. However, there is clear evidence of significant economic losses caused by pests such as leatherjackets, sitona weevil and slugs (Clements 1994; Clements & Cook 1996). Nevertheless, the use of pesticide-based control measures, particularly on established grass swards, has been negligible compared with their use on arable land.

Perhaps of more widespread importance to grassland biodiversity than the use of pesticides for controlling damage to the grass crop is the use of anthelmintic products, such as the avermectins. Residues of ivermectin have been found in cattle dung following the treatment of livestock and these residues have been associated with reduced numbers and variety of insects in the dung (see 4.3.2 below).

4.3.2 Impact on botanical composition

Newly sown grassland is more vulnerable to colonisation by unsown plant species than established grassland because of the exposure of bare ground and provision of numerous germination sites. A main objective, therefore, when establishing new grassland is to obtain an adequate population of sown species over the whole field. Many more seeds of the grassland crop species, Perennial Rye-grass, Italian Rye-grass and/or White Clover, for example, are sown per unit area than the number of plants that could be sustained on that area. This means that losses of sown seed and seedlings are greater than would be tolerated with sowings of arable crops (Lewis & Hopkins, in press). The high sowing density tends to ensure that invasion by unsown species ('weeds') is reduced. Nevertheless, newly sown leys are still vulnerable to invasion by numerous weed species including annual dicotyledonous species, such as Common Chickweed, which can be controlled by herbicide treatment (Haggar *et al.* 1985). Broad-spectrum herbicide application to newly sown grassland simplifies the botanical composition, enabling rapid domination by the sown species. Such herbicide treatment significantly reduces colonisation by annual weeds and, in turn their seed production.

The definition of a 'weed' in grassland is not straightforward. Unlike the situation with arable or horticultural crops, unsown species in grassland can make some contribution to the yield and quality of the product (Barber 1985; Dibb 1985). The presence of broad-leaved species in grass swards can extend the range of concentration of some major elements (Wilman & Derrick 1994; Tallowin & Jefferson in press). Therefore, weed control is restricted to the prevention or eradication of serious infestations in more productive swards and of species that cause physical injury to grazing animals or are toxic to them when ingested. In the UK, herbicide use can be enforced when an infestation of a perennial weed listed as an 'Injurious Weed' under the Weeds Act 1959 is deemed to present a risk to neighbouring farms.

Docks, predominantly broad-leaved dock and curled dock, are widespread in sown grass leys and permanent grassland in the British Isles. They are arguably the most important weed problem affecting lowland grassland, particularly on dairy farms (Hopkins & Peel 1985). Frequently, the level of infestation is sufficient to reduce both forage production and herbage digestibility (Courtney 1985). Infestations are encouraged by inputs of nitrogen and slurry that increase soil fertility, and by cutting managements that reduce sward density in the spring (Hopkins & Peel 1985). Various herbicide treatments have been approved for dock control in the UK (Whitehead 1998), of which asulam has been the most widely used. Non-chemical methods are, however, also available (Courtney 1985; Hopkins *et al.* 1997).

Creeping thistle and, to a lesser extent, the spear thistle are widespread in grassland in the British Isles. Thistles are associated particularly with fields that are either cut late for hay or never mown and are extensively grazed in summer by sheep alone, sheep with cattle, or by horses (Hopkins 1986). Also, high levels of phosphorus and potassium in the soil increase the risk of infestations. The herbicide clopyralid, alone or in mixture, has been approved for thistle control in the UK (Whitehead 1998). Mechanical control is by repeated mowing, which weakens the plants and prevents further seeding; this may be the only appropriate control in some situations, e.g. organic farms.

Common ragwort, which is widespread in the British Isles, and marsh ragwort, which is locally abundant, are amongst the most poisonous of grassland plant species. Their significance and control were reviewed by Forbes (1985). Few cases of livestock poisoning by ragwort are reported, but the risk is greatly increased when the plant is cut and dried, as in hay making. Ragwort thrives in overgrazed open swards and areas of rejected herbage typical of many horse paddocks. Extensive cattle grazing can also allow infestations to occur. The herbicide MCPA has been approved for ragwort control in the UK (Whitehead 1998). Cutting does not kill the plant, and there is a risk of cut foliage being consumed by grazing animals.

Bracken is the most important weed species affecting grazing land in upland and marginal areas of the British Isles. In the British Isles, the rapid spread of bracken by rhizomatous growth, particularly on brown-earth soils in upland areas, poses a serious land-use problem. Annual rates of spread of up to 3% per year have been reported for some localities (Taylor 1985). This spread is attributed to the decline in cattle numbers, relative to sheep, in the uplands, and to the reduction of labour-intensive management practices which, historically, would have contained bracken. The herbicide asulam has been approved for bracken control in the UK (Whitehead 1998), including aerial application, which is the only suitable means for spraying large areas in the uplands. Asulam is most effective when applied in late July/early August in the UK, when the fronds are fully open but relatively unlignified. This treatment results in severe local damage to the fronds, but an integrated programme of follow-up management is required to prevent regeneration from the rhizomes.

4.3.3 Impact on invertebrates

The use of pesticides in permanent grassland is not as widespread as in short-term arable rotation leys, and pesticide use is mainly confined to the period of establishment after reseeding. The invertebrates commonly targeted by insecticides and molluscicides are leatherjackets larvae, fruit fly larvae, wireworms larvae, slugs and snails. With the increasing awareness of these groups as pest species in grassland, their control has become more common.

The change from organochlorine to organophosphate insecticides for treating grassland pests has meant that damage to the grassland invertebrate fauna as a whole has been reduced. Most invertebrate groups were adversely affected by the use of organochlorines, such as HCH, DDT, chlordane, aldrin, and dieldrin, for several years (Thompson & Gore 1972; Edwards & Thompson 1973; Edwards 1965, 1974, 1977; Brown 1977). Although organophosphates are less persistent than organochlorines, they may be equally as detrimental to non-target invertebrates in the short-term. For example, the use of chlorpyrifos spray and fonofos seed treatment in newly-sown grass has been shown significantly to deplete numbers of ground beetles (Asteraki *et al.* 1992a). Edwards and Thompson (1975) and Hassan *et al.* (1987) also found many organophosphates harmful to ground beetles. Phorate, and to a lesser extent parathion, have been demonstrated to be toxic to earthworms; in studies by Edwards (1980) and Clements (1981), long-term use of the former caused a prolonged absence of earthworms from the soil, resulting in changes in the soil structure. Some carbamate insecticides and molluscicides are more toxic to soil invertebrates than organochlorines or organophosphates (Edwards 1977). For example, carbaryl, aldicarb, carbofuran and methiocarb are very toxic to earthworms and ground beetles (Edwards 1980, 1983; Bieri *et al.* 1989; Büchs *et al.* 1989).

Herbicides can affect grassland invertebrates both directly and indirectly by altering plant cover and food supply. Examples of direct toxic effects of herbicides are MCPA reducing the numbers of ground beetles (Kegel 1989) and atrazine, simazine and PCP decreasing numbers of earthworms and other soil animals (Fox 1964; Curry 1970). Altering the structure of a sward by the use of herbicides will have a large effect on some predatory insects and spiders (Asteraki *et al.* 1992b). Phytophagous insects will be especially affected if their food plant is targeted by the herbicide. Botanical composition influences the distribution and abundance of some monophagous and oligophagous herbivores as well as some polyphagous foliage feeders, for example, grasshoppers (Mulkern 1967; Gyllenberg 1969; Bernhays & Chapman 1970). A less complex sward structure created by the use of herbicide will support a depleted fauna of species able to utilise the remaining plants and habitat.

The introduction of the use of avermectins to control internal and external parasites in cattle in 1981 has implications for the dung-pat colonising insect fauna, as some of the avermectin is excreted unchanged in the faeces. Although both Halley *et al.* (1993) and Wratten *et al.* (1993) conclude that, due to the availability of residue-free dung and the mobility of the insects concerned, the overall effect on dung associated insects is likely to be limited, at a local level there could be severe effects. It is likely that an avermectin, if used, would be given to all cattle on any one farm. This could mean that a large proportion of excreted dung would be contaminated. Many studies (for example, Floate 1998; Madsen *et al.* 1990; McCracken & Foster 1992, 1993; Wardhaugh *et al.* 1993) have found that insect activity is significantly reduced in dung from cattle treated with a recommended dose of ivermectin (an avermectin). It was found that a diverse group of insects was affected, including coprophagous flies, parasitic wasps and both predaceous and coprophagous beetles. Strong and Wall (1994, 1996) found that dung from ivermectin treated cattle contained fewer larval Scarabaeidae and larval Cyclorrhapha (Diptera) and that the development of *Aphodius* spp. (Scarabaeidae) larvae within ivermectin contaminated dung was arrested.

4.3.4 Impact on birds

In recent years, the direct effect of pesticides on bird populations has been reduced as organochlorines have been phased out and the emphasis is now on the indirect effects. Nevertheless, sublethal effects of potential population significance to birds may still be widespread, particularly as reductions of food availability through changes in farming practices may have placed many individuals under greater physiological stress. There is little information on the effects of pesticides on birds in pastoral systems and the emphasis has been on arable systems (e.g. Campbell *et al.* 1997). In arable areas, pesticides have been shown to impact on the survival of Grey Partridge chicks (Potts 1986) and have reduced populations of some invertebrates that are fed on by birds (Greig-Smith *et al.* 1992). Pesticide use has also been implicated in declines of Linnet, Corn Bunting, Cirl Bunting and Stone Curlew though hard data remain elusive (Campbell *et al.* 1997). Pesticides used on grassland may impact on the ecology of grassland birds both in summer and winter. Though no studies have looked specifically at the effects on birds (and especially the effect at the population level), it may be possible to predict effects as information is available on the effects of pesticides on plant and invertebrate populations (see previous section).

One of the most common and widespread groups of pesticides used in grassland systems are the range of anti-parasitic chemicals. The total extent of use is unknown but concern has been raised over the use of the broad-spectrum anti-parasitic drug, ivermectin (JNCC 1991). It is used in cattle, sheep, goats, pigs and horses, and residues in the dung can have a large impact on the survival, reproduction and development of invertebrate dung fauna, especially dung beetles (JNCC 1991 also see 4.3.3). The presence of ivermectin residues in dung also impact not only at the individual but also at the community level both within, and below, the dung (McCracken & Foster 1993; Madsen *et al.* 1990; Wardhaugh *et al.* 1993). Chemicals such as benzimidazoles, imidazothiazoles or tetrahydropyrimidines, which perform a similar function to ivermectin for internal parasites, do not appear to have an adverse effect on invertebrate dung fauna (McCracken (1995) though some recent work suggests benzimidazole residues in dung may have insecticidal properties (Wardhaugh *et al.* 1993).

Changes in the invertebrate community in dung are likely to impact on the species of bird that poke around in animal dung or feed on invertebrates attracted to it. Many species of invertebrate-eating birds use dung, such as pipits and wagtails, lapwings, thrushes and corvids. In particular, cow dung is extremely important for the Chough (McCracken & Foster 1992), especially during the breeding season. The use of ivermectins in areas where Chough are present may have a detrimental effect on breeding success and juvenile survival (McCracken 1993), although effects at the population level are unknown.

In terms of additions of herbicides and insecticides to the sward, little is known on the direct or indirect effects on bird populations. The commonly targeted groups of invertebrates (leatherjackets, fruit fly, elaterid larvae, slugs and snails) are all taken by birds (Wilson *et al.* 1996a) and widespread control of these groups may reduce the quality and quantity of the food available to invertebrate-feeding birds. The increased use of the organophosphates insecticides can lead to reduction in non-target invertebrates. Ground beetles, which are susceptible to use of chlorpyrifos spray and fonofos seed treatment, are key components of the diet of species like Lapwing and Stone Curlew. The loss of earthworms in soil treated with phorate will affect species such as winter thrushes and waders but again, the effect at a population level on these species is unknown.

Seed-eating birds may also be affected by the use of chemical herbicides. Reduction in plant diversity and the spraying-off of weed species before seed set will reduce the amount of granivorous food available. Herbicides may also have an indirect effect on invertebrates, such as grasshoppers, which are important food for species such as Cirl Bunting (see section 4).

In conclusion, the information on the indirect effects of pesticide application to grass swards on bird populations is extremely poor. However, pesticide use is low on grassland and is only practised on 5-10% of the grassland area. Potentially more important is the widespread use of ivermectins, which reduce the amount of invertebrate food available to dung-feeding birds.

4.4 Livestock Stocking Practices

4.4.1 Recent changes in livestock grazing practices

Between 1950 and 1990 the total number of sheep more than doubled in seven predominantly grassland farming counties of England (Devon, Herefordshire and Worcester, Somerset, Gloucester, Oxfordshire, Wiltshire, and Dorset) as illustrated in Figure 4.1 (The Digest of Agricultural Census Statistics). However, these data show that, since the beginning of the 1990s there has been a decreasing trend in sheep numbers and they have declined by about 10% from their recorded maximum. The pattern of change in sheep numbers was relatively consistent across all these 'grassland' counties. The apparent recent and relatively small changes in the total sheep flock are probably of less significance to overall grassland management practice than the marked decline in the dairy herd that has occurred during the last 20 years (Figure 4.2). This decline in the dairy herd is probably correlated with the downward trend in fertiliser nitrogen use on grassland farms since the 1980s. The contraction of the dairy sector has been buffered to some extent by increases in the beef herd, but changes in total cattle numbers, shown in Figure 4.3, still indicate that there has been an overall decline in these 'grassland' counties over the last two decades.

The high total sheep population that is still present could offset any decline in cattle numbers in terms of the overall liveweight of stock that is present today compared with 40-50 years ago. In order to convert livestock numbers to liveweight it has been assumed that an average sheep weight is 55 kg equivalent to 0.1 of a livestock unit, (a livestock unit being 550 kg, equivalent to the average weight of a dairy cow). An average cattle liveweight 495 kg has been used on the basis that the dairy herd still comprises about 90% of the total cattle population, thus an average cattle livestock unit is equivalent to about 0.9. Multiplying the total sheep and cattle numbers for the seven 'grassland' counties combined by the respective average liveweights then the overall difference in liveweight carried in 1997 is a modest, *c.* 4%, increase compared with 1980. Some caution has to be exercised in interpretation of the liveweight conversions using the standard livestock unit of 550 kg because there has been a tendency for increased breed weights, with heavier continental beef breeds and heavier dairy cows, to become more common over the last 20-30 years.

The overall stock liveweight figures (sheep and cattle combined) for a sample of different counties in England are shown in Figure 4. The more eastern counties of Oxford and Wiltshire have tended to show a decrease in overall stocking levels of 15-20%, whereas, in Devon, and Herefordshire and Worcestershire, for example, there has been a 14% and 12% increase, respectively. Any such regional differences may indicate that the polarisation of arable versus grassland farming that has occurred between eastern and western UK could be continuing. The county stocking density figures also indicate that the intensity of livestock farming has continued to increase even in the last decade in the more westerly and predominantly grassland counties. In a survey of grassland in south-west England in 1983, Hopkins *et al.* (1985) found that virtually all the grassland was grazed for at least part of the year; 34% was grazed by cattle only and the remaining 56% was used for mixed grazing by cattle and sheep, although on half of this area the sheep grazing was confined to the winter months. Only 9% of the grassland was grazed solely by sheep and less than 1% by horses. Caution is clearly needed in assuming that these proportions represent current practice, reflecting the need for further survey information.

4.4.2 Impact on botanical composition and sward and soil structure

Grazing acts on individual plants and plant communities in a variety of different ways: through defoliation, removal of plant material, treading and pawing, deposition of dung and urine, and poaching (Jensen 1985). These effects all combine to alter the relative competitive abilities of the different plant species and, as a result, individual plant species differ in their responses to differential levels of grazing. The increase in stocking density during the post-war years will have had a considerable impact on grassland structure. The maintenance of a high grazing pressure on grassland in order to achieve a high level of utilisation of herbage by the livestock will create densely tillered swards (Tallowin 1981; Grant *et al.* 1983; Tallowin *et al.* 1989). Maintaining intensive grazing pressure by sheep can produce very dense swards. Orr *et al.* (1988) found that continuous grazing by sheep of Perennial Rye-grass dominated grassland to an average sward surface height of 50 mm created tiller densities of 25-30,000 m^{-2}. These authors also demonstrated that even under frequent cutting management, at 28-day intervals, swards were created with only about half the tiller densities that were achieved by sheep grazing. Continuous grazing by cattle at high stocking densities does not create such densely tillered swards as sheep grazing (Tallowin *et al.* 1986). Sheep, largely by virtue of their smaller mouth size, can select herbage at a finer scale than cattle and thus create sward structural heterogeneity at a finer scale than cattle. Swards grazed by sheep tend to comprise a mosaic of lightly grazed and heavily grazed areas at low stocking densities but are much more uniform and short-cropped at high densities (Kiehl *et al.* 1996; Berg *et al.* 1997). Cattle-grazed swards have greater spatial heterogeneity of structure than sheep grazed swards due to the more patchy distribution of dung (Richards & Wolton 1976) and the associated rejection of herbage around dung pats. It is therefore contended that any decline in cattle numbers within the grassland areas of the UK, coupled with the maintenance of high sheep numbers, could result in more general uniformity of pasture structure.

Grazed fields tend to have a higher level of spatial variability than mown fields (particularly silage fields) and this can provide a greater range of niches (*sensu* Grubb, 1977) to be exploited. However, much of the grazed, intensively managed grassland is structurally very uniform throughout the year compared with extensively managed semi-natural grasslands. This uniformity has come about through exploiting our better understanding of relationships between pasture growth and utilisation potential, by adopting rigorous height-based management guidelines and the adoption of buffer feeding strategies to sustain maximum utilisation and animal performance throughout the grazing season (Frame *et al.* 1995). These intensive grazing practices favour competitive species such as Perennial Rye-grass and White Clover and species with strongly developed defences against herbivory such as Creeping Thistle, Spear Thistle and some *Rumex* spp. Intensive grazing can also favour species that can adapt morphologically to reduce the impact of high grazing pressure such as Rough Meadow Grass (Tallowin *et al.* 1995; Tallowin & Brookman 1996). High defoliation frequency of most intensive grazing systems severely reduces the opportunity for flowering and seeding.

There is a general tendency for the proportion of sown species (e.g. Perennial Rye-grass, Italian Rye-grass and White Clover) to decline with length of time since the sward was sown (Hopkins *et al.* 1985). During the first two years of a sward's life sown species were found to contribute on average about 90% of the vegetation cover. The cover of sown species then declined to an average of 55% for swards aged nine to 20 years. As swards aged, they tended to be colonised by Bent spp. and to a lesser extent by Yorkshire Fog. Swards over 20 years of age had a mean content of 36% sown species. Dicotyledonous species cover remained relatively constant across all age categories, at about 5% cover. Hopkins *et al.* (1985) found considerable variation in the contribution of sown species within age categories and some of this variation could be attributed to differences in fertiliser use, grazing or cutting management or drainage status. For example, on soils with poor or bad drainage, the overall average for Perennial Rye-grass cover was 39%, whereas, on soils with good to only slightly impeded drainage, the cover of this species was 47%. There was an interaction between age of sward, fertiliser use and Perennial Rye-grass cover; younger swards tended to have higher fertiliser inputs and higher cover values for sown species. Generally the cover of Perennial Rye-grass increased with increasing amounts of fertiliser nitrogen application especially among swards over eight years of age. Fields grazed by dairy cattle contained, on average, 54% Perennial Rye-grass, compared with 37% for fields grazed by other cattle (e.g. beef or suckler cows and calves) and 46% for fields grazed only by sheep. However, these apparent differences between livestock type are confounded by the fact that higher inputs of fertiliser nitrogen are used on grassland grazed by dairy cattle. Grasslands fertilised with organic manures (solid and slurries) every year contained on average 51% of Perennial Rye-grass, compared with 44% on fields that received periodic manure applications or only 37% on fields that never received organic manure (Hopkins *et al.* 1985).

The cover of sown legumes, such as White Clover, tended to be greatest on young swards, swards on soils with good drainage and in grasslands that received less than 200 kg inorganic fertiliser nitrogen annually (Hopkins *et al.* 1985). In grazed grassland, the highest cover of *T. repens* was found on pastures grazed by sheep only. Lower amounts of this species were found on swards subjected to mixed grazing by cattle and sheep and the lowest abundance was found in swards grazed by cattle only or by cattle in the summer and sheep in the winter.

There can also be an effect of the increased stocking intensity and liveweight carried on the soil structure particularly on soils that have inherently unstable structures. The size, shape, spacing and aggregation of solid particles in the soil constitute the soil structure (Curtis *et al.* 1976). Soils with a high silt content appear to be more prone to structural instability than organic, clay or soils containing iron colloids. The structural stability of soils will also be influenced by the length of time that they have been in cultivation. In general, old permanent pasture soils have much greater structural stability than soils subjected to prolonged periods of cultivation, due to a large extent on the accumulated organic matter (Curtis *et al.* 1976); the latter may include soils under short term leys.

There is likely to be an interaction between stocking density and drainage status of soils. Scholefield *et al.* (1988) found that either drainage of an old permanent pasture on a clay loam, or cultivation and reseeding both caused soil bulk density and shear strength to increase compared with the undrained old pasture soil. These structural changes were associated with large differences in the earthworm biomass; the drained old permanent pasture soil receiving 400 kg N ha^{-1} contained the highest earthworm biomass compared with the undrained or reseeded grassland. Scholefield *et al.* (1988) also found that there was a tendency for earthworm biomass to be greater on drained fields receiving 400 kg N ha^{-1} compared with fields receiving only half this amount of fertiliser nitrogen. The high stocking density associated with the greater input of fertiliser nitrogen clearly did not change soil structural conditions sufficiently to inhibit earthworm abundance.

4.4.3 Impact on invertebrate communities

Although all methods of management lower the mean height of the vegetation and reduce the standing crop, there are important differences between grazing and other sward management practices, particularly in terms of their effects on invertebrates (Morris 1990a, b). Grazing is always to some extent selective, with thistles and plants with glandular hairs more resistant to defoliation. Insects feeding on such plants tend to survive even intensive grazing, but succumb to other management methods such as mowing. Because of its selectivity, grazing usually allows the survival of some flowers and seedheads, while all are removed abruptly when grasslands are mown. However, intensive grazing does produce a shorter sward than cutting. The effects of trampling by grazing animals are important, though often disregarded or under-estimated; work on the effects of human trampling on grassland invertebrate communities showed them to be considerable (Duffey 1975). Very few invertebrate species responded positively to experimental trampling treatments; Coleoptera, Auchenorryncha, Araneae, Isopoda and Mollusca are particularly affected.

Work to date on British calcareous grasslands has suggested that in general invertebrate diversity is greater under grazing rather than cutting regimes, but that the timing and level of grazing pressure has very different effects on invertebrate communities. Although there is little quantitative data, grazing, probably by sheep or rabbits rather than cattle or horses during particular seasons of the year, is more effective, in terms of increasing sward heterogeneity and hence invertebrate diversity, than continuous grazing (Morris 1971, 1973, 1979; Morris & Rispin 1987). In experiments on an Oxfordshire calcareous grassland, Brown *et al.* (1990) confirmed that seasonal grazing by sheep was better than continuous grazing for promoting insect diversity, and also suggested that spring grazing may be deleterious to more species than autumn grazing. The species richness and abundance of leaf-miners were directly related to the season and intensity of grazing, while Heteroptera were enhanced by autumn grazing, but reduced by spring grazing. The data on individual species of leaf-miners, herbivorous Coleoptera and Heteroptera underlined the importance of the effects of grazing on plant structure as well as foodplant abundance, both of which may interact in complex ways in terms of their effects on grassland invertebrate communities. The results also emphasised the ease with which individual species may be excluded by single events at key phases of their life cycle.

Grazing can influence grassland invertebrates by altering the botanical composition and structure of the sward, and by altering the nature and rates of organic matter return to the soil (see 4.2.3). Selective grazing at moderate levels can result in a structurally heterogeneous sward, which will present a range of plant structures for specialisation by feeding guilds of herbivorous invertebrates (Strong *et al.* 1984). Morris (1971) demonstrated a positive relationship between vegetation height and the species richness of sap-feeding Auchenorrhyncha in grassland. Furthermore, increases in stocking rates or defoliation intensity generally reduce numbers and biomass of phytophagous grassland invertebrates (East & Pottinger 1983). The effects of increasing grazing intensity are more severe on species feeding on above-ground parts of pasture plants than on those living in the more buffered soil environment. Nevertheless, several economically important soil dwelling invertebrates such as soldier fly, grass grub and some other chafers are also influenced by changes in stocking rates (East & Pottinger 1983). The effects of stocking rate appear to relate mainly to defoliation and trampling that may kill invertebrates directly or may modify their living space. Invertebrates which are found in the litter and superficial soil layers are likely to be most affected when grazing is heavy (Morris 1968; Hutchinson & King 1980), although some species, including certain species of Homoptera, which prefer sparse ground cover, are exceptions (Hutchinson & King 1980). Mesofauna (Acari, Collembola and Enchytraeidae) show general trends of declining density with increasing sheep stocking rates (King & Hutchinson 1976).

Soil compaction, whether by the use of heavy machinery or high stocking rates, will have most effect on the soil invertebrates. However, it is likely that there will also be fatality in the surface dwelling organisms by accidental trampling. The earthworm, however, can burrow into soil which is compacted and it has also been shown to penetrate a 'plough pan' deep in the soil (Joschko *et al.* 1989). Conversely, the activity of the earthworm may be restricted by compaction under conditions of high water potential (Kretzschmar 1991). Soil compaction has also been shown to decrease slug populations in New Zealand pastures where the manipulation of stocking rates is used as a cultural control method (Ferguson *et al.* 1988).

A specialised component of the fauna which is particularly abundant under intensive grazing but absent from grasslands managed by cutting is that which inhabits dung (see 4.2.3). Herbivore dung is initially colonised by a few species of coprophageous dung flies and beetles and later by an increasingly complex community comprising many general litter-dwelling species (Curry 1979). The composition of the dung community varies considerably throughout the year, with seasonal, rather than continuous, presence of most groups associated with dung.

4.4.4 Impact on birds

The timing, type and intensity of grazing are important factors in determining the extent of direct and indirect effects on both wintering and breeding birds. Direct effects largely comprise of the destruction of nests or chicks through trampling or, occasionally, the predation of eggs or chicks by sheep, although this is probably confined to Scottish islands (Fuller 1996). Indirect effects act through, for example, changes in sward structure and composition, soil compaction, associated changes in invertebrate communities and seed densities. Increased grazing has been implicated in widespread declines of many species in the Welsh uplands and has been attributed to the loss of heather-dominated vegetation due to intensive sheep grazing (Lovegrove *et al.* 1994, 1995). However, evidence that this has been the key mechanism is lacking and grazing may have exacerbated a long-term reduction in carrying capacity (Fuller & Gough in press). The mechanisms by which changes in grazing can potentially affect bird populations in the upland systems include loss of preferred habitat and/or alteration of food supplies and predator pressures, all of which also apply to grassland systems (Fuller & Gough, in press).

The most direct impact of grazing on breeding waders, such as Lapwing, Redshank and Snipe, is the destruction of nests through trampling (Beinteima 1985; Green 1986, 1988; Shrubb 1990). The rate of nest destruction depends on the type and density of stock, the timing of grazing and the bird species involved although, when comparing cattle and sheep in terms of livestock units, the rate of nest trampling seems to be similar (Beinteima & Muskens 1988). A stocking rate of approximately 2.5 cows ha^{-1} for the whole of the incubation period leads to approximately 70% of Redshank, 60% of Snipe and 35% of Lapwing nests being trampled. Redshank nests seem particularly vulnerable to trampling and increased stock densities in breeding areas can have a large negative impact on breeding success (Green 1986; Beintima & Muskens 1987). Lapwing breeding success is also low on grazed pasture and has probably decreased due to increased nest loss from higher stocking rates (Shrubb 1990). Increased stocking rates, especially of sheep, can also lead to a uniform sward structure which can lead to higher nest losses due to predation, perhaps due to the increased visibility of the nest (Baines 1989).

Indirect effects include changes in sward height, the effect of which has already been discussed in relation to increased fertiliser input (see section 4.2.4). Although the direct effects are entirely negative, in some instances indirect effects may be positive. Lightly grazed areas, for example, tend to be preferred by many invertebrate-feeding species possibly due to the increased availability of invertebrates as a result of shorter sward lengths (Milsom *et al.* 1998). Grazed swards tend to have a wider structural and species diversity and these factors encourage a wider diversity of invertebrates (see section 4.4.3). Preferences for certain sward heights shown by breeding waders, for example, often mean that grazing (or mowing - see section 4.5.4) are essential management tools required to maintain suitable habitat for a range of bird species (Ward 1994). The type of livestock with which an area has been grazed does seem to be important for some wader species, a factor almost certainly related to the different swards that persist under cattle and sheep grazing. Lapwings, for example, are associated with grazed areas rather than ungrazed areas, but this association is strongest with horse or sheep-grazed turf which is generally shorter than that produced by low-intensity cattle grazing (Shrubb & Lack 1991). Breeding Redshank, on the other hand, prefer a varied sward structure and tend to select areas of tussocky pasture which are grazed by cattle rather than sheep (Herbert *et al.* 1990; Norris *et al.* 1998).

The importance of short swards as foraging habitat for a number of passerines associated with grassland has already been discussed in relation to the detrimental effects of fertiliser-induced increases in sward height (see section 4.2.4). The nest sites of these species are, in general, less susceptible to trampling than waders and grazing by cattle, sheep or horses will maintain the short sward many of them prefer for foraging. For example, Wheatears, once distributed across lowland Britain, are short-turf specialists (Conder 1989) and occur in heavily rabbit or sheep grazed areas. Although increases in sheep may have benefited Wheatears in some areas, the reduction in rabbits due to the introduction of myxomatosis has led to an increase in vegetation length in some regions and a reduction in number of burrows, which are important as nest sites, and may have contributed to the range contraction of this species (Conder 1989; Marchant *et al.* 1992). Passerines may also benefit from grazing through the fact that the addition of dung will enhance soil invertebrate populations and provide rich feeding patches themselves (see section 4.3.2 and 4.4.3)

For some passerines, such as Skylark, the level of disturbance and the sward structure caused by heavy grazing creates unsuitable habitat, although light levels of cattle grazing may provide a enhance soil invertebrate populations and provide rich feeding patches themselves (see section 4.3.2 and 4.4.3)

For some passerines, such as Skylark, the level of disturbance and the sward structure caused by heavy grazing creates unsuitable habitat, although light levels of cattle grazing may provide a patchy sward suitable for nesting (Shrubb 1990; Chamberlain & Gregory 1999). However, in a national survey of Skylarks, grazed improved pasture and heavily grazed sheep pasture were among the least preferred habitats (Browne *et al.* in press). A recent study of Skylarks in Environmentally Sensitive Areas showed clear preferences for, and higher breeding success in, long (15-25 cm) as opposed to short (< 10 cm) experimentally grazed grass (Wakeham-Dawson *et al.* 1999). In the latter study, this difference was attributed to higher food availability in longer swards where invertebrates and seeds were more abundant.

In winter, grass pasture is of widespread importance for two waders; Golden Plover, Lapwing. On grass fields in coastal areas, these species are often supplemented by Black-tailed Godwit, Curlew and Oystercatcher. Sward height and the degree of field enclosure are the most important factors determining the use of grassland fields by waders in coastal areas (Townsend 1981; Lack 1986; Milsom *et al.* 1998). Tucker (1992) showed that plover numbers were also positively correlated with the frequency of grazing by cattle but not by sheep. Individual models for Curlew, Lapwing and Black-tailed Godwit constructed by Milsom *et al.* (1998) showed that each species preferred large fields with open boundaries and with a short sward. For all wader species combined, the models indicated that the amount of short grass was the most important factor in determining field usage by feeding waders and grazing (or mowing) may be a suitable management technique for improving swards for wintering and staging waders (Milsom *et al.* 1985, 1994, 1998). In inland areas, the distribution of Lapwing and Golden Plover is also correlated with the availability of short grass and the degree of field enclosure (Barnard & Thompson 1985; Milson *et al.* 1985).

The feeding preferences of many grazing wildfowl are often heavily influenced by sward height. Wigeon prefer swards grazed by cattle to a length of 2-3 cm (Rijnsdorp 1986). Bewick's Swans selected areas of pasture with a higher grass biomass and hence length. These pastures tended to be those which had been used for hay or silage or where grazing cattle had been removed by the end of October (Rees 1990). These areas had a significantly higher biomass of grass than areas where cattle had been removed later. The selection of feeding sites by all species of geese wintering in Britain is closely related to sward height. In general, dark geese such as Brent and Barnacle Geese show a greater preference for shorter swards than grey geese (Vickery & Gill 1999). Pink-footed Geese and Bean Geese wintering in Norfolk appear to prefer grass heights of *c.* 13-20 cm (Vickery *et al.* 1997; Allport 1989). Brent Geese however, select grass fields with short (<5 cm) as opposed to long (>10 cm) swards (Summers & Critchley 1990; Vickery *et al.* 1994) although there may be a minimum sward height below which it is unprofitable to feed. For example, intake rates have been shown to decline for Brent Geese at sward heights of less than 4 cm (Riddington *et al.* 1997) and less than 2 cm for Barnacle Geese (Drent & Swiestra 1977). Preferences for cattle- as opposed to sheep-grazed or grazed as opposed to mown grassland has only been investigated experimentally for Brent Geese (Vickery *et al.* 1994). For this species it seems that, in general, as long as the resulting sward is short and green in October when the geese arrive, the management regime had very little influence on the subsequent grazing intensity by the geese.

Few studies have specifically assessed the importance of grassland to passerine bird communities in winter and most information derives from bird-habitat association studies and not experimental work. Wilson *et al.* (1996b) and Tucker (1992) have described the bird community on mixed, lowland farmland. Grazed grass (and stubble) held the majority of birds in winter, whereas ungrazed temporary grass leys (as well as bare till, cereals or broad-leaved crops) were little used. Grazed, permanent grass or long-term leys were important for invertebrate-feeding birds, and were used more than would be expected, if field choice was random by Starling, Blackbird, Carrion Crow, Jackdaw, Magpie, Rook and Mistle Thrush. This is probably related to the larger numbers of invertebrates in permanent grass.

4.5 Cutting Management of Grasslands

4.5.1 Recent changes in cutting management of grasslands

Approximately 40% of the British enclosed grassland area is mown either every year or in most years (MAFF/FMA/Scottish Office 1997). Hopkins *et al.* (1985) found in a survey of south-west England that 52% of grassland was mown with two-thirds being cut every year. Forty percent of the mown grassland yielded at least two cuts (silage and/or hay) each year, the other 60% being evenly divided between a single cut of silage or a single cut of hay. Hopkins *et al.* (1985) found that fields grazed by sheep during the winter only, (mainly breeding ewes) had the most intensive mowing with 29% mown at least twice a year.

Traditionally grassland was cut for hay during July or even August, and although silage making became firmly established in Britain in the late 19th century there was almost a 100 year lag before its use overtook that of the hay crop (Brassley 1996). Technical innovation and improvements in the scientific understanding of silage making and utilisation are amongst the most significant of all developments to affect agricultural grassland management in the post 1940 period (Frame *et al.* 1995). However, even as recently as the early 1970s the ratio of hay to silage (expressed on a dry weight basis) harvested on British farms was about 85:15, something which was to change markedly over the following decade. Farmers in the upland areas of Britain largely stayed with hay until into the late 1980s, as the economics of upland stock farming did not justify the investment in silos. The 1980s saw the advent of the big round baler (Forster 1989) and wrapped bale silage, which now accounts for about 20% of UK silage. This has provided a cheap alternative to hay in situations where permanent silos are uneconomic, thus extending silage making on to areas where haymaking had persisted previously (Eyers 1989). Estimates for the mid 1990s of the proportion of grassland under different managements indicated that *c.* 90% was grazed, *c.* 30% was cut for silage and only *c.* 12% of grassland was cut for hay (MAFF/FMA/Scottish Office 1997).

In addition to changes in the area of land cut at different intensities, there have also been changes in mechanisation. Mowers are much faster today. The conventional cutterbar mower with a reciprocating blade has largely been replaced by impact mowers such as drum or disc mowers. The average work rate for cutterbar mowers is *c.* 0.2-0.6 ha h^{-1} for a 1.5 m wide machine (Halley & Soffe 1988). The cutting edge of impact mowers moves at speeds of 50-90 m s^{-1} and can cut 0.5-1.5 ha h^{-1}. In conventional silage making, the grass crop is usually allowed to wilt for 24 hours before being removed by a forage harvester. Forage harvesters pick up the crop but can also chop the grass into short lengths to aid compaction in the silage clamp or bag. Modern forage harvesters can achieve a work rate of *c.* 0.5 ha h^{-1}. In addition, the speed of rotation of the

The adoption of silage making as the principal means of conserving grassland forages for winter-feeding of livestock has had a considerable impact on both grassland structure and botanical diversity. Silage can be, and therefore generally is, mown earlier in the season (e.g. mid-late May) before most forbs and many grass species have flowered and set seed. Early cutting, particularly when followed by subsequent cuts, effectively prevents seed rain (the same applies when hay is mown early, e.g. Smith *et al.* (1996)). Silage making is relatively independent of the weather, unlike hay making which may be excessively delayed in some seasons, benefitting late flowering species. In the past, before haymaking was mechanised, mowing and harvesting were spread over a long season, particularly in years with inclement weather (Smith & Jones 1991). The early harvesting of silage crops enables farmers to get maximum benefits from applications of high rates of fertilisers at the time of maximum herbage growth in early summer. This encourages higher fertiliser use than for hay crops (MAFF/FMA/Scottish Office 1997), to the detriment of late flowering species. Furthermore, hay usually contains seed of grasses and forbs and, when fed to overwintered stock (whether directly outdoors or on straw bedding which is eventually spread as manure), opportunities for seed dispersal are thereby created. Such opportunities do not exist when silage is fed (Marshall & Hopkins 1990).

Contamination of silage by soil can cause spoilage by introducing *Clostridium* species, which ferment carbohydrates and lactic acid to butyric acid, and make the silage rancid and unpalatable or toxic to livestock (Halley & Soffe 1988). Therefore, in order to avoid the risk of soil contamination, grass fields that are to be cut for silage are generally rolled in the early spring. Heavy rolling while the ground is moist will largely eliminate most microtopographical features such as mole hills and can severely reduce populations of leatherjackets and slugs (Clements and Cook 1996). Soil contamination is not perceived to be a major problem with haymaking and thus grassland rolling would not have been a routine management practice on cutting fields in the past.

Sown grasses, particularly Perennial Rye-grass, are better suited than many permanent pasture species for making high digestibility silage (Wilson & Collins 1980) and this may often be used to justify reseeding. In a grassland survey of south-west England conducted by Hopkins *et al.* (1985), it was found that there was a strong relationship between the cover of sown species and the age of the sward. Swards aged one to four years had an average of 86% cover of sown species, including Italian Rye-grass, Perennial Rye-grass, other sown grasses, and sown legumes such as White Clover. Swards aged five to eight years contained, on average, 66% sown species, while the cover value declined to 55% for swards of nine to 20 years of age and to 36% for older swards. Grassland that was never mown had an average Perennial Rye-grass cover of 36% compared with 52% for fields which were mown either every year or most years. The cover of *T. repens* tended to be greatest on grasslands that received a single hay cut, compared with silage fields or multi-cut fields.

The effects of mowing are similar to those of grazing in that both drastically reduce the size and complexity of the above ground habitat, prolong the vegetative phase of grass growth and tend to increase primary production. However, mowing differs from grazing as a form of management in several important ways. It is non-selective, and usually of a more catastrophic nature than grazing and therefore the sward heterogeneity associated with grazing is absent. In grasslands managed for hay or silage most of the shoot production is removed from the site, with little organic matter returned to the soil by way of plant litter or dung.

4.5.3 Impact on invertebrates

A number of studies, which include work on calcareous grasslands and the management of grassy arable field margins, have shown grassland fauna to be depleted by cutting and removal of the herbage (Curry & Tuohy 1978; Morris 1990a, b; Kirby 1992; Smith 1993; Feber *et al.* 1996). Even traditional hay cuts occur at a time when invertebrate populations are developing, especially those dependent on flower, fruit or seed resources (Volkl *et al.* 1993). However, the interval between successive defoliations under mowing management is usually longer than in intensively grazed pastures, often allowing recovery of invertebrate populations (Purvis & Curry 1981). The faunas of established but regularly managed grassland tend to comprise a high proportion of eurytopic species, with high fecundity and good colonising abilities (Curry 1994), both of which facilitate rapid recovery from mowing (Andrzejewska 1979). This suggests that the faunas of recently established grassland are likely to be intrinsically robust to the effects of management. Morris (1990a, b) showed that the Auchenorrhyncha fauna of a recently established grass sward comprised a larger proportion of bi- and multi-voltine species than those of mature semi-natural grasslands. In semi-natural grassland, Morris and Lakhani (1979) found that effects of cutting on both the abundance and species richness of Auchenorrhyncha persisted into the following year.

Marked differences in the impacts of cutting are likely to result from the interaction between the precise timing of the cut and the phenology of each species' life cycle. Both direct physical damage, and indirect effects on the provision of food and shelter, are likely to be important for different heteropteran species. For example, Morris (1979) found that double-brooded mirid species were less affected by summer cutting than single-brooded species, and species in which most adults emerged in early summer were less affected by cutting in July than those emerging later. Most of the immediate deleterious effects of cutting, particularly on the species richness of Auchenorrhyncha, have been attributed to loss of vegetation structure (*e.g.* Morris 1981). Similarly, in experiments on limestone grasslands, Duffey *et al.* (1974) showed that cutting in May allowed a more rapid recovery of invertebrate populations than cutting in July. Andrzejewska (1965) showed that the Auchenorrhyncha fauna was vertically stratified while Morris (1971) demonstrated a positive relationship between vegetation height and the species richness of sap feeding Auchenorrhyncha in grassland. The strength of the relationship between vegetation height and abundance, or species richness, is likely to depend on the variation in height at the time of measurement.

Other taxa show similar responses to cutting management (e.g. Smith 1993; Feber *et al.* 1996). On grassy arable field margins Baines *et al.* (1997), showed that, in general, factors which increased the structural diversity of the swards also increased the abundance and species richness of spiders (Araneae). Thus, spiders were encouraged in the absence of regular, annual cutting. During the first four years after establishment of the arable field margins, the abundance and species richness of Araneae was much higher on field margin plots that were left uncut than on cut plots. Cutting in mid-summer had larger and more persistent negative effects on both abundance and species richness than cutting in either the spring or the autumn. Close relationships between the species richness and abundance of Araneae and vegetation height and structure, suggested by the impact of management regimes and by the correlation with vegetation height, were likely to result both from the requirement of many species for specific web-building sites and from higher prey densities in taller vegetation (Southwood, Brown & Reader 1979).

Cutting management has also been shown to have effects on Coleoptera. A field experiment in which cutting in May, in July, and a combination of both, was compared with an uncut control, showed varied effects on individual species (Morris & Rispin 1987). The single July cut had no significant effect compared with the May cut (either alone or in combination), but one species of rove beetle, increased on the plots cut in May (Morris & Rispin 1988). The larger number of species recorded from the unmanaged grassland compared with the cut plots included some detritivorous and saprophagous groups, such as Leiodidae and Lathridiidae.

Morris & Lakhani (1979) detected cumulative deleterious effects of summer cutting on the Hemipteran fauna of ancient limestone grassland, over a three year period. They found fewer Heteroptera than Auchenorrhyncha in this habitat, as well as recording effects of cutting that were less consistent and persistent on Heteroptera than Auchenorrhyncha. Heteroptera are characteristic of most grassland habitats (Morris & Lakhani 1979) and are thought to form an important part of the diet of many farmland birds, including juvenile grey partridges (Moreby 1994). The abundance and species richness of Heteroptera on uncropped grassy field margins also showed less clear-cut reactions to cutting regimes of uncropped field margins than those of either the Araneae or Auchenorryncha (Smith 1993). The broader ecological range of Heteroptera, and particularly the greater variety of their feeding habits (Miller 1971), together with the lower numbers captured, were likely to contribute to the more complex responses to management of this group (Morris 1979).

The height of the cut is also important. Southwood and Emden (1967) reported that in areas of farm grasslands maintained at 5-15cm by cutting there were greater numbers of invertebrate individuals, particularly of phytophagous and saprophagous species of Collembola, Coleoptera and Hymenoptera. However, more predatory species of Coleoptera and herbivorous Heteroptera occurred in uncut than in cut grassland (Southwood & Emden 1967).

4.5.4 Impact on birds

The timing, type and intensity of cutting are all important factors in determining the impact of cutting on wintering and breeding birds. In many ways, these impacts are rather similar to those of grazing. Direct effects relate primarily to the destruction of nests or chicks whilst indirect effects operate largely through changes in sward structure and composition, soil compaction and associated changes in invertebrate communities and available seed densities. However, unlike grazing, the direct rather than the indirect effects of cutting are probably more severe.

Probably the most dramatic and well documented example of the effects of the increase in intensity of cutting regimes on a bird species is that of the Corncrake. Corncrakes are a species typical of low-input farming and were once widespread across the British agricultural landscape (Green 1986). They breed in species-rich hay fields and require tall marshland vegetation as spring cover. The decline of the British and Irish populations, to extinction in some regions, can be seen as a direct result of agricultural intensification of grassland systems and particularly the switch from hay to silage production. This switch, accompanied by an increased use of improved grass varieties and inorganic fertilisers, has led to faster grass growth which allows more frequent mowing and earlier harvest dates. This, in turn, has led to increased Corncrake nest losses and adult and chick mortality, which are known to be important in causing the decline and range contraction of the species (Green 1994; Green & Stowe 1993). Increased hectarage of hay, later mowing dates and Corncrake-friendly mowing regimes are now widely advocated as important factors in reversing the decline (Green 1994).

For breeding waders, the impact of earlier and more frequent mowing on nesting success can also be severe. Studies in the Netherlands (Bientema *et al.* 1985; Bientema & Muskens 1987) suggest large reductions in breeding success arise from increased egg loss due to more frequent and intensive mowing (as well as increased stocking densities). In general, waders have a well-developed capacity for replacing lost clutches. Most species will replace nests which are lost early in the season but the likelihood of replacement declines as the season progresses (Bientema & Muskens 1987, Green *et al.* 1987).

Although very little work has been done on the impact of cutting regimes on grassland passerines it seems likely that ground-nesting species will be affected in a similar way to ground-nesting waders. Some species, such as Skylark, are multi-brooded and can lay replacement clutches but earlier and more frequent mowing is known to reduce breeding success (P.F. Donald unpublished data). A number of passerines associated with grassland are not ground nesters and Wheatear and Starling, for example, are both hole nesters and thus not vulnerable to trampling or use of machinery in pastures. Similarly, several passerine species nest in dense vegetation at the base of hedges or banks (Vickery & Fuller 1998) and are thus also often protected from trampling by livestock.

In the case of wintering wildfowl, the nature of summer cutting (and/or the grazing regime) will largely determine the sward structure the following winter, and sward height is an extremely important factor determining the suitability of grassland for feeding. The majority of grazing wildfowl prefer relatively short swards and foraging habitat may be enhanced through summer cutting as in the case of grazing (see section 4.4.4). For example, grass management experiments showed that increased grazing intensity by Brent Geese was associated with increased cutting frequency of the grass sward from two to five cuts in a summer. Although the increases in grazing intensity were not significant, the experiment was performed in one year only and authors suggest that in wetter years, with more grass growth, the effect may well have been significant (Vickery *et al.* 1994).

Changes in cutting management will also affect seed-eating birds. Traditionally-managed hay meadows which are cut in late June are a good source of seeds as the single late cut allows seeds to set; cuts on silage fields are generally too early and too frequent to allow seeds to set (see 4.5.2) and consequently silage fields are little used by foraging seed-eating birds.

4.6 Drainage of Grassland

4.6.1 Recent changes in drainage of grasslands

Widescale land drainage began after the enclosure acts of the 18th century (Trafford 1970). In the 19th century about 5 million ha were under-drained and many wetland areas were converted to arable land (Trafford 1970). By the beginning of the 20th century it was estimated that 50,000-100,000 ha of farmland were being drained annually (Trafford 1977). There was an active period of drainage during the period 1940-1980 encouraged by grant aid, with approximately 750,000 ha of land being drained or re-drained. During this period about 35,000 ha of grassland were drained annually (O'Brien & Self 1994; Garwood 1988). However, following the reduction in capital grants by MAFF the amount of drainage has probably fallen since the 1980s. Forbes *et al.* (1980) assessed the drainage status of permanent grassland in England and Wales between 1973 and 1976. Their survey, covering a total of 28,000 ha of enclosed grassland, found that 31% of fields showed signs of poor or bad drainage, and a further 45% had imperfect drainage as indicated by mottling or colouration of the topsoil. The high proportion of permanent grassland fields with poor or impeded drainage imposes some management constraints, particularly on cattle grazing in the spring. However, studies by Tyson *et al.* (1992), showed that field drainage may result in only modest livestock production benefits. Gains in dry matter production in the spring may be largely negated by reduced sward production in mid-season due to the effects of enhanced soil-moisture deficits on drained land. Where field drainage is carried out it is usually followed by earlier and increased fertiliser applications and the introduction of silage making or increased stocking rates over extended grazing periods (Williams & Bowers 1987).

4.6.2 Impact on botanical composition

Changes in soil hydrology due to drainage affect wet grassland communities either directly by creating edaphic conditions that disadvantage wetland species or indirectly, by enabling other changes such as earlier grazing, silage cutting, higher fertiliser inputs etc, and often accompanied by a complete reseeding. For the purposes of this review, wet grasslands will be categorized according to broad habitat types (HMSO 1995) and the National Vegetation Classification (Rodwell 1991; Rodwell 1992). Lowland wet grassland may be defined as managed pastures or meadows that occur on land below 200 m above sea level and which have a high water table and/or subjected to periodic inundation (Dargie 1993; Jefferson & Grice 1998).

The total area of wet grassland in England is estimated to be 215-220,000 ha, most of which is agriculturally improved or semi-improved and of low nature conservation value (Dargie 1993; Jefferson & Grice 1998). Throughout the history of agricultural development in lowland Britain wet grasslands have suffered extensive destruction, damage or modification by various human activities (HMSO 1995). The surviving area of unimproved semi-natural wet grassland probably amounts to less than 30,000 ha (Tallowin & Mountford 1997; Jefferson & Grice, 1998). The total extent of unimproved wet neutral grassland is estimated to occupy an area of less than 10,000 ha in England (Jefferson & Robertson 1996). These figures, respectively, represent less than 5% of the resource that was present in the 1930s (Fuller 1987). Relic unimproved wet grasslands now commonly exist as small, isolated and often fragmented sites. Many sites are still at risk from activities such as borehole abstraction, drainage or eutrophication of water sources within catchment areas, inappropriate agricultural management or abandonment (HMSO 1995).

Numerous studies have shown that drainage improvements on extensively managed grasslands can destroy the indigenous wet communities and their botanical diversity. In mixed farming areas, such as the East Anglian marshes, drained grassland including *Juncus subnodulosus-Cirsium palustre* fen-meadow (M22) (Rodwell 1991) has usually been converted to arable land (Tallowin & Mountford 1997). In western grassland areas, such as the Devon Culm Measures, nationally scarce and highly valued *Molinia caerulea-Cirsium dissectum* fen-meadow (M24) (Rodwell 1991) communities have been converted to Perennial Rye-grass-dominated swards with affinities to MG6 and MG7 grassland. On more intensively managed grassland, the effect of drainage on botanical composition, *per se,* is likely to be relatively small compared with that of applying inorganic nitrogen fertiliser. Relatively species-poor *Festuca rubra-Agrostis stolonifera-Potentilla anserina* (MG11) grassland or the *Agrostis stolonifera-Alopecurus* *geniculatus* (MG13) inundation pasture or *Holcus lanatus-Juncus effusus* (MG10) rush pasture are likely to be further impoverished in species diversity towards *Lolium perenne-Cynosurus cristatus* (MG6) grassland (Rodwell 1992).

4.6.3 Impact on invertebrates

There is very little published information on the impact of drainage of neutral grasslands on the associated invertebrate fauna. It is known that, within moorland habitats, wet flushes support high concentrations of invertebrates (Hudson 1988, Coulsen & Butterfield 1985) and the same may be true of lowland grassland. Many important invertebrate prey items for birds, such as earthworms, tipulid and chironomid larvae are associated primarily with the top layers of soil or plant litter and plant bases (Ward 1994). The height of the water table is of considerable importance in determining the invertebrate fauna of these soil or plant layers (Ausden & Treweek 1995). Thus, when soils dry out, due to deliberate drainage or other causes, prey becomes less abundant. In particular, surface invertebrates, such as the beetle and insect larvae taken by Redshank and Lapwing, become fewer and harder to find (Hudson *et al.* 1994) and soil dwelling invertebrates such as earthworms burrow deeper (Edwards & Lofty 1977). In addition, dry soil is impenetrable and so even the invertebrates present become less accessible to species, such as Snipe, that probe the soil for food.

4.6.4 Impact on birds

Although drainage of grasslands has been extensive (see section), the most severe impacts have been on one particular type of neutral grassland, namely wet lowland grasslands (Ausden & Treweek 1995). These wet grasslands may also be acidic or basic but since most of the information available refers to wet lowland grasslands in general and for the purposes of this review we assume the impacts will be rather similar regardless of soil type. However, because wet lowland grasslands are highly threatened habitats and often support important populations of breeding and wintering waterfowl and waders they have been the focus of considerable ornithological research both in the UK (e.g. Self *et al.* 1994; Williams & Bowers 1987) and abroad (e.g. Bientema 1988; Klinner 1991; Hotker 1991a). Waders such as Redshank and Snipe and waterfowl such as Shoveler and Tufted Duck commonly breed only on lowland wet grasslands. However, Lapwing are widespread and Redshank and Snipe do breed in wet flushes and small areas of undrained land within neutral grasslands. Thus, although the information in this section relates almost entirely to wet lowland grasslands, the mechanisms whereby birds are affected by this management practice are likely to be common to grasslands in general.

Drainage of lowland wet grassland has a highly detrimental impact on the associated bird community. Probable immediate effects are mainly related to changes in the abundance and accessibility of invertebrate prey. Other effects relate to subsequent increases in the intensity with which the land is managed as a result of drainage, such as increased stocking densities and mowing rates (see 4.2.4 - nitrogen, 4.3.4 - grazing and 4.4.4 - cutting).

Recent population declines and range contractions in breeding waders on lowland wet grasslands have been documented throughout the UK (Smith 1983; Thom 1986; Marchant *et al.* 1992; Hudson *et al.* 1994; Self *et al.* 1994) and elsewhere in Europe (Bientema 1998; Hotker 1991a, 1991b). The principal causes for these downward trends are considered to be changes in agricultural practices, particularly drainage, and subsequent intensification of farming (O'Brien

& Self 1994; Hotker 1991a & b). The wader species associated with lowland wet grasslands feed almost entirely on invertebrates by probing the soil or pecking prey from the surface of the soil or vegetation, and drainage has a direct effect on both the abundance and accessibility of these prey (Green & Cadbury 1987; Self & O'Brien 1994; section 4.6.4). Overall, breeding density (e.g. Vickery *et al.* 1997) and breeding success (e.g. Green 1986) of grassland waders tend to be much higher on lowland wet grasslands that have not been subject to extensive drainage.

Different species of wader exhibit different levels of vulnerability to drainage largely due to differences in their foraging ecology (Bientema 1983, 1991). Snipe, for example, feeds by probing the soil for invertebrates and, because incubating adults and adults with young prefer to feed close to the nest site, they are particularly vulnerable to any drying out of the soils within their territories (Green 1986, 1988). Redshank have a slightly higher tolerance to drainage by their mobility and hence ability to exploit wet areas at some distance from the nest site. Lapwing chicks are less vulnerable since they feed by picking prey from the surface of soil of vegetation although adults feed by probing (Bientema & Visser 1990).

Another potential impact of drainage is a subsequent increase in predation of nests and young, either because predators can detect nests or young more readily, or because adult birds have to forage further afield leaving nests unattended (Bientema & Muskens 1987). Increases in nest mortality are, however, more likely to be caused indirectly by increases in management intensity, though birds, such as Snipe and Redshank, are likely to abandon sites very soon after drainage. Once drained the grassland can be farmed earlier and more intensively; with earlier applications of nitrogen and fertiliser inputs, the sward can support livestock grazing earlier in the year and for longer. The impact of earlier and more intensive grazing and mowing have already been reviewed in previous sections (see 4.4.4 and 4.5.4). In general, the result is a reduction in breeding success due to increased egg loss to mowing and trampling of nests and lack of cover as protection from predation.

Wildfowl are also dependent for breeding on open water in pools and ditches during the summer (Self *et al.* 1994). Many species, such as Garganey and Shoveler and Tufted Duck preferentially nest close to water in Britain and abroad (Thomas 1980, Self *et al.* 1994, Dunn 1994). These species are almost entirely restricted to wet lowland grasslands and potential impact on breeding in these species will not be considered further here.

As is the case for many of the grassland management practices, far less is known about the impact of drainage on passerines than for waders and wildfowl. Yellow Wagtails feeding on grassland show a clear preference for moist pastures often feeding near shallow surface water. It does breed on drier farmland in some parts of the range but usually at much lower densities. This preference is probably related to diet and feeding technique since it often feeds around pools taking Diptera, larval and adult mayflies, grasshoppers and beetles. Overall, passerines are less likely to be affected by drainage since they feed on aerial or soil surface invertebrates and do not require wet grassland habitat for nesting.

Although the main cause of the decline of the Corncrake is increased mortality and nest losses associated with more rapid and earlier mowing of grass for silage rather than hay (see section 4.5.4), the installation of field drains and improved maintenance of ditches has reduced the extent of tall marshland which is important for spring cover for Corncrakes (Green 1995). Similarly wet ground in some hay meadows, such as those on the Shannon Callows, may also delay the development, and hence cutting, of hay crops and promote breeding success of Corncrakes nesting within them (Nairn *et al.* 1988).

In winter, grassland forms an important staging or wintering habitat for waders such as Golden Plover and Lapwing, both of which show a strong preference for feeding on grassland in some regions (e.g. Fuller 1988; Milson *et al.* 1985; Tucker 1992). There is little detailed information relating to the finer scale habitat preferences of these species. In some regions Lapwings have been suggested to prefer damp soils (Crooks & Moxey 1966) and Golden Plover, well-drained subsoils such as chalk and sands (Lister 1964) although whether these are general preferences remains unknown. The reasons underlying these preferences remain largely unknown though it is likely to be related to food availability and differences in foraging ecology. Whimbrel also show a preference, on their staging grounds, for damp tussocky pastures which are rich in major prey items, such as the larvae of elaterid beetles (wireworms), noctuid caterpillars and adult sawflies of the genus *Dolerus* (Ferns *et al.* 1979).

Most lowland wet grassland sites are more important as wintering rather than breeding sites for wildfowl when the level of drainage influences the availability of roosting and feeding sites. The maintenance of a high watertable and regularity of early spring flooding are important factors determining the numbers and diversity of wildfowl using a site. Wintering wildfowl are very susceptible to disturbance (Vickery & Gill 1999; Mayhew & Houston 1989) and large numbers of birds will only use sites where there are nearby sanctuary areas, usually open water, for roosting.

Temporary or permanent shallow flooding in winter (2-20 cm) may make seeds and invertebrates available to foraging wildfowl (Thomas 1980) and will favour inundation-tolerant plants such as some sedges *Carex* spp., docks, buttercups and persicarias, whose seed are important foods for species such as Teal and Mallard. Bewick's Swans and Wigeon are both known to prefer grazing on flooded pasture rather than drier areas (Rees 1990; Mayhew & Houston 1989) a preference which is also related to the availability of favoured food plants on wet pastures (Owen & Cadbury 1975; Thomas 1982; Owen & Thomas 1979).

The intensive grassland management that often follows drainage may benefit some wintering wildfowl. Short, heavily grazed swards are preferred as feeding areas by Brent Geese and Barnacle Geese (Vickery & Gill 1999) and Wigeon (Owen & Thomas 1979; Ausden & Treweek 1995) and the use of fertiliser has been shown to increase the attractiveness of grass swards for a range of geese (Owen 1975; Percival 1993; Vickery *et al.* 1994). Moderate to heavy cattle grazing following drainage of wet grasslands can reduce the dominance of Reed Sweet-grass and Reed Canary-grass, both of which are of little value to wintering waterfowl (Owen & Thomas 1979; Thomas 1980, 1982).

4.7 Ploughing and Reseeding of Grassland

4.7.1 Trends in ploughing and reseeding of grassland

About 200,000 hectares of grassland are reseeded annually, though much of this consists of renewals of ageing grass leys (Hopkins & Hopkins 1994). Despite the reduction of grasslands of high conservation value, it appears that at least 50% of swards are at least 20 years old with, in some cases, no known history of being ploughed (Forbes *et al.* 1980; Hopkins 1986; Hopkins *et* *al.* 1985). A note of caution accompanies these statements since only limited information on areas sown can be derived from annual census returns, grassland surveys have provided the main source of information, and only limited information is available for recent years. The most recent national grassland surveys (field-scale botanical records combined with farmer interviews on management history and output) were conducted in the 1970s (Forbes *et al.* 1980; Green 1982) with some sample areas resurveyed in the early/mid 1980s (Hopkins *et al.* 1985; Hopkins & Wainwright 1989). In the survey by Hopkins *et al.* (1985) of a sample of grassland farms in south-west England 26% was classified as arable grassland (in rotation with crops), the remainder being permanent grassland (including reseeded grassland to grass). Fifty-six percent of the permanent grassland was over 20 years old. However, big differences emerged between types of grassland farm; only 37% of established grassland on dairy farms was aged over 20 years compared with 53% on other types of livestock farms. About 19% of the permanent grassland were one to four years old. Eighty-five percent of the reseeded swards had been sown to replace an existing grass sward.

4.7.2 Impact on botanical composition and sward structure

During the earlier part of this century grass seed mixtures were relatively complex and contained a range of grass species, legumes and forage herb species (Davies 1960). Modern seed mixtures are relatively simple, often pure Perennial Rye-grass, and this, combined with better seed cleaning, better weed control during the crop phase of ley-arable rotation, and improved techniques for sward establishment, has resulted in greatly reduced botanical diversity and the likelihood of reduced seed banks of agriculturally improved grassland. Hopkins *et al.* (1985) found that swards aged one to four years were dominated by sown species (86% cover). Volunteer grasses, principally Bent spp. and Rough Meadow Grass, contributed, on average, 10% cover and dicotyledonous species about 3% of the cover. Grasses dominated the swards of all grassland age categories; the average cover of grasses (sown and unsown) of swards aged more than 20 years was 89%. In general, all agriculturally improved grassland, whether sown or unsown, consisted of species-poor grass dominated communities.

4.7.3 Impact on invertebrates

Agricultural improvement of grassland, through ploughing and re-seeding, will affect invertebrates both through the disruption caused by cultivation, and the change to a less species-rich sward which generally results (4.7.2 above). Several studies have shown soil arthropods to decline in numbers after cultivation of old pasture (Sheals 1956; Edwards & Lofty 1975), particularly in terms of abundances of collembolans and mites. Earthworm biomass is also greatly reduced following ploughing, but there is fairly rapid recovery of population levels (Edwards & Lofty 1988). Neale (1996) suggests that at least two but no more than four years of grass ley is required for earthworm populations to recover to levels found on permanent pasture.

Because many herbivores are associated with particular plant species, or families, changes in the floristic composition of the sward will have significant effects on the invertebrate community. A dicotyledonous species such as Stinging Nettle, for example, has a number of specialist feeders associated with it (Davis 1973). Certain grass-feeding Hemiptera are closely associated with particular species (Southwood & Leston 1959). Many Heteropteran species feed on the forb components of the swards while most Auchenorrhynca feed on grasses (Morris 1990b). Gibson (1976) found that the species occurring on calcareous grassland fed on a spectrum of plant species which changed both seasonally, and with the age of the insect. Morris (1990a) found that Heteroptera were less sensitive than Auchenorrhyncha to the species composition of different grass mixtures. Denno (1994) showed that the presence of non-host plants, as well as host plants can enhance the abundance of some Auchenorrhyncha although the mechanisms for this are poorly understood. Morris (1990b) found that swards sown with fine-leaved grasses tended to support more Auchenorrhyncha species in summer while coarse-leaved grass swards tended to support more species in winter, probably because they afforded greater physical protection.

4.7.4 Impact on birds

The species composition of the sward, and frequency of reseeding, can potentially impact on bird populations which use pastoral areas in several ways. Older swards tend to hold a greater diversity of plants and invertebrates which, in turn, provide a greater diversity of food for both breeding and wintering birds. Ploughing and reseeding on a frequent basis reduces invertebrate numbers, especially Lumbricid worms (see 4.7.2). The composition of seed mixes currently tends to produce a monoculture of rye grass offering very limited food resources for seed-eating birds. The process of re-seeding is intricately linked with many other management practices most of which have been considered in previous sections (e.g. increased fertiliser use 4.2.4, grazing intensity 4.4.4 or cutting frequency 4.5.4). The impact of re-seeding per se on birds is really the impact of a loss of unimproved or older pastures.

During the breeding season, the decline in rough grazing and their conversion to improved grass, particularly that of dry semi-natural grassland and sheepwalk, may have contributed to the decline in Stone Curlew, Wheatear and Whinchat (O'Connor & Shrubb 1986). Reseeding of traditionally managed hay meadows has coincided with dramatic declines in Corncrakes across western Europe although it is difficult to distinguish whether this is related to re-seeding per se or subsequent management of re-seeded grassland (Nairn *et al.* 1988). Breeding Lapwings prefer rough grazing and permanent grass, but lower numbers occur on grass leys (Shrubb & Lack 1991). In contrast, there is some evidence to suggest that Skylarks prefer young (<3 years) leys, although the reason for this preference is unclear (O'Connor & Shrubb 1986).

In winter, farmland in Britain supports large numbers of invertebrate-feeding birds, including internationally important populations of Golden Plover and Lapwing and important populations of Rook, Jackdaw, Starling, Redwing and Fieldfare (Tucker 1992). The age of grassland is an important factor in determining the use birds make of a field, especially Golden Plover, Starling, Rook and Carrion Crow (Tucker 1992). Permanent grass and older swards tend to be preferred by a wide variety of species including Golden Plover (Fuller & Youngman 1979; Fuller & Lloyd 1981), Lapwing (Milsom *et al.* 1998), Starling (Feare 1984), Rook (Waite 1984), Fieldfare and Redwing (Barnard & Stephens 1983). In an area of mixed farming in the southern midlands Tucker (1992) demonstrated that most species occurred at higher densities on permanent grass. Leys and cereal fields supported moderate densities of birds and bare till, winter cereal and rape fields were little used. Lumbricid worms are important components of plover winter diet (Gillings & Fuller 1998) and densities of these and other soil dwelling invertebrates are higher in permanent grass fields rather than temporary grass and are an order of magnitude higher than in cultivated land (Edwards & Lofty 1975). Invertebrate densities tend to increase with increasing age of a pasture (Edward & Lofty 1977; Barnard & Thompson 1985; Tucker 1992), suggesting that the use of rotational grass leys and arable crops or frequent reseeding will have a negative impact on the use of such areas by invertebrate-feeding birds in winter.

Regular reseeding can also have a positive impact on bird populations. In winter, Bewick's Swans prefer young fertilised grass leys because the crude protein content of the grass is higher than in older leys (Rees 1990). New leys tend to contain a high proportion of one or two plant species, usually Perennial Rye-grass, as other meadow grasses have not yet appeared. In the Netherlands, Rjinsdorp (1986) demonstrated that Wigeon spent more time feeding in wet pasture in a peat bog area rather than pasture in a reclaimed polder area. Experiments showed that birds preferred softer grasses such as Marsh Fox-Tail, Meadow grass spp and Creeping Bent rather than the coarse Perennial Rye-grass. The differences in habitat use could be related to the higher digestibility of the softer grasses (Owen 1975; Rjinsdorp 1986).

5 CONCLUSIONS AND FRAMEWORK FOR FUTURE RESEARCH

5.1 Conclusions

The management of grassland has altered dramatically in Britain in the last 40-50 years, with changes in the nature, level and/or extent of both chemical inputs and physical management practices. Probably the two most dramatic changes relate to the increased use of fertiliser nitrogen and the switch in cutting regimes from hay to silage. Overall, 86% and 48% of all agriculturally improved grassland in the UK receives inorganic and organic (solid manure or liquid slurry) fertiliser, and since the 1940s the average use of fertiliser nitrogen has increased two to three fold. Approximately 40% of enclosed grassland in Britain is mown every year, but whereas in 1970 the ratio of hay to silage was 85:15, by the mid 1990s a widespread switch to silage had taken place, resulting in a ratio around 30:70.

Of the remaining major categories of grassland management practices, changes in physical management, particularly grazing regimes, have tended to be greater than changes in chemical inputs. The nature and extent of grazing has altered markedly since the 1940s. Sheep numbers doubled between 1950 and 1990 and then declined by *c.* 10% in the subsequent years. The beef herd has also increased in recent years, while a marked decline in the dairy herd in the last 20 years has resulted in an overall reduction in cattle numbers supported on British grassland. However, overall, the livestock live weight carried by grassland in Britain in 1997 differed by only 4% from that carried in 1980. These trends vary regionally across the country with overall stocking levels decreasing in eastern and increasing in western regions - reflecting increased polarisation of arable and grassland systems. Ecologically, the most important change in livestock grazing has been the increase in sheep, which has resulted in larger areas of tightly grazed swards. Changes in the practices of drainage and re-seeding have been less extensive than changes in other management practices within neutral grasslands. There was widescale historical drainage of grassland in 18th and 19th centuries but, with the exception of an active period of drainage in 1940-1980, the rate of drainage on permanent grassland has probably fallen since the 1980s. With respect to re-seeding, although large areas of grassland are re-seeded annually, much of this involves re-seeding old grass leys rather than creating new grassland. The presence of weeds and pests has generally been tolerated more on grassland than on arable crops. There has been an increase in herbicide use associated with the establishment of grass leys, but use of pesticide-based control measures, e.g. for leatherjackets and slugs, is negligible compared to arable land.

In general, the trends in grassland management have resulted in structurally diverse and species-rich swards being replaced by relatively dense, fast-growing and relatively uniform swards dominated by competitive species such as Perennial Rye-grass. High levels of inorganic fertiliser, intensive grazing by sheep, management for silage, involving drainage, re-seeding, rolling and early and repeated cutting all reduce botanical diversity and structural complexity of the sward. Because many herbivorous invertebrates are associated with particular plant species or families, reductions in the floristic diversity of the sward will have had significant negative effects on the abundance and diversity of the associated invertebrate fauna. For example, many dicotyledenous species, such as Stinging Nettle, support a range of specialist feeders and a number of Hemiptera are closely associated with specific grass species. Reductions in these invertebrate species will, in turn, result in reductions in the numbers and diversity of predatory and parasitic invertebrates that depend on them. The effects of management on the invertebrate community are, however, complex and differ depending on the timing and intensity of that management and the phenology of the invertebrate species concerned. For example, double-brooded mirid species are less affected by summer cutting than single-brooded species. Another example is that earthworms show increased densities at low levels of fertiliser application, but densities decrease with higher fertiliser application levels. In general, however, high inputs of organic and inorganic fertiliser seem to decrease abundance and diversity of invertebrates as a whole and change the faunal composition. Similarly, high stocking rates reduce the numbers and biomass of phytophagous grassland invertebrates, and hence the predatory and parasitic species that depend on them, as does the regular cutting and removal of herbage and frequent re-seeding associated with silage production. Compared with these gross changes in the sward itself, the modest increases in pesticide applications have had a relatively small impact on grassland invertebrate communities.

Changes in sward composition and structure, associated with these changes in management practices, have direct and indirect effects on birds associated with grassland. Direct effects result from an alteration of the quality of the habitat for nesting and feeding and the quality and abundance of food for herbivorous birds, such as grazing wildfowl. Indirect effects operate via alterations in the abundance and availability of invertebrates which are important prey for a range of species, particularly passerines and waders.

Nesting success of some grassland species is likely to be affected in one of two ways. First changes in the sward structure will alter its suitability as nesting habitat. Second increased intensity of cutting and grazing will result in direct loss through trampling or mechanical destruction. Dense fast growing uniform swards generated by high levels of inorganic fertiliser and management for silage will provide poor nesting habitat for species such as Lapwing, which prefer to nest in short or patchy vegetation. It seems likely that much modern, fertilised, mown grassland will be entirely unsuitable for characteristic ground-nesting farmland birds, notably Skylark and Lapwing. Intensive grazing may have the opposite effect, producing short swards. Nests may also be less well camouflaged in uniform swards and hence more vulnerable to predators. The most important impact of changes in grassland management on nesting productivity are through direct nest loss, as a result of trampling by livestock and destruction by early and repeated mowing associated with silage production. Loss of nests and young through mowing operations has been identified as the major cause of the population decline of the Corncrake and extensive nest losses have been documented in a range of waders.

A more general mechanism through which many grassland management practices will have detrimental effects on bird populations associated with grassland is through altering the abundance and availability of invertebrate prey. Uniform swards support a lower diversity and usually, though not always, a lower abundance of invertebrates. Important prey items, such as earthworms and tipulid larvae, are associated with the top layers of the soil and will be less accessible in tall dense swards to a range of waders, such as Lapwing and Snipe, and passerines, such as Wheatears and Whinchats. For species that feed by probing the soil, drainage will also reduce the abundance and accessibility of soil dwelling invertebrate prey.

However, moderate levels of management may provide increased feeding opportunities in some instances. Low additions of organic fertiliser may increase the abundance of invertebrates, such as earthworms, and bring them closer to the surface, hence increasing their availability to birds. Moderate levels of grazing may benefit a number of birds associated with grassland, by creating areas of short swards where invertebrate prey are more accessible to a range of foraging waders and passerines in winter and summer. Light to moderate grazing also creates a structurally heterogeneous sward that supports a wider range and abundance of invertebrates and the addition of dung will also enhance soil invertebrate populations and provide rich feeding patches.

Increases in nitrogen content of the sward increases its quality as forage for grazing wildfowl in winter and, since many grazing geese and ducks show preferences for relatively short grazed swards, grazing and cutting in summer may increase sward attractiveness for these species. Re-seeding, which may reduce foraging success for seed and invertebrate feeders, may in contrast, benefit wintering grazing wildfowl which often show a preference for young grass leys due to higher forage quality.

The interactions between grassland management, sward structure and the associated invertebrate and bird communities are complex. Impacts of management on plants, invertebrates and birds differ between species and in relation to timing and intensity of that management. Although intensive management may benefit a number of grazing wildfowl species, by increasing the quality of the grassland as forage, these species tend to be very localised in their winter distribution and utilise a relatively small proportion of grassland in the UK. In terms of the extent of grassland utilised, and the abundance and diversity of species involved, impacts of management on passerines and waders are potentially much more important. For these species, low to moderate levels of management, particularly grazing and organic fertiliser application, are predicted to be beneficial by maintaining a diverse sward structure and invertebrate community. However, in general, intensive management creating dense, fast growing and relatively uniform swards often dominated by competitive species such as Perennial Rye-grass and supporting an impoverished invertebrate fauna are likely to create very poor feeding and breeding habitat for many species of grassland wader and passerines.

Future trends in grassland management are not easy to predict but further increases in fertilisers and other inputs, particularly pesticides, seem unlikely, and their use may decline. As farmers strive to achieve greater efficiency in a static or declining market, the total agricultural grassland area may fall. In fact reductions of 2-4 million hectares by 2015 have been suggested (North 1990). In the short term, changes in support prices for cereals will reduce the cost advantage of grass silage, relative to maize, cereals and concentrates. This will probably affect the amount and average quality of silage, with delayed and heavier first cuts, possibly with less fertiliser, and subsequent cuts replaced by grazing. Such changes would affect grassland production, sward structure and composition.

5.2 Framework for Future Research

The information presented in this review highlights a number of clear information gaps with respect to the impact of changes in grassland management practices on birds. Relatively good information exists on the changes and trends in grassland management in Britain and the impacts of these changes on botanical composition and sward structure. However, very little information exists relating to the effects of these changes on the associated invertebrate fauna, on which many grassland birds depend for food. In addition, no studies to date have assessed bird populations on neutral grassland in winter or summer in relation to management regimes, sward structure and compositions and invertebrates on that grassland. Thus, despite the importance of grassland in Britain, and the extent to which it is used by birds in winter and summer, very little is known about the detailed distribution of birds within grassland systems with respect to management intensity. Furthermore, the factors influencing this distribution, particularly invertebrate abundance and diversity, remain poorly understood. This is particularly true for passerines utilising grassland as breeding and wintering habitat. However, it is perhaps important to point out that one practical problem in addressing these issues within the current agricultural landscape in Britain is the relative scarcity of low intensity grassland. This is likely to make studies of invertebrates and birds on strictly comparable low and high intensity grassland (e.g. similar altitude and topography) difficult.

Information derived from the review enable three general hypotheses to be developed concerning the distribution, abundance and foraging efficiency of birds on grassland under management regimes of differing intensity. The following predictions can be made:

1. Compared with grassland fields managed under low intensity regimes (defined by low inputs of fertiliser N), grassland fields managed under intensive farming regimes will:

    a. support swards with relatively more uniform structure and botanical composition.
    b. support an impoverished invertebrate community
    c. support a lower diversity and abundance of breeding and wintering passerines and waders
    d. probably support higher numbers of grazing wildfowl in winter*

2. Following from (1) and given that range contractions of farmland birds have generally been greatest in western Britain (Chamberlain *et al.* 1999, BTO Research Report 209), the great majority of neutral grasslands in England and Wales will now support extremely low populations of ground-nesting species, such as Lapwing and Skylark.

3. Passerines and waders on grassland fields will exhibit reduced foraging use of fields managed under intensive farming regimes compared with grassland fields managed under low intensity regimes. The reverse is likely to be true for grazing wildfowl in winter*.

4. The differences predicted in 1 and 2, between intensive and extensive fields, will also be apparent, although to a lesser degree, between cut and grazed fields. Cut fields are predicted to support generally lower biodiversity than grazed fields.

* (this aspect will not be addressed within the current study since these species are unlikely to be encountered in any number in the inland study area).

Acknowledgements

This review was funded by a contract from the Ministry of Agriculture Fisheries and Food. We are very grateful to Alan Hopkins (IGER) for his invaluable contribution to chapters 2 and 4 and to Nicola Read for extensive help in the final production of this report.

References

ADAS/FMA (1992) *Fertilizer use on farm crops in England and Wales 1991*. MAFF, London.

Allport, G. (1989) Norfolk's bean geese and their management. *RSPB Conservation Review*, **3**, 59-60.

Andersen, C. (1980) The influence of farmyard manure and slurry on the earthworm population (Lumbricidae) in arable soil. In *Soil Biology as related to Land Use Practices* (ed. D.L. Dindal). Proceedings of the 7th International Colloquium of Soil Zoology, pp.325-335. Syracuse, New York.

Andrzejewska, L. (1979) Herbivorous fauna and its role in the economy of grassland systems. I. Herbivores in natural and managed meadows. *Polish Ecological Studies*, **5**, 5-54.

Asteraki, E.J., Hanks, C.B. & Clements, R.O. (1992a) The impact of two insecticides on predatory ground beetles (Carabidae) in newly-sown grass. *Annals of Applied Biology*, **120**, 25-39.

Asteraki, E.J., Hanks, C.B. & Clements, R.O. (1992b) The impact of the chemical removal of the hedge-base flora on the community structure of carabid beetles (Col., Carabidae) and spiders (Araneae) of the field and hedge bottom. *Journal of Applied Entomology*, **113**, 398-406.

Ausden, M. & Treweek, J. (1995) Grasslands. In *Managing Habitats for Conservation* (eds. W.J. Sutherland and D.A. Hill). Cambridge University Press, Cambridge.

Baines, D. (1989) The effects of improvement of upland marginal grasslands on the breeding performance of Lapwings *Vanellus vanellus* and other waders. *Ibis*, **131**, 497-506.

Barber, W.P. (1985) The nutritional value of common weeds. In *Weeds, pests and diseases of grasses and herbage legumes* (ed. J.S. Brockman) pp 104-111. British Grassland Society Occasional Symposium No. 18.

Barnard, C.J. & Stephens, H. (1983) Costs and benefits of single and mixed species flocking in fieldfares (*Turdus pilaris*) and redwing (*T. iliacus*). *Behaviour*, **84**, 91-123.

Barnard, C.J. & Thompson, D.B.A. (1985) *Gulls and Plovers*. Croom Helm, London

Barnard, C.J. & Thompson, D.B.A. (1985) *Gulls and Plovers: The ecology and behaviour of mixed-species feeding groups.* Croom Helm, London and Sydney.

Barr, C., Bunce, R.G.H., Clarke, R.T., Fuller, R.M., Furse, M.T., Gillespie, M.K., Groom, G.B., Hallam, C.J., Hornung, M., Howard, D.C. & Ness, M.J. (1993) *Countryside Survey 1990, Main Report*. DoE, London.

Barr, C.J., Britt, C.P. & Sparks, T.H. (1995) *Hedgerow management and wildlife.* Institute of Terrestrial Ecology, Grange-Over-Sands.

Berg, G., Esselink, P., Groeneweg, M. & Kiehl, K. (1997) Micropatterns in *Festuca rubra* dominated salt-marsh vegetation induced by sheep grazing. *Plant Ecology*, **132**, 1-14.

Bernhays, E.A. & Chapman, R.F. (1970) Food selection by *Chortippus parallelus* (Zetterstedt)(Orthoptera: Acrididae) in the field. *Journal of Animal Ecology*, **39**, 383-394.

Bientema, A.J. (1983) Meadow birds as indicators. *Environmental Monitoring and Assessment*, **3**, 391-398.

Bientema, A.J. (1988) *Conservation of Grassland Bird Communities in The Netherlands.* International Council for Bird Protection. Technical Publication 7. ICBP, Cambridge

Bientema, A.J. (1991) What makes a meadow bird a meadow bird? *Wader Study Group Bulletin* **61 Supp**, 12-13.

Bientema, A.J., Bientema-Hietbrink, R.J. & Muskens, G.J.D.M. (1985) A shift in the timing of breeding in meadow birds. *Ardea*, **73**, 83-89.

Bientema, A.J. & Muskens, G.J.D.M. (1987) Nesting success of birds breeding in Dutch agricultural grasslands. *Journal of Applied Ecology*, **24**, 743-758.

Bientema, A.J. & Visser, G.H. (1990) The effect of weather on time budgets and development of chicks of meadow birds. *Ardea*, **77**, 181-192.

Bieri, M., Schweizer, K., Christensen, K. & Daniel, O. (1989) The effect of metaldehyde and methiocarb slug pellets on *Lumbricus terrestris* Linne. In *Slugs and Snails in World Agriculture.* pp. 237-244. BCPC Mono No 41.

Bolger, T. & Curry, J.P (1980) Effects of cattle slurry on soil arthropods in grassland. *Pedobiologia*, **20**, 246-253.

Brassley, P. (1996) Silage in Britain 1880-1990: the delayed adoption of an innovation. *Agricultural History Review*, **44**, 61-82.

Brown, A.W.A. (1977) *Ecology of Pesticides*. Wiliey, New York.

Brown, V.K., Gibson, C.W.D. and Sterling, P.M. (1990) The mechanisms controlling insect diversity in calcareous grassland. In *Calcareous Grasslands - Ecology and Management* (eds. S.H. Hillier, D.W.H. Walton & D.A. Wells).

Browne, S.J., Vickery, J.A. & Chamberlain, D.E. (in press) Densities and population estimates of breeding Skylarks *(Alauda arvensis)* in Britain in 1997.

Büchs, W., Heimbach, E. & Czarnecki, E. (1989) Effects of slug baits on non-target carabid beetles. In *Slugs and Snails in World Agriculture,* pp. 245-252. BCPC Mono No 41.

Bunce, R.G.H., Carey, P., Howeard, D.C., Van de Poll, H.M., Roy, D., Hill, M.O. Wilson, P., Smart, S.M., Rothery, P., Metcalfe, J. & Duckworth, J. (1998) *Ecological factors controlling biodiversity in the British Countryside (ECOFACT). Module 6 - Understanding the causes of change in Biodiversity in Britain and England and Wales.* Institute of Terrestrial Ecology, Merlewood.

Brown, V.K. (1993) *Subterranean insect herbivores in grassland ecosystems.* 6th Australasian Conference on grassland Invertebrate Ecology. Hamilton, New Zealand.

Byers, R.A. & Jung, G.A. (1979) Insect populations on forage grasses: effect of nitrogen fertilizer and insecticides. *Envir. Entomol.*, **8**, 11-18.

Campbell, L.H., Avery, M.I., Donald, P., Evans, A.D., Green, R.H., & Wilson, J.D.(1997) *A review of the indirect effect of pesticides on birds.* Joint Nature Conservancy Council, Peterborough.

Chamberlain, D.E., Fuller, R.J., Shrubb, M., Bunce, R.G.H., Duckworth, J.C., Garthwaite, D.G., Impey, A.J. & Hart, A.D.M. (1999) The Effects of Agricultural Management on Farmland Birds. *British Trust for Ornithology Research Report 209.* British Trust for Ornithology, Thetford.

Chamberlain, D.E. & Gregory, R.D. (1999) Coarse and fine scale habitat associations of breeding skylarks *Alauda arvensis* in the UK. *Bird Study*, **46**, 34-47.

Clarke, J.H., Jones, N.E., Hill, D.A., & Tucker, G.M. (1997) The management of set-aside within a farm and its impact on birds. In *The 1997 Brighton Crop Protection Conference. Weeds*, Pp. 1170-1184. British Crop Protection Council, Farnham, Surrey.

Clements, R.O. (1981) *Some consequences of large and frequent pesticide applications to grassland* (ed. K.E. Lee) pp 393-396. Proc. 3rd Australian Conf. Grassl. Invert. Ecol., Adelaide.

Clements, R.O. (1994) *The importance of pests and diseases to agricultural grassland in England and Wales.* MAFF, London. (Restricted circulation).

Clements, R.O. & Cook, R. (1996) Pest damage to established grass in the UK. *Agricultural Zoology Reviews*, **7**, 157-179.

Conder, P. (1989) *The Wheatear.* Christopher Helm, London.

Cotton, D.C.F & Curry, J.P. (1980a) The effects of cattle and pig slurry fertilizers on earthworms (Oligochaeta, Lumbricidae) in grassland managed for silage production. *Pedobiologia*, **20**, 181-188.

Cotton, D.C.F & Curry, J.P. (1980b) The response of earthworm populations (Oligochaeta, Lumbricidae) to high applications of pig slurry. *Pedobiologia*, **20**, 189-196.

Coulsen, J.C. & Butterfield, J.E.L. (1985) The invertebrate communities of peat and upland grasslands in the north of England and some conservation implications. *Biological Conservation*, **34**, 197-225.

Courtney, A.D. (1985) Impact and control of docks in grassland. In *Weeds, pests and diseases of grasses and herbage legumes* (ed J.S. Brockman) pp 120-127. British Grassland Society Occasional Symposium No. 18.

Cramp, S. (1988) *Handbook of the Birds of the Middle East and North Africa.* Volume V. Oxford University Press, Oxford.

Cramp, S. & Perrins, C.M. (1994) *Handbook of the Birds of the Middle East and North Africa* Volume VIII. Oxford University Press, Oxford.

Cramp, S. & Simmons, K.E.L. (1983) *Handbook of the Birds of the Middle East and North Africa* Volume III. Oxford University Press, Oxford.

Cranswick, P.A., Waters, R.J., Musgrove, A.J. & Pollitt, M.S. (1997) *The Wetland Bird Survey 1995-96: Wildfowl and Wader Counts.* BTO/WWT/RSPB/JNCC, Slimbridge.

Crick, H.Q.P., Baillie, S.R., Balmer, D.E., Bashford, R.I., Beaven, L.P., Dudley, C., Glue, D.E., Gregory, R.D., Marchant, J.H., Peach, W.J., & Wilson, A.M. (1998) Breeding Birds in the Wider Countryside: their Conservation Status (1971-1995). *BTO Research Report*, **198**, British Trust for Ornithology, Thetford.

Crofts, A. & Jefferson, R.G. (eds) (1994) *The lowland grassland management handbook.* English Nature/The Wildlife Trusts. English Nature, Peterborough.

Cromack, H.T.C., Mudd, C.H. & Strickland, M.J. (1970) A comparison of types of lime and their frequency of application to grassland. *Experimental Husbandry*, **19**, 40-48.

Crooks, S.E. & Moxley, P.A. (1966) Study of a wintering lapwing population in North West Middlesex. *The London Bird Report for 1965* (ed F.H.Jones).

Cummins, R.P. & French, D.D. (1994) Floristic diversity, management and associated land use in British hedgerows. In *Hedgerow Management and Nature Conservation* (eds T.A.Watt & G.P. Buckley) pp 95-106. Wye College press, Wye.

Curry, J.P. (1970) The effects of different methods of new sward establishment and the effects of the herbicides paraquat and dalapon on the soil fauna. *Pedobiologia*, **10**, 329-361.

Curry, J.P. (1976) Some effects of animal manures on earthworms in grassland. *Pedobiologia*, **16**, 425-438.

Curry, J.P (1979) The arthropod fauna associated with cattle manure applied as slurry to grassland. *Proceedings of the Royal Irish Academy*, **79B**, 15-27.

Curry, J.P (1994). *Grassland Invertebrates*. Chapman and Hall, London.

Curry, J.P. & Tuohy, C.F. (1978) Studies on the epigeal microarthropod fauna of grassland swards managed for silage production. *Journal of Applied Ecology*, **15**, 727-741.

Curtis, L.F., Courtney, F.M. & Trudgill, S.T. (1976) *Soils in the British Isles*. Longman, London.

Dargie T.C. (1993). The Distribution of Lowland Wet Grassland. *English Nature Research Report*, **49**. English Nature, Peterborough.

Davies, B.N.K. (1973) The Hemiptera and Coleoptera of stinging nettle (Urtica dioica) in East Anglia. *Journal of Applied Ecology*, **10**, 213-237.

Davies, W. (1960) *The Grass Crop: Its development use and maintenance*. Second edition. Spon., London.

Dennis, P. & Fry, G.L.A. (1992). Filed margins: can they enhance natural enemy population densities and general arthropod diversity on farmland? *Agriculture, Ecosystems and the Environment*, **40**, 95-115.

Denno, R. F. (1994) Influence of habitat structure on planthoppers In: *Planthoppers: their Ecology and Management.* (eds R.F. Denno and T.J. Perfect) Chapman and Hall, London

Devon Wildlife Trust (1990) *Survey of Culm Grasslands in Torridge District.* Devon Wildlife Trust, Exeter.

Dibb, C. (1985) Problems and benefits of grass weeds. In *Weeds, pests and diseases of grasses and herbage legumes* (ed. J.S. Brockman) pp 112-119. British Grassland Society Occasional Symposium No. 18.

Dinden, D.L., Schwert, D.P., Moreau, J.P. & Theoret, L (1977) Earthworm communities and soil nutrient levels as affected by municipal wastewater irrigation. In *Soil organisms as Components of Ecosystems* (eds. U. Lohn & T. Persson) pp 284-290. Ecological Bulletins No 25 (Stockholm).

Dmowska, E. & Kozlowska, J. (1988) Communities of nematodes in soil treated with semi-liquid manure. *Pedobiologia*, **32**, 323-330.

Dodd, M.E., Silvertown, J., McConway, K., Potts, J. & Crawley, M. (1994) Application of the British National Vegetation Classification to the communities of the Park Grass Experiment through time. *Folia Geobotanica et Phytotaxonomica, Praha*, **29**, 321-334.

Dowdeswell, W.H. (1987) *Hedgerows and Verges*. Allen and Unwin, London

Drent, R. & Prins, H.H.T. (1987) The herbivore as a prisoner of its food supply. In *Disturbance in Grassland, Causes, Effects and Processes* (eds. J. van Andel, J.P. Bakker & R.W. Snaydon) *Geobaotany*, **10** 131-147

Drent, R. & Swierstra P. (1977) Goose flocks and food finding: field experiments with barnacle geese in winter. *Wildfowl*, **28**, 15-20

Dunn, E. (1994) Case studies of farming and birds in Europe: lowland wet grasslands in The Netherlands and Germany. *RSPB Studies in European Agriculture and Environmental Policy*, **10**. RSPB, The Lodge.

Duffey, E. (1975) The effects of human trampling on the fauna of grassland litter. *Biological Conservation*, 7, 255-274.

Duffey, E., Morris, M.G., Sheail, J., Ward, L.K., Wells, D.A. & Wells, T.C.E. (1974) *Grassland Ecology and Wildlife Management.* Chapman & Hall, London.

East, R. & Pottinger, R.P. (1983) Use of grazing animals to control insect pests of pasture. *New Zealand Entomologist*, 7, 352-359.

Edwards, C.A. (1965) Effects of pesticide residues on soil invertebrates and plants. In *Ecology and the Industrial Society,* pp 239-261. 5th Symposium of the British Ecological Society, Blackwell, Oxford.

Edwards, C.A. (1974) Some effects of insecticides on myriapod populations. In *Symposia of the Zoological Society of London* (ed. J.G. Blower) pp 645-655, Myriapoda, No 32.

Edwards, C.A. (1977) Investigations into the influence of agricultural practice on soil invertebrates. *Annals of Applied Biology*, **87**, 515-520.

Edwards, C.A. (1980) Interactions between agricultural practice and earthworms. In *Soil Biology as related to Land Use Practices* (ed. D.L. Dindal) pp 325-335. Proceedings of the 7th International Colloquium of Soil Zoology, Syracuse, New York.

Edwards, C.A. (1983) Earthworm ecology in cultivated soils. In *Earthworm Ecology* (ed. J.E. Satchell) pp. 123-137. Chapman and Hall, London.

Edwards, C.A. & Lofty, J.R. (1975) The influence of soil cultivation on soil animal populations. Progress in *Soil Zoology* (ed. J Vaneck), pp 399-407. Junk, The Hague.

Edwards, C.A. & Lofty, J.R. (1975) The invertebrate fauna of the Park Grass Plots. 1. Soil fauna, pp. 133-154, Part 2. *Rothamsted Experimental Station Annual Report for 1974.*

Edwards, C.A. & Lofty, J.R. (1977) *The Biology of Earthworms.* Chapman and Hall, London.

Edwards, C.A. & Lofty, J.R. (1982) Nitrogenous fertilizers and earthworm populations in agricultural soils. *Soil Biology and Biochemistry*, **14**, 515-521.

Edwards, C.A. & Thompson, A.R. (1973) *Pesticides and the soil fauna. Residue Reviews,* **45**, 1-79.

Edwards, C.A. & Thompson, A.R. (1975) Some effects of insecticides on predatory beetles. *Annals of Applied Biology*, **80**, 132-135.

Evans, A. (1997) The importance of mixed farming for seed-eating birds in the UK. In *Farming and birds in Europe: the Common Agricultural Policy and its implications for bird conservation*, (ed. D.J. Pain & M.W. Pienkowski) pp 331-357. Academic Press, London.

Eyers, B. (1989) Place for big bales in the current silage scene. In *Big Bale Silage,* pp 1.1 - 1.7. Proceedings of British Grassland Society Conference, February 1989. NAC Stoneleigh.

Feare, C. (1984) *The Starling*. Oxford University Press.

Feber, R.E., Smith, H. & Macdonald, D.W. (1996) The effects of management of uncropped edges of arable fields on butterfly abundance. *Journal of Applied Ecology,* **33**, 1191-1205.

Fenner, M. & Palmer, L. (1998) Grassland management to promote diversity: creation of a patchy sward by mowing and fertilizer regimes. *Field Studies,* **9**, 313-324.

Ferguson, C.M., Barratt, B.I.P. & Jones, P.A. (1988) Control of the grey field slug (*Deroceras reticulatum* (Müller)) by stock management prior to direct-drilled pasture establishment. *Journal Of Agricultural Science,* **111**, 443- 449.

Ferns, P.N., Green, G.H. & Round, P.D. (1979) Significance of the Somerset and Gwent Levels in Britain as a feeding areas for migrant Whimbrels *Numenius phaeopus. Biological Conservation,* **7**, 7-22.

Firbank, L.G., Carter, N., Darbyshire, J.F. & Potts, G.R. (eds) (1991) *The Ecology of Temperate Cereal Fields.* 32nd Symposium of The British Ecological Society. Blackwell Scientific Publications, Oxford.

Floate, K.D. (1998) Off-target effects of ivermectin on insects and dung degradation in southern Alberta, Canada. *Bulletin of Entomological Research,* **88**, 25-35.

Forbes, J.C. (1985) The impact and control of ragwort (*Senecio jacobaea* and *S. aquaticus*) in grassland. In *Weeds, pests and diseases of grasses and herbage legumes* (ed. J.S. Brockman) pp 147-154. British Grassland Society Occasional Symposium No. 18.

Forbes, T.J., Dibb, C., Green, J.O., Hopkins, A. & Peel, S. (1980) *Factors affecting the productivity of permanent grassland - a national farm study.* GRI/ADAS Permanent Pasture Group, Hurley.

Forster, L. (1989) Handling and storing of big bales. In *Big Bale Silage,* pp 8.1-8.4. Proceedings of British Grassland Society Conference, February 1989, NAC Stoneleigh.

Fox, C.J.S. (1964) Effects of five herbicides on the numbers of certain invertebrate animals in grassland soil. *Canadian Journal of Plant Science,* **44**, 405-409.

Frame, J., Baker, R.D. & Henderson, A.R. (1995) Advances in grassland technology over the past fifty years. In *Grassland into the 21st Century* (ed. G.E. Pollott) pp 31-63. British Grassland Society Symposium No. 29.

Fuller, R.J. (1996) Relationships between grazing and birds with particular reference to sheep in the British uplands. *BTO Research Report,* **164**. British Trust for Ornithology, Thetford.

Fuller, R.J. (1988) Wintering golden plovers in central Buckinghamshire: annual variation in numbers and distribution. *Buckinghamshire Bird Report 1998*, 4-8.

Fuller, R.J. (1994) Changes in breeding populations of curlews and lapwings in central Buckinghamshire, 1981-1990. *Buckinghamshire Bird Report 1994*, 11-16.

Fuller, R.J. & Gough, S.J. (in press) Changes in sheep numbers in Britain: implications for bird populations. *Biological Conservation.*

Fuller, R.J. & Glue, D.E. (1977) The breeding biology of the Stonechat and Whinchat. *Bird Study* **24**, 215-28.

Fuller, R.J., Gregory, R.D., Gibbons, D.W., Marchant, J.H., Wilson, J.D., Baillie, S.R., & Carter, N. (1995) Population declines and range contractions among lowland farmland birds in Britain. *Conservation Biology*, **9**, 1425-1441.

Fuller, R.J. & Lloyd, D. (1981) The distribution and habitats of wintering Golden Plovers in Britain, 1977-1978. *Bird Study*, **28**, 169-185.

Fuller, R.J., Reed, T.M., Buxton, N.E., Webb, A., Willimas, T.D. & Pienkowski, M.W. (1986) Populations of breeding waders Charadrii and their habitats on the crofting lands of the Outer Hebrides, Scotland. *Biological Conservation*, **37**, 333-361.

Fuller, R.J., Trevelyan, R.J. & Hudson, R.W. (1997) Landscape composition models for breeding bird populations in lowland English farmland over a 20 year period. *Ecography*, **20**, 295-307.

Fuller, R.J. & Youngman, R.E. (1979) The utilisation of farmland by Golden Plovers wintering in southern Britain, 1977-1978. *Bird Study*, **26**, 37-46.

Fuller, R.M. (1987) The changing extent and conservation interest of lowland grasslands in England and Wales: a review of grassland surveys 1930-84. *Biological Conservation*, **40**, 281-300.

Garthwaite D.G., Thomas M.R., Banham A.R. & De'ath A. (1998) Grassland and fodder crops in Great Britain 1997. *Pesticide Usage Survey Report,* **151**. MAFF Publications, London.

Gibbons, D.W., Reid, J.B. & Chapman, R.A. (1993) *The New Atlas of Breeding Birds in Britain and Ireland: 1988-1991*. Poyser, London.

Gibson, C.W.D. (1976) The importance of foodplants for the distribution and abundance of some Stenodemini (Hetroptera: Miridae) of limestone grassland. *Oecologia*, **25**, 55-76.

Gibson, C.W.D. (1998) South Somerset SSSIs. A study of neutral grassland succession. *English Nature Research Report Number 266*. English Nature, Peterborough.

Gibson, C.W.D., Hambler, C. & Brown, V.K.B. (1992) Changes in spider (Araneae) assemblages in relation to succession and grazing management. *Journal of Applied Ecology*, **29**, 132-142.

Gillings, S. & Fuller, R.J. (1998) Winter ecology of Golden Plovers and Lapwings: a review and consideration of extensive survey methods. *BTO Research Report.* British Trust for Ornithology, Thetford.

Gillings, S. & Fuller, R. J. (in press) Distribution and habitat preferences of skylarks *Alauda arvensis* wintering in Britain in 1997/98. *Bird Study.*

Grant, S.A., Barthram, G.T., Torvell, L., King, J. & Smith, H.K. (1983) Sward management, lamina turnover and tiller population density in continuously-stocked *Lolium perenne* - dominated swards. *Grass and Forage Science,* **38**, 333-344.

Green, J.O. (1982) *A sample survey of grassland in England and Wales, 1970-72.* GRI, Hurley.

Green, R.E. (1986) *The management of lowland wet grasslands for breeding waders.* Unpublished report RSPB, Sandy.

Green, R.E. (1988) Effects of environmental factors on the timing and success of breeding of common Snipe *Gallinage gallinago* (Aves: Scolopacidae). *Journal of Applied Ecology,* **25**, 79-93.

Green, R.E., Osborne, P.E., & Sears, E.J. (1994) The distribution of passerine birds in hedgerows during the breeding season in relation to characteristics of the hedgerow and adjacent farmland. *Journal of Applied Ecology*, **31**, 677-692.

Green , R.E. (1995) The decline of the Corncrake *Crex crex* continues. *Bird Study,* **42**, 66-75.

Green, R.E. & Cadbury, C.J. (1987) Breeding waders of lowland wet grasslands. *RSPB Conservation Review,* **1**, 10-13.

Green, R.E., Cadbury, C.J. & Williams, G. (1987) Floods threaten black-tailed godwits breeding at the Ouse Washes. *RSPB Conservation Review,* **1**, 14-16.

Green, R. & Griffiths, G.H. (1994) Use of preferred nesting habitat by Stone Curlews *Burhinus oedicnemus* in relation to vegetation structure. *Journal of Zoology,* **233**, 457-471.

Green, R.E. & Stowe, T.J. (1993) The decline of the Corncrake *Crex crex* in Britain and Ireland in relation to habitat change. *Journal of Applied Ecology,* **30**, 689-695.

Gregory, R.D. (1987) Comparative winter feeding ecology of Lapwings *Vanellus vanellus* and Golden Plovers *Pluvialis apricaria* on cereals and grasslands in the Lower Derwent Valley, North Yorkshire. *Bird Study,* **34**, 244-250.

Greig-Smith, P.W., Frampton, G.K. & Hardy, A.R. (eds) (1992) *Pesticides, Cereal Farming and The Environment: the Boxworth Project.* HMSO, London.

Grubb, P.J. (1977) The maintenance of species-richness in plant communities: the importance of the regeneration niche. *Biological Reviews,* **52**, 107-145.

Gyllenberg, G. (1969) The energy flow through *Chortippus parallelus* (Zett.) (Orthoptera) population on a meadow in Tvärminne, Finland. *Acta Zoologica Fennica*, **123**, 4-74.

Haggar, R.J., Standell, C.J. & Birnie, J.E. (1985) Occurrence, impact and control of weeds in newly sown leys. In *Weeds, pests and diseases of grasses and herbage legumes* (ed J.S. Brockman) pp 11-19. British Grassland Society Occasional Symposium No. 18.

Halley, R.J. & Soffe, R.J. (1988) Primrose McConnell's: *The Agricultural Notebook*, 18th Edition. Butterworths, London.

Halley, B.A., Vanden Heuvel, W.J.A., Wislocki, P.G. & Wardhaugh, K. (1993) Environmental impact of avermectin usage in livestock. In *Proceedings of an Invitational Workshop, Columbus* (eds R. Herd & L. Strong). *USA Veterinary Parasitology*, **48**, 109-125

Hassan, S.A., Albert, R., Bigler, F., Blaisinger, P., Bogenschütz, H., Boller, E., Brun, J., Chiverton, P., Edwards, P., Englert, W.D., Huang, P., Inglesfield, C., Naton, E., Oomen, P.A., Overmeer, W.P.J., Rieckmann, W., Samsøe-Petersen, L., Stäubli, A., Tuset, J.J., Viggiani, G., & Vanwetswinkel, G. (1987) Results of the third joint pesticide testing programme by the IOBC/WPRS-working group "Pesticides and Beneficial Organisms." *Journal of Applied Entomology*, **103**, 92-107.

Herbert, I.J., Heery, S. & Meredith, C.R.M. (1990) Distribution of breeding waders in relation to habitat features on the River Shannon callows at Shannon harbour, Ireland, 19887-89. *Irish Birds*, **4**, 203-215.

HMSO (1995) *Biodiversity: The UK Steering Group Report. Volume 2: Action Plans*. HMSO, London.

Hopkins, A. (1986) Botanical composition of permanent grassland in England and Wales in relation to soil, environment and management factors. *Grass and Forage Science,* **41**, 237-246.

Hopkins, A., Jones, E.L., Bowling, P.J. & Johnson, R.H. (1997) *Cultural methods of dock control in permanent pasture,* pp 39-40. Proceedings British Grassland Society Fifth Research Conference, Newton Abbot.

Hopkins, A. & Hopkins, J.J. (1994) UK grasslands now: agricultural production and nature conservation. In *Grassland Management and Nature Conservation* (ed. R.J. Haggar & S. Peel.) pp 10-19. British Grassland Society Occasional Symposium No. 28.

Hopkins, A., Gilbey, J., Dibb, C., Bowling, P.J. & Murray, P.J. (1990) Response of permanent and reseeded grassland to fertilizer nitrogen. 1. Herbage production and herbage quality. *Grass and Forage Science,* **45**, 43-55.

Hopkins, A. & Wainwright, J. (1989) Changes in botanical composition and agricultural management of enclosed grassland in upland areas of England and Wales, 1970-86, and some conservation implications. *Biological Conservation,* **47**, 219-235.

Hopkins, A. & Peel, S. (1985) Incidence of weeds in permanent grassland. In *Weeds, pests and diseases of grasses and herbage legumes,* (ed. J.S. Brockman) pp 93-103.. British Grassland Society Occasional Symposium No. 18.

Hopkins, A., Matkin, E.A., Ellis, J.A. & Peel, S. (1985). South-west England grassland survey 1983: 1. Age structure and sward composition of permanent and arable grassland and their relation to manageability, fertilizer nitrogen and other management features. *Grass and Forage Science,* **40**, 349-59.

Hotker H. (1991a) Waders breeding on wet grasslands in the countries of the European Community - a brief summary of current knowledge on population sizes and population trends. *Wader Study Group Bulletin*, **61** (Supplement), 50-55.

Hotker H. (Ed) (1991b) Waders breeding on wet grasslands. *Wader Study Group Bulletin*, **61** (Supplement).

Hudson, P.J. (1988) Spatial variations, patterns and management options in upland bird communities. In *Ecological Change in the Uplands* (eds M.B. Usher & D.B.A. Thompson) pp 381-397. Special Scientific Publication no. 7. British Ecological Society Blackwell Scientific Publications, Oxford.

Hudson, R, Tucker, G.M. & Fuller (1994) Lapwing *Vanellus vanellus* populations in relation to agricultural changes: a review. In *The ecology and conservation of Lapwings* Vanellus vanellus (eds. G.M. Tucker, S.M Davies & R.J. Fuller), pp 1-13. UK Nature Conservation No. 9, Joint Nature Conservation Committee, Peterborough.

Hutchinson, K.J. & King, K.L. (1980) The effects of sheep stocking level on invertebrate abundance, biomass and energy utilization in a temperate, sown grassland. *Journal of Applied Ecology*, **17**, 367-387.

Janssens, F., Peeters, A., Tallowin, J.R.B., Bakker, J.P., Bekker, R.M., Fillat, F. & Oomes, M.J.M. (1998) Relationship between soil chemical factors and grassland diversity. *Plant and Soil*, **202**, 69-78.

Jefferson R.G. & Grice P.V. (1998) The conservation of lowland wet grassland. In *European wet grassland: biodiversity, management and restoration* (ed. C.B. Joyce & P.M. Wade) pp 31-48. John Wiley, Chichester.

Jefferson R.G. & Robertson H.J. (1996) Lowland grassland: wildlife value and conservation status. *English Nature Research Report*, **169**. English Nature, Peterborough.

Jensen, A. (1985) The effect of cattle and sheep grazing on salt marsh vegetation at skallingen, Denmark. *Vegetatio*, **60**, 37-48.

Jones, L.L.I. (1967) Studies on Hill Land in Wales. *Technical Bulletin of Welsh Plant Breeding Station* No 2. WPBS, Aberystwyth.

Joschko, M, Diestel, H. & Larink, O. (1989) Assessment of earthworm burrowing efficiency in compacted soil with a combination of morphological and soil physical measurements. *Biol. Fertil. Soils*, **8**, 191-196.

Kegel, B. (1989) Laboratory experiments on the side effects of selected herbicides and insecticides on the larvae of three sympatric Poecilus-species (Col., Carabidae). *Journal of Applied Entomology*, **108**, 144-155.

Kiehl, K., Eischeid, I.M., Gettner, S. & Walter, J. (1996) Impact of different sheep grazing intensities on salt marsh vegetation in northern Germany. *Journal of Vegetation Science*, **7**, 180-189.

King, K.L. & Hutchinson, K.J. (1976) The effects of sheep stocking intensity on the abundance and distribution of mesofauna in pastures. *Journal of Applied Ecology*, **13**, 41-55.

Kirby, P. (1992) Habitat Management for Invertebrates: A Practical Handbook. RSPB, JNCC, National Power.

Kirkham, F.W., Mountford, J.O. & Wilkins, R.J. (1996). The effects of nitrogen, potassium and phosphorus addition on the vegetation of a Somerset peat moor under cutting management. *Journal of Applied Ecology*, **33**, 1013-1029.

Klinner, B. (1991) Breeding waders on wet grasslands (inland sites) in West Germany: recent data. *Wader Study Group Bulletin*, **61** Suppl., 22-25.

Kretzschmar, A. (1991) Burrowing ability of the earthworm *Aporrectodea longa* limited by soil compaction and water potential. *Biol. Fertil. Soils*, **11**, 48-51.

Lack, P. (1986) *The Atlas of Wintering Birds in Britain and Ireland*. Poyser, Carlton.

Lack, P. (1992) *Birds on Lowland Farms*. HMSO, London.

Lane. S.J. (1994) *Selection of feeding sites by overwintering dark-bellied brent geese* Branta bernicla bernicla (L.) Unpublished PhD thesis, University of East Anglia Norwich.

Lewis, G.C. & Hopkins, A. (in press) Weeds, pests and diseases of grassland. In *Grass: Its Production and Utilization* (ed. A. Hopkins), 3rd Edition. Blackwell Science, Oxford.

Linzell, B.S. & Madge, D.S. (1986) Effects of pesticides and fertilizer on invertebrate populations of grass and wheat plots in Kent in relation to productivity and yield. *Grass and Forage Science*, **41**, 159-174.

Lister, M.D. (1964) The Lapwing habitat enquiry, 1960-61. *Bird Study*, **11**, 128-147.

Lock, L. (1998) *Review of farmland birds and lowland pastoral systems in SW England*. Royal Society for the Protection of Birds, Exeter.

Lovegrove, R., Willimas, G. & Williams, I. (1994) *Birds in Wales*. Poyser, London.

Lovegrove, R., Shrubb, M. & Williams, I. (1995) *Silent fields: the Current Status of Farmland Birds in Wales*. Royal Society for the Protection of Birds Newtown, Wales.

MacDonald, D.W. & Johnson, P.J. (1995) The relationship between bird distribution and the botanical and structural characteristics of hedges. *Journal of Applied Ecology*, **32**, 492-505.

Madsen, M., Nielsen, B.O., Holter, P., Pedersen, O.C., Jespersen, J.B., Jensen, K.M., Nansen, P., & Gronvold, J. (1990) Treating cattle with ivermectin: Effects on the fauna and decomposition of dung pats. *Journal of Applied Ecology*, **27**, 1-15.

MAFF (1987) *June 1988 Agricultural and Horticultural Census: England and Wales, Regions and Counties*. Ministry of Agriculture Fisheries and Food, Guildford.

MAFF (Ministry of Agriculture, Fisheries and Food), The Scottish Office Agriculture, Environment and Fisheries Department, Department of Agriculture for Northern Ireland, Welsh Office. (1997) *The Digest of Agricultural Census Statistics, United Kingdom*. The Stationery Office, London.

MAFF (Ministry of Agriculture, Fisheries and Food), FMA (Fertilizer Manufacturers Association) and The Scottish Office Agriculture (1996) *The British Survey of Fertilizer practice. Fertilizer Use on Farm Crop for Crop Year 1996*. The Stationery Office, London.

Marchant, J.H., Hudson, R., Carter, S.P. & Whittingdon, P. (1992) *Population Trends in British Breeding Birds*. British Trust for Ornithology, Thetford.

Marrs, R.H. (1993) Soil fertility and nature conservation in Europe: Theoretical considerations and practical management solutions. *Advances in Ecological Research*, **24**, 241-300.

Marshall, E J P & Hopkins, A. (1990). Plant species composition and dispersal in agricultural land. In *Species Dispersal in Agricultural Habitats* (eds R.G.H. Bunce & D.C. Howard) pp. 98-116. Belhaven Press.

Marshall, V.G. (1977) *Effects of manures and fertilizers on soil fauna: A review*. Commonwealth Bureau of Soils, Special Publication No. 3, pp 79. Farnham Royal: Commonwealth Agricultural Bureau.

Maudsley, M.J., West, T., Rowcliffe, H. & Marshall, E.J.P. (1997) Spatial variability in plant and insect (Heteroptera) communities in hedgerows in Great Britain. In *Species Dispersal and Land Use Processes* (ed. A. Cooper & J. Power) pp. 229-236. IALE(UK).

Mayhew, P. & Houston, D. (1989) Feeding site selection by Wigeon *Anas penelope* in relation to water. *Ibis*, **131**, 1-8.

McCracken, D.I. (1993) The potential for avermectins to affect wildlife. *Veterinary Parasitology*, **48**, 273-280.

McCracken, D.I. (1995) Short note on potential environmental problems of cattle and sheep anthelmintics. *Extensive Farming Systems Unit Briefing Paper* 7. Joint nature Conservation Committee, Paisley.

McCracken, D.I., Foster, G.N., & Kelly, A. (1995) Factors affecting the size of leatherjacket (Diptera: Tipulidae) populations in pastures in the west of Scotland. *Applied Soil Ecology,* **2**, 203-213.

McCracken, D.I. & Foster, G.N. (1992) The effect of Ivermectin on the invertebrate fauna associated with cow dung. *JNCC Report No. 112.* Joint Nature Conservation Committee, Peterborough.

McCracken, D.I. & Foster, G.N. (1993) The effect of ivermectin on the invertebrate fauna associated with cow dung. *Environmental Toxicology and Chemistry*, **12**, 73-84.

McNeill, S. (1973) The dynamics of a population of Leptoterna dolabrata (Heteroptera: Miridae) in relation to its food resources. *Journal of Animal Ecology*, **42**, 495-507.

Miller, N.C.E. (1971) *The Biology of the Heteroptera*. E.W. Classey, Hampton.

Milsom, T.P. (1994) Trends in habitat selection by Lapwings during the non-breeding season. In *The Ecology and Conservation of Lapwings* (eds. G.M. Tucker, S.M. Davies & R.J. Fuller) pp 45-46. Joint Nature Conservation Committee, Peterborough.

Milson, T.P., Holditch, R.S. & Rochard, J.B.A. (1985) Diurnal use of an airfield and adjacent agricultural habitats by lapwings *Vanellus vanellus*. *Journal of Applied Ecology*, **22**, 313-326.

Milsom, T.P., Ennis, D.C., Haskell, D.J. Langton, S.D. & McKay, H.V. (1998) Design of grassland feeding areas for waders during winter: The relative importance of sward landscape factors and human disturbance. *Biological Conservation*, **84**, 119-129.

Ministry of Agriculture, Fisheries and Food (1979) *Slugs and Snails*. Ministry of Agriculture, Fisheries and Food, advisory leaflet No. 115. HMSO, London.

Moreby, S.J. (1994) The influence of field boundary structure on heteropteran densities within adjacent cereal fields. In *Field margins: integrating agriculture and conservation* (ed. N. Boatman) pp 117-121. Proceedings of a symposium held at the University of Warwick, Coventry, 18-20 April 1994. BCPC, Farnham, UK.

Morris, M.G. (1971) Differences between the invertebrate faunas of grazed and ungrazed chalk grassland. IV. Abundance and diversity of Homoptera: Auchenorrhynca. *Journal of Applied Ecology*, **8**, 37-52.

Morris, M.G. (1973) The effects of seasonal grazing on the Heteroptera and Auchenorrhynca (Hemiptera) of chalk grassland. *Journal of Applied Ecology*, **10**, 761-780.

Morris, M.G. (1979) Responses of grassland invertebrates to management by cutting. II. Heteroptera. *Journal of Applied Ecology*, **16**, 417-432.

Morris, M.G. (1981) Responses of grassland invertebrates to management by cutting. III. Adverse effects on Auchenorrhynca. *Journal of Applied Ecology*, **18**, 107-123.

Morris, M.G. (1990a) The effects of management on the invertebrate community of calcareous grassland. In *Calcareous Grasslands - Ecology and Management* (eds. S.H. Hillier, D.W.H. Walton and D.A. Wells).

Morris, M.G. (1990b) The Hemiptera of two sown calcareous grasslands. II. Differences between treatments. *Journal of Applied Ecology*, **27**, 379-393.

Morris, M.G. & Lakhani, K.H. (1979) Responses of grassland invertebrates to management by cutting. I. Species diversity of Hemiptera. *Journal of Applied Ecology*, **16**, 77-98.

Morris, M.G. & Rispin, W.E. (1987) Abundance and diversity of the coleopterous fauna of a calcareous grassland under different cutting regimes. *Journal of Applied Ecology*, **24**, 451-465.

Morris, M.G. & Rispin, W.E. (1988) A beetle fauna of oolitic limestone grassland, and the responses of species to conservation management by different cutting regimes. *Biological Conservation*, **43**, 87-105.

Mountford, J.O., Lakhani, K.H. & Kirkham, F.W. (1993) Experimental assessment of the effects of nitrogen addition under hay-cutting and aftermath grazing on the vegetation of meadows on a Somerset peat moor. *Journal of Applied Ecology,* **30**, 321-332.

Mountford, J.O., Tallowin, J.R.B., Kirkham, F.W. & Lakhani, K.H. (1994) Effects of inorganic fertilizers in flower-rich hay meadows on the Somerset Levels. In *Grassland Management and Nature Conservation* (eds R.J. Haggar & S. Peel) pp 74-85. British Grassland Society Occasional Symposium No. 28.

Morris, D.L. & Webb, N.R. (1987) The importance of field margins for the conservation of insects. In *Field Margins* (eds M.J. Way & P.W. Greig-Smith) pp 53-65. BCPC Monograph No 35.

Morris, M.G. (1992) Responses of auchenorrhyncha (Homoptera) to fertilizer and liming treatments at Park Grass, Rothamsted. *Agric. Ecosys. Envir.*, **41**, 263-283.

Mulkern, G.B. (1967) Food selection by grasshoppers. *Annual Review of Entomology*, **12**, 59-78.

Murton, R.K. (1965) *The Woodpigeon*. Collins, London

Nairn, R.G.W., Herbert, I.J. & Heery, S. (1988) Breeding waders and other wet grassland birds of the Shannon Callows, Ireland. *Irish Birds*, **3**, 521-537.

NCC (Nature Conservancy Council) (1989) *Guidelines for selection of biological SSSIs*. Nature Conservancy Council, Peterborough.

Neale, S. (1996) Modelling earthworm communities. *Elm Farm Research Centre Bulletin*, **26**, 9-10.

Norris, K., Brindley, E.A., Cook, T., Babbs, S., Forster Brown, C. & Yaxley, R. () Is the density of Redshank *Tringa totanus* nesting on saltmarshes in Great Britain declining due to changes in grazing management? *Journal of Applied Ecology*, **35**, 621-634.

North, J. (1990) Future agricultural land use patterns. In *Agriculture in Britain: changing pressures and policies* (ed. D. Britton) pp 69-93. CAB, Wallingford.

Nuutinen, V., Pitkanen, J., Kuusela, E., Widbom, T. & Lohilahti, H. (1998) Spatial variation of an earthworm community related to soil properties and yield in a grass-clover field. *Appl. Soil. Ecol.*, **8**, 85-94.

O'Brien, M. & Self, M. (1994) Changes in number of breeding waders on lowland wet grasslands in the UK. *RSPB Conservation Review*, **8**, 38-44.

O'Connor, R.J. & Shrubb, M. (1986) *Farming and birds*. Cambridge University Press, Cambridge.

O'Connor, R.J. (1987) Environmental interests of field margins for birds. In *Field Margins* (eds M.J. Way & P.W. Greig-Smith) pp 35-48. BCPC Monograph No 35.

O'Riordan, T. (1985) Halvergate: the politics of policy change. In *Countryside Planning Yearbook*, **6**, 101-106. Geobooks, Norwich.

Orr, R.J., Parsons, A.J., Treacher, T.T. & Penning, P.D. (1988) Seasonal patterns of grass production under cutting or continuous stocking managements. *Grass and Forage Science*, **43**, 199-207.

Owen, M. (1971) The selection of feeding sites by white-fronted geese in winter. *Journal of Applied Ecology*, **8**, 905-917.

Owen, M. (1975) Cutting and fertilising grassland for winter goose management. *Journal of Wildlife Management*, **39**, 163-167.

Owen, M. (1975) An assessment of faecal analysis technique in waterfowl feeding studies. *Journal of Wildlife Management*, **31**, 271-243.

Owen, M. (1977) The role of wildfowl refuges on agricultural land in lessening the conflict between farmers and geese in Britain. *Biological Conservation*, **11**, 209-222.

Owen, M. & Cadbury, C.J. (1975) The ecology and mortality of swans at the Ouse Washes. *Wildfowl*, **26**, 31-42.

Owen, M. & Thomas, G.J. (1979) The feeding ecology and conservation of Wigeon wintering at the Ouse Washes, England. *Journal of Applied Ecology*, **16**, 795-809.

Pain, D.J., Hill, D. & McCracken, D.I. (1997) Impact of agricultural intensification of pastoral systems on bird distributions in Britain 1970-1990. *Agriculture, Ecosystems & Environment*, **64**, 19-32.

Parish, T., Lakhani, K.H., & Sparks, T.H. (1994) Modelling the relationship between bird population variables and hedgerow and other field margin attributes. I. Species richness of winter, summer and breeding birds. *Journal of Applied Ecology*, **31**, 764-775.

Pallant, D. (1972) The food of the grey field slug *Agriolimax reticulatus* (Mull.) on grassland. *Journal of Animal Ecology* **41**, 761-769.

Percival, S.M. (1993) The effects of reseeding, fertilizer application and disturbance on the use of grasslands by barnacle geese and the implications for refuge management. *Journal of Applied Ecology*, **30**, 437-443.

Porley, R.D. & Ulf-Hansen, P.F. (1991) *Unimproved neutral grassland in Dorset: survey and conservation. Proceedings of the Dorset Natural History and Archaeological Society,* **113**, 161-165.

Potts, G.R. (1986) *The Partridge. Pesticides, Predation and Conservation.* Collins, London.

Prestidge, R.A. (1982) The influence of nitrogenous fertilizer on the grassland Auchenorrhyncha (Homoptera). *Journal of Applied Ecology*, **19**, 735-749.

Purvis, G. & Curry, J.P. (1981) The influence of sward management on foliage arthropod communities in a ley grassland. *Journal of Applied Ecology*, **18**, 711-725.

Redfern, C.P.F. (1982) Lapwing nest sites and chick mobility in relation to habitat. *Bird Study*, **29**, 201-208.

Rees, E.C. (1990) Bewick's swans: their feeding ecology and coexistence with other grazing anatidae. *Journal of Applied Ecology*, **27**, 939-951.

Rees, C.E., Kirby, J.S., & Gilburn, A. (1997) Site selection by swans wintering in Britain and Ireland; the importance of habitat and geographic location. *Ibis*, **139**, 337-352.

Richards, I.R. & Wolton, K.M. (1976) The spatial distribution of excreta under intensive cattle grazing. *Journal of the British Grassland Society*, **31**, 89-92.

Riddington, R., Hassall, M. & Lane, S.J. (1997) The influence of interactions between food quality and quantity in selection of grass swards by brent geese *Branta b. bernicla. Biological Conservation*, **78**, 239-245.

Rjinsdorp, A.D. (1986) Winter ecology and food of Wigeon in inland pasture areas in the Netherlands. *Ardea*, **74**, 121-128.

Rodwell J.S. (1991) *British Plant Communities. Volume 2. Mires and heaths.* Cambridge University Press, Cambridge.

Rodwell, J.S. (1992) *British Plant Communities*. Volume 3. Grasslands and montane communities. Cambridge University Press, Cambridge.

Sanderson, R.A. (1993) Factors affecting the Hemiptera of naturally colonised derelict land in North West England. *Entomologist*, **112**, 10-16.

SAS Institute (1996) *SAS/STAT Users Guide*. Version 6.1. SAS Institute Inc., Cary, North Carolina.

Satchell, J.E. (1955) Some aspects of earthworm ecology. In *Soil Zoology* (ed. D.K. Kevan McE), pp 180-201. Butterworths, London.

Schlapfer, A. (1988) Population studies of the Skylark *Alauda arvensis* in an area of intensive agriculture. *Orn. Beobachter*, **85**, 309-371.

Scholefield, D., Garwood, E.A. & Titchen, N.M. (1988) The potential of management practices for reducing losses of nitrogen from grazed pastures. In *Nitrogen Efficiency in Agricultural Soils* (eds. D.S. Jenkinson & K.A. Smith) pp 220-230. Elsevier Applied Science, London.

Schon, M. (1999) On the significance of micro-structures in arable land: does the Skylark (*Alauda arvensis*) show a preference for places with stunted growth? *Journal fur Ornithologie*, **140**, 87-91

Scullion, J. & Ramshaw, G.A. (1987) Effects of manurial treatments on earthworm activity in grassland. *Biological Agriculture and Horticulture*, **4**, 271-281.

Sedlacek, J.D., Barrett, G.W. & Shaw, D.R. (1988) Effects of nutrient enrichment on the Auchenorrhyncha (Homoptera) in contrasting grassland communities. *J. Appl. Ecol.*, **25**, 537-550.

Self, M., O'Brien, M. & Hirons, G. (1994) Hydrological management for waterfowl on RSPB lowland wet grassland reserves. *RSPB Conservation Review*, **8**, 45-56.

Sharrock, J.T.R. (1976) *The Atlas of Breeding Birds in Britain and Ireland*. Poyser, Berkhamsted.

Sheals, J.G. (1956) Soil population studies. 1. The effects of cultivation and treatment with insecticides. *Bulletin of Entomological Research*, **47**, 803-822.

Shrubb, M. (1990) Effects of agricultural change on nesting Lapwing *V. vanellus*. *Bird Study*, **37**, 115-127.

Shrubb, M. & Lack, P.C. (1991) Effects of agricultural change on nesting Lapwings *Vanellus vanellus* in England and Wales. *Bird Study*, **37**, 115-127.

Shrubb, M. & Lack, P.C. (1994) Breeding distribution and abundance of Lapwings in England and Wales in 1987. In *The ecology and conservation of Lapwings* (eds G.M. Tucker, S.M. Davies & R.J. Fuller) pp 34-36. JNCC, Peterborough.

Siepel, H. (1990) The influence of management on food size in the menu of insectivorous animals. In *Experimental and Applied Entomology* (eds. M.J. Sommeijer & J. van der Blom). Nederlandse Entomologische Vereniging, Amsterdam.

Siriwardena, G.M., Baillie, S.R., Buckland, S.T., Fewster, R.M., Marchant, J.H. & Wilson, J.D. (1998) Trends in the abundance of farmland birds: a comparison of smoothed Common Birds Census Indices. *Journal of Applied Ecology*, **35**, 24-43.

Skinner, R.J. (1997) *Lime - who needs it?* Grass Farmer. The British Grassland Society, Reading, UK.

Skinner, R.J., Church, B.M. & Kershaw, C.D. (1992) Recent trends in soil pH and nutrient status in England and Wales. *Soil Use and Management*, **8**, 16-20.

Smith, H. & MacDonald, D.W. (1992) The impacts of mowing and sowing on weed populations and species richness in field margin set-aside. In: *Set-aside* (ed. J. Clarke). BCPC Monograph No. 50. BCPC Publications, Farnham.

Smith, H., Feber, R.E., Johnson, P., McCallum, K., Younes, M. & MacDonald, D.W. (1993) *The Conservation Management of Arable Field Margins*. English Nature Science No. 18. English Nature, Peterborough.

Smith, K.W. (1983) The status and distribution of waders breeding on wet lowland grasslands in England and Wales. *Bird Study*, **30**, 177-192.

Smith, R.S. (1994) Effects of fertilizers on plant species composition and conservation interest of UK grassland. In *Grassland Management and Nature Conservation* (ed. R.J. Haggar & S. Peel) pp 64-73. *British Grassland Society Occasional Symposium* No. 28.

Smith, R.S., Pullan, S. & Sheil, R.S. (1996) Seed shed in the making of hay from mesotrophic grassland in a field in northern England: effects of hay cut date, grazing and fertilizer in a split-split-plot experiment. *Journal of Applied Ecology*, **33**, 833-841.

Smith, R.S. & Jones, L. (1991) The phenology of mesotrophic grassland in the Pennine Dales, northern England: historic hay cutting dates, vegetation variation and plant species phenologies. *Journal of Applied Ecology*, **28**, 42-59.

Snow, B. & Snow D. (1988) *Birds and Berries*. T & AD Poyser, Calton.

Southwood, T.R.E. & van Emden, H.F. (1967) A comparison of the fauna of cut and uncut grasslands. *Zeitschrift fur Angewandte Entomologie*, **60**, 188-198.

Southwood, T.R.E. & Leston, D. (1959) *Land and Water Bugs of the British Isles*. Frederick Warne, London.

Southwood, T.R.E., Brown, V.K. & Reader, P.M. (1979) The relationships of plant and insect diversities in succession. *Biological Journal of the Linnean Society*, **12**, 327-348.

Sparks, T.H. & Martin, T. (1999) Yields of hawthorn *Crataegus monogyna* berries under different hedgerow management. *Agriculture, Ecosystems & Environment*, **72**, 107-110.

Standen, V. (1984) Production and diversity of enchytraeids, earthworms and plants in fertilized hay meadow plots. *Journal of Applied Ecology*, **21**, 293-312.

Stowe, T.J. & Hudson, A.V. (1988) Corncrake studies in the Western Isles. *RSPB Conservation Review*, **2**, 38-42.

Strong, D.W., Lawton, J.H. & Southwood, T.R.E. (1984) *Insects on Plants. Community patterns and mechanisms*. Blackwell.

Strong, L. & Wall, R. (1994) Effects of ivermectin and moxidectin on the insects of cattle dung. *Bulletin of Entomological Research*, **84**, 403-409.

Strong, L., Wall, R., Woolford, A. & Djeddour, D. (1996) The effect of faecally excreted ivermectin and fenbendazole on the insect colonisation of cattle dung following the oral administration of sustained-release boluses. *Veterinary Parasitology*, **62**, 253-266.

Summers, R.W. & Critchley, C.N.R. (1990) Use of grassland and field selection by brent geese *Branta bernicla*. *Journal of Applied Ecology*, **27**, 834-846.

Tallowin, J.R.B. (1998) *Use and Effects of Lime Application on Neutral, Acidic and Marshy Grasslands in Britain.* Contract review for Countryside Council for Wales, English Nature, Scottish Natural Heritage and the Joint Nature Conservancy Council. Contract No. FC 73-01-185.

Tallowin, J.R.B. (1981) An interpretation of tiller number changes under grazing. In *Plant Physiology and Herbage Production* (ed C.E. Wright) pp 77-80. British Grassland Society Occasional Symposium No 13.

Tallowin, J.R.B. & Jefferson, R.G. (In press) Hay production from lowland semi-natural grasslands: a review of implications for livestock systems. *Grass and Forage Science.*

Tallowin, J.R.B. & Mountford J.O. (1997) Lowland Wet Grasslands in ESAs. In *Grassland management in the ESAs* (ed. R.D. Sheldrick) pp 100-111. British Grassland Society Occasional Symposium No 32.

Tallowin, J.R.B., Brookman, S.K.E. & Santos, G.L. (1995) Leaf growth and utilization in four grass species under steady state continuous grazing. *Journal of Agricultural Science,* **124**, 403-417. Cambridge.

Tallowin, J.R.B. & Brookman, S.K.E. (1996) The impact of differences in nitrogen content, nitrogen utilization and loss from laminae on competition between four grass species in an old pasture. *Journal of Agricultural Science,* **126**, 25-35.

Tallowin, J.R.B., Kirkham, F.W., Brookman, S.K.E. & Patefield, M. (1990). Response of an old pasture to applied nitrogen under steady-state continuous grazing. *Journal of Agricultural Science,* **115**, 179-194.

Tallowin, J.R.B., Williams, J.H.H. & Kirkham, F.W. (1989). Some consequences of imposing different continuous grazing pressures in the spring on tiller demography and leaf growth. *Journal of Agricultural Science,* **112**, 115-122.

Tallowin, J.R.B., Williams, J.H.H. & Large, R.V. (1986). Some consequences of imposing different continuous grazing pressures in the spring on sward morphology, herbage quality and the performance of young beef cattle. *Journal of Agricultural Science,* **106**, 129-139. Cambridge.

Tansley, A.G. (1939) *The British Islands and their Vegetation.* Cambridge University Press, Cambridge.

Taylor, J.A. (1985) Bracken encroachment rates in Britain. *Soil Use and Management*, **1**, 53-60.

Thom, V.M. (1986) *Birds in Scotland.* Calton, Poyser.

Thomas, G.J. (1980) The ecology of breeding waterfowl at the Ouse Washes, England. *Wildfowl,* **31**, 73-88.

Thomas, G.J. (1982) Autumn and winter feeding ecology of waterfowl at the Ouse Washes, England. *Journal of the Zoological Society of London*, **197**, 131-72.

Thomas, M.R. & Garthwaite, D.G. (1994) Grassland and fodder crops in Great Britain 1993. *Pesticide Usage Survey Report,* **119**. MAFF Publications, London.

Thompson, A.R. & Gore, F.L. (1972) Toxicity of twenty-nine insecticides to *Folsomia candida*: Laboratory studies. *Journal of Economic Entomology*, **69**, 1255-1260.

Townsend, D.J. (1981) The importance of field feeding to the survival of wintering male and female Curlews Numenius arquata in the Tees estuary. In *Feeding and Survival Strategies of Estuarine Organisms* (eds N.V. Jones & W.J. Wolff) pp 261-273. Plenum Press, New York.

Trafford, B.D. (1977) Recent progress in field drainage: part 1. *Journal of the Royal Agricultural Society of England*, **138**, 27-42.

Trafford, B.D. (1970) Field drainage. *Journal of the Royal Agricultural Society of England*, **131**, 129-152.

Tucker, G.M. (1992) Effects of agricultural practices on field use by invertebrate-feeding birds in winter. *Journal of Applied Ecology*, **29**, 779-790.

Tucker, G.M. & Heath, M.F. (1994) *Birds in Europe: their conservation status*. BirdLife International, Cambridge.

Tyler, G., Green, R.E. & Casey, C. (1998) Survival and behaviour of Corncrake *Crex crex* chicks during the mowing of agricultural grassland. *Bird Study*, **45**, 35-50.

Tyson, K.C., Garwood, E.A., Armstrong, A.C. & Scholefield, D. (1992) Effects of field drainage on the growth of herbage and the liveweight gain of grazing beef cattle. *Grass and Forage Science*, **47**, 290-301.

Unwin, R.J. & Lewis, S. (1986) The effect upon earthworms of very large applications of pig slurry to grassland. *Agricultural Wastes*, **16**, 67-73.

Van Breeman, N. Mulder, J. & Driscoll, C.T. (1985) Acidification and alkalinization of soils. *Plant Soil*, **75**, 283-308.

Van Dijk, G. (1991) The status of semi-natural grasslands in Europe. In *The Conservation of Lowland Dry Grassland Birds in Europe* (eds P. Goriup, L.A. Batten & J.A. Norton) pp 15-36. Joint Nature Conservation Committee, Peterborough.

Van Wingerden, W.K.R.E., Vankreveld, A.R. & Bongers, W. (1992) Analysis of species composition and abundance of grasshoppers (Orth, Acrididae) in natural and fertilized grasslands. *J. Appl. Ent.*, **113**, 138-152.

Vickery, J.A., Sutherland, W.J. & Lane, S.J. (1994) The management of grass pastures for brent geese. *Journal of Applied Ecology*, **31**, 282-290.

Vickery, J.A., Sutherland, W.J., O'Brien, M., Watkinson, A.R. & Yallop, A. (1997) Managing coastal grazing marshes for breeding waders and overwintering geese: is there a conflict? *Biological Conservation*, **79**, 23-34.

Vickery, J.A. & Gill, J.A. (1999) Managing grassland for wild geese: a review. *Biological Conservation*.

Volkl, W., Zwolfer, H., Romstock-Volkl, M. & Schmelzer, C. (1993) Habitat management in calcareous grasslands: effects on the insect community developing in flower heads of *Cynarea*. *Journal of Applied Ecology*, **30**, 307-315.

Waite, R.K. (1984) Winter habitat selection and foraging behaviour in sympatric corvids. *Ornis Scandinavica*, **15**, 55-62.

Wakeham-Dawson, A., Szoszkiewicz, K., Stern, K. & Aebischer, N.J. (1999) Breeding Skylark *Alauda arvensis* on Environmentally Sensitive Area arable reversion grass in southern England: survey-based and experimental determination of density. *Journal of Applied Ecology*, **35**, 635-648.

Ward, D. (1994) Management of lowland wet grassland for breeding waders. *British Wildlife*, **6**, 89-98.

Wardhaugh, K.G., Mahon, R.J., Axelsen, A., Rowland, M.W. & Wanjura, W. (1993) Effects of ivermectin residues in sheep dung on the development and survival of the bug fly *Musca vetustissima* and a scarabaeine dung beetle *Euniticellus fulvus*. *Veterinary Parasitology*, **48**, 139-157.

Warren, R.G. & Johnston, A.E. (1964) The Park Grass Experiment. *Rothamsted Experimental Station Report for 1963*. 240-262.

Whitehead, R. (ed) (1998) *The UK pesticide guide*. CAB International/British Crop Protection Council.

Williams, E.D. (1978) *Botanical composition of the Park Grass Plots at Rothamsted*. Rothamsted Experimental Station, Harpenden.

Williams, G. & Bowers, J.K. (1987) Land drainage and birds in England and Wales. *Biological Conservation*, **89**, 93-106.

Wilman, D. & Derrick, R.W. (1994) Concentration and availability to sheep of N, P, K, Ca, Mg and Na in chickweed, dandelion, dock, ribwort and spurrey, compared with perennial ryegrass. *Journal of Agricultural Science*, **122**, 217-223.

Wilson, J.D., Arroyo, B.E., & Clark, S.C. (1996a) *The diet of bird species of lowland farmland: a literature review*. Unpublished report by BBSRC-NERC for DoE, JNCC & EN.

Wilson, J.D., Evans, J., Browne, S.J., & King, J.R. (1997) Territory distribution and breeding success of Skylarks *Alauda arvensis* on organic and intensive farmland in southern England. *Journal of Applied Ecology*, **34**, 1462-1478.

Wilson, J.D., Taylor, R. & Muirhead, L.B. (1996b) Field use by farmland birds in winter: an analysis of field type preferences using resampling methods. *Bird Study*, **43**, 320-332.

Wilson, R.K. & Collins, D.P. (1980) Silage making with old permanent pasture grasses. *Food and Farm Research*, 124-125.

Zajonc, I. (1975) Variations in meadow associations caused by the influence of nitrogen fertilizers and liquid-manure irrigation. In *Progress in Soil Zoology* (ed. J. Vanek) pp 497-503, Proceedings of the 5th International Colloquium of Soil Zoology. Junk, The Hague.

	Species	Highest probability of occurrence	Farming landscapes which differ by <10%
	Barn Owl	A	A
	Corn Bunting	A	A
	Hobby	A	A
A	Montagu's Harrier	A	A
R	Red-legged Partridge	A	A
A	Sedge Warbler	A	A
B	Turtle Dove	A	A
L	Grey Partridge	A	AM
E	Pheasant	A	AM
	Skylark	A	AM
	Whitethroat	A	AM
	Cirl Bunting	M	AM
	Yellow Wagtail	A	AM
	Grasshopper Warbler	M	AM
	Greenfinch	M	AM
	Linnet	M	AM
	Quail	M	AM
	Stock Dove	M	AM
	Swift	M	AM
M	Tree Sparrow	M	AM
I	Yellowhammer	M	AM
X	Long-eared Owl	M	M
E	Woodlark	M	M
D	Bullfinch	M	MP
	Great Tit	M	MP
	Jackdaw	M	MP
	Lapwing	M	MP
	Little Owl	M	MP
	Mistle Thrush	M	MP
	Rook	M	MP
	Buzzard	P	P
	Curlew	P	P
	Golden Plover	P	P
P	Meadow Pipit	P	P
A	Nightjar	P	P
S	Pied Wagtail	P	P
T	Redshank	P	P
O	Ring Ouzel	P	P
R	Stonechat	P	P
A	Snipe	P	P
L	Stone Curlew	P	P
	Tree Pipit	P	P
	Wheatear	P	P
	Whinchat	P	P
	Goldfinch	AMP	AMP
	Kestrel	AMP	AMP
	Reed Bunting	AMP	AMP
W	Blackbird	M	AMP
I	Blue Tit	M	AMP
D	Chaffinch	M	AMP
E	Crow	M	AMP
S	Dunnock	M	AMP
P	Magpie	M	AMP
R	Robin	M	AMP
E	Song Thrush	M	AMP
A	Sparrowhawk	M	AMP
D	Starling	M	AMP
	Swallow	M	AMP
	Woodpigeon	M	AMP
	Wren	M	AMP

Table 3.1 Associations of farmland birds with farming landscape type during the breeding seasons using the 1988-1991 breeding bird atlas data (Gibbons *et al.* 1993) and ITE Land Cover data. The table shows the landscape type each species is most likely to occur in and associated landscape types. The preferred landscape type is defined as the one in which the species has the highest probability of occurrence. Arable (A)= < 25% pasture/rough grass; Mixed (M)= >25% and <75% pasture/rough grass; Pastoral (P)= > 75% pasture/rough grass.

Family		Arable	Arable Mixed	Mixed	Mixed Pastoral	Pastoral	Widespread
Hawk & falcons	Accipitridae/Falconidae	2				1	2
Larks	Alaudidae		1	1			
Nightjars	Caprimulgidae					1	
Wren	Certhiidae						1
Waders	Charadridae				1	5	
Dove & pigeons	Columbidae	1	1				1
Crows	Corvidae	1			2		2
Buntings	Emberizidae	1	2			1	1
Finches	Fringillidae		3				2
Swallows, martins & swifts	Hirundinidae / Apodidae		1				1
Tits	Paridae				1		1
Pipits, wagtails & sparrows	Passeridae		2			3	1
Gamebirds	Phasianidae	1	3				
Starlings	Sturnidae						1
Warblers	Sylviidae		1				
Thrushes	Turdinae				1	3	3
Owls	Tytonidae/Strigidae	1		1	1		
	TOTAL	7	14	2	7	14	16

Table 3.2 Distribution of bird species across farming landscape type during the breeding season grouped by family. Arable (A)= < 25% pasture/rough grass; Mixed (M)= >25% and <75% pasture/rough grass; Pastoral (P)= >75% pasture/rough grass. Arable/Mixed (AM) refers to species for which the probability of occurrence and Arable and Mixed squares differs by <10%; Mixed/Pastoral (MP) refers to species for which the probability of occurrence and Pastoral and Mixed squares differs by <10%

Food	Arable	Arable Mixed	Mixed	Mixed Pastoral	Pastoral	Widespread
Invertebrates	1	3	1	5	12	10
Invertebrates/Seeds	2	7		1	1	2
Carnivores	3		1	1	1	2
Seeds	1	3				1
Seeds & plant material		1				1
TOTAL	7	14	2	7	14	16

Table 3.3 Associations between diet during the breeding season and landscape preference type by 54 farmland bird species. Values indicate the number of bird species in each dietary category associated with the four landscape type categories. Arable (A)= < 25% pasture/rough grass; Mixed (M)= >25% and <75% pasture/rough grass; Pastoral (P) = >75% pasture/rough grass. Arable/Mixed (AM) refers to species for which the probability of occurrence and Arable and Mixed squares differs by <10%; Mixed/Pastoral (MP) refers to species for which the probability of occurrence and Pastoral and Mixed squares differs by <10%

	Species	Highest probability of occurrence	Farming landscapes which differ by <10%	Farming landscapes which differ by <25%
	Bewick's Swan	A	A	A
	Golden Plover	A	A	A
	Hen Harrier	A	A	A
	Pheasant	A	A	A
A	Pink-footed Goose	A	A	A
R	Red-legged Partridge	A	A	A
A	Whooper Swan	A	A	A
B	Barn Owl	A	A	AM
L	Blackbird	A	A	AM
E	Herring Gull	A	A	AM
	Merlin	A	A	AM
	Kestrel	A	AM	AM
	Reed Bunting	A	AM	AM
	Skylark	A	AM	AM
	Corn Bunting	M	AM	AM
	Great- Black-backed Gull	M	AM	AM
	Greenfinch	M	AM	AM
	Grey Partridge	M	AM	AM
	Linnet	M	AM	AM
	Mute Swan	M	AM	AM
	Stock Dove	M	AM	AM
	Tree Sparrow	M	AM	AM
	Woodpigeon	M	AM	AM
	Bullfinch	M	AM	AMP
	Song Thrush	M	AM	AMP
	Lapwing	M	M	AM
	Yellowhammer	M	M	AM
	Goldfinch	M	M	AMP
	Stonechat	M	M	AMP
M	Bean Goose	M	M	M
I	Canada Goose	M	M	M
X	Lesser Black-backed Gull	M	M	M
E	Rook	M	M	M
D	Black-headed Gull	M	M	MP
	Greylag Goose	M	M	MP
	Jackdaw	M	M	MP
	Little Owl	M	M	MP
	Mistle Thrush	M	M	MP
	Pied Wagtail	M	M	MP
	Snipe	M	M	MP
	Sparrowhawk	M	M	MP
	Blue Tit	M	MP	MP
	Carrion Crow	M	MP	MP
	Chaffinch	M	MP	MP
	Common Gull	M	MP	MP
	Fieldfare	M	MP	MP
	Great Tit	M	MP	MP
	Magpie	M	MP	MP
	Wren	M	MP	MP
	Redwing	P	P	MP
PAST-	Robin	P	P	MP
ORAL	Buzzard	P	P	P
			P	
	Cirl Bunting	P	P	
	Long-eared Owl	AMP	AMP	AMP
WIDE-	Meadow Pipit	AMP	AMP	AMP
SPREAD	Starling	AMP	AMP	AMP
	Wigeon	AMP	AMP	AMP

Table 3.4 Associations of farmland birds with winter farming landscape type using 1981/82 - 1984/84 winter bird atlas data (Lack 1986) and MAFF agricultural statistics. The table shows the landscape type that each species is most abundant in and associated landscape types, where the estimated abundance is less than 10% or 25% different. Arable (A)= < 25% pasture/rough grass; Mixed (M)= >25% and <75% pasture/rough grass; Pastoral (P)= >75% pasture/rough grass.

Family		Arable	Arable Mixed	Mixed	Mixed Pastoral	Pastoral	Widespread
Ducks & swans	Anatidae	3	1	2	1		1
Gamebirds	Phasianidae	2	1				
Raptors	Falconidae/Accipitridae	1	2		1	1	
Waders	Charadridae	1	1		1		
Gulls	Laridae		2	1	2		
Owls	Tytonidae/Strigidae		1		1		1
Thrushes & chats	Turdidae		1		4		2
Buntings	Emberizidae		3			1	
Larks	Alauidae		1				
Pipits, wagtails & sparrows	Passeridae		1		1		1
Starlings	Sturnidae						1
Pigeons & doves	Columbidae		2				
Finches	Fringillidae		2		1		2
Crows	Corvidae			1	3		
Tits	Paridae				2		
Wrens	Certhidae				1		
	TOTAL	7	18	4	18	2	8

Table 3.5 Preferred landscape type of birds on farmland grouped by family. Arable (A)= < 25% pasture/rough grass; Mixed (M)= >25% and <75% pasture/rough grass; Pastoral (P)= A= >75% pasture/rough grass. Arable/Mixed (AM) refers to species for which the probability of occurrence and Arable and Mixed squares differs by <10%; Mixed/Pastoral (MP) refers to species for which the probability of occurrence and Pastoral and Mixed squares differs by <25%

Diet	Arable	Arable Mixed	Mixed	Mixed Pastoral	Pastoral	Widespread
Carnivores	1	3		1	1	1
Insectivores	1	4	2	15		4
Herbivored	3	3	2	1		1
Granivores	2	8		1	1	2
Total	7	18	4	18	2	8

Table 3.6 Distribution of birds in winter across farming landscape types according to diet. Arable (A)= < 25% pasture/rough grass; Mixed (M)= >25% and <75% pasture/rough grass; Pastoral (P)= >75% pasture/rough grass. Arable/Mixed (AM) refers to species for which the probability of occurrence and Arable and Mixed squares differs by <10%; Mixed/Pastoral (MP) refers to species for which the probability of occurrence and Pastoral and Mixed squares differs by <25%

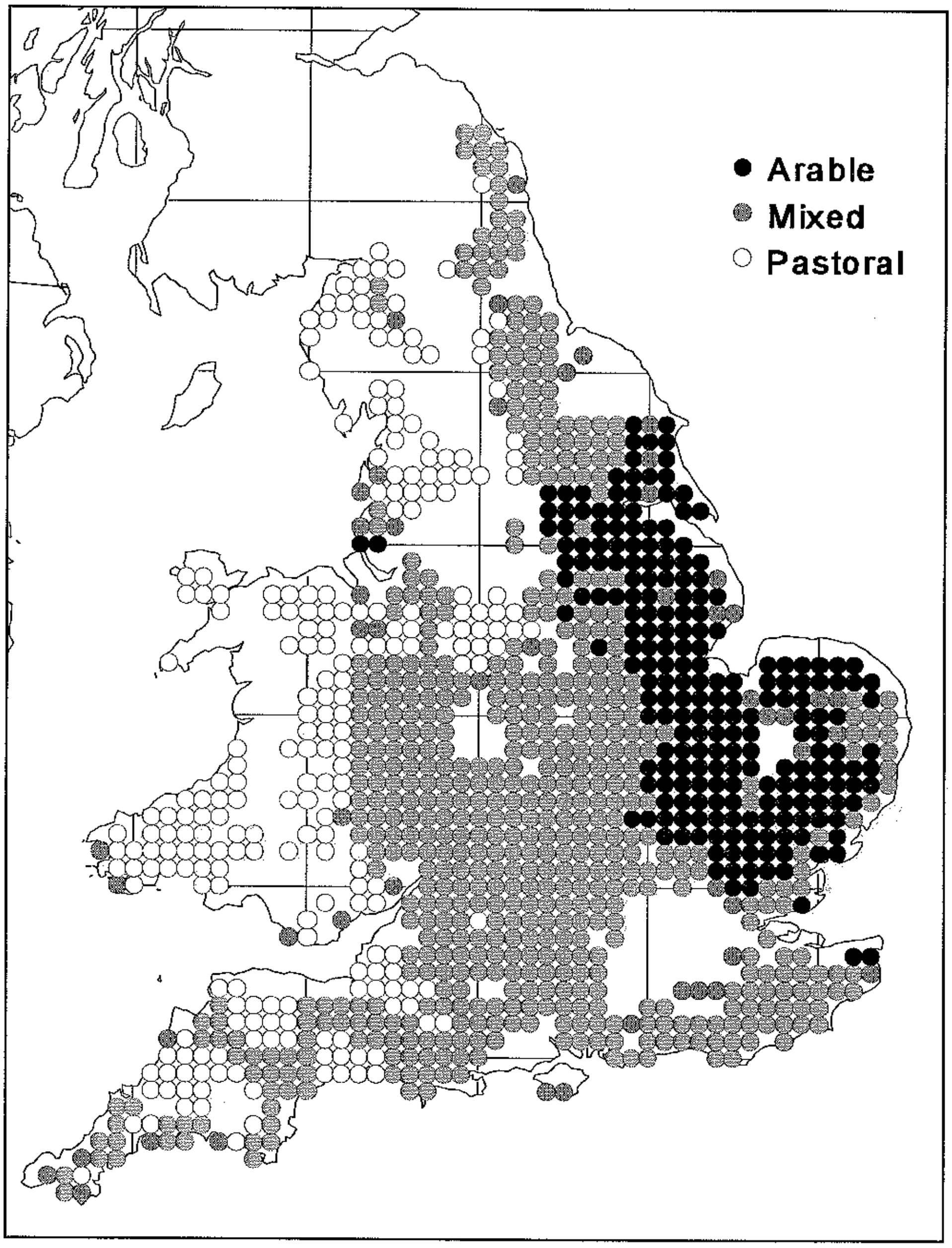


Figure 3.1 Distribution of 10-km squares of the national grid with > 50% landcover of grassland, crops or rough grazing. Arable squares=<25% pasture/rough grass; Mixed=>25% and <75% pasture/ rough grass; Pastoral=>75% pasture/rough grass.

Fig. 4.1. Changes in total sheep number in different counties of England

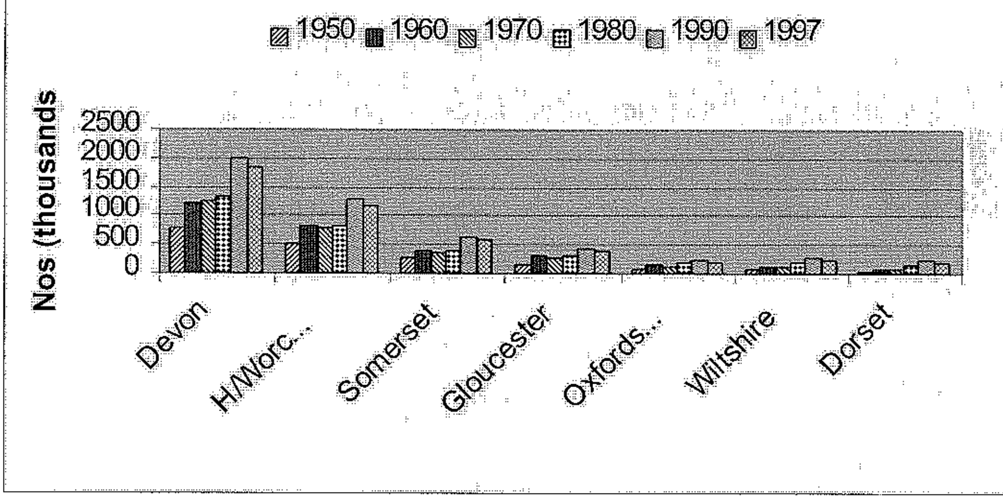


Fig. 4.2. Changes in total dairy cow numbers in different counties of England

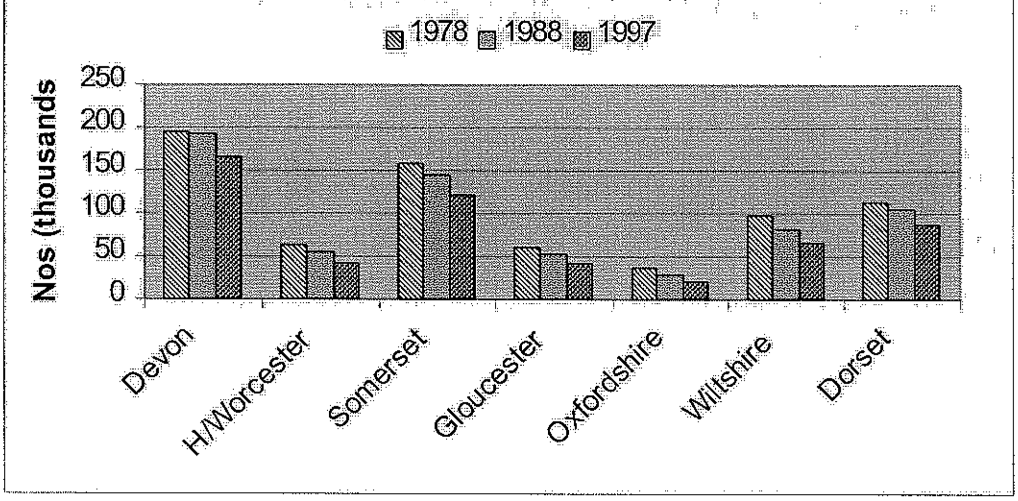


Fig. 4.3. Changes in total cattle numbers in different counties of England

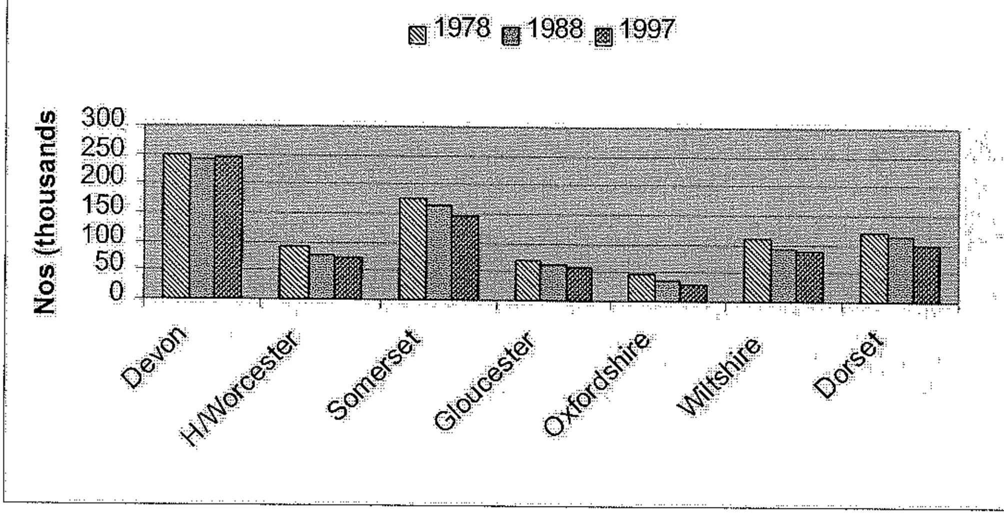
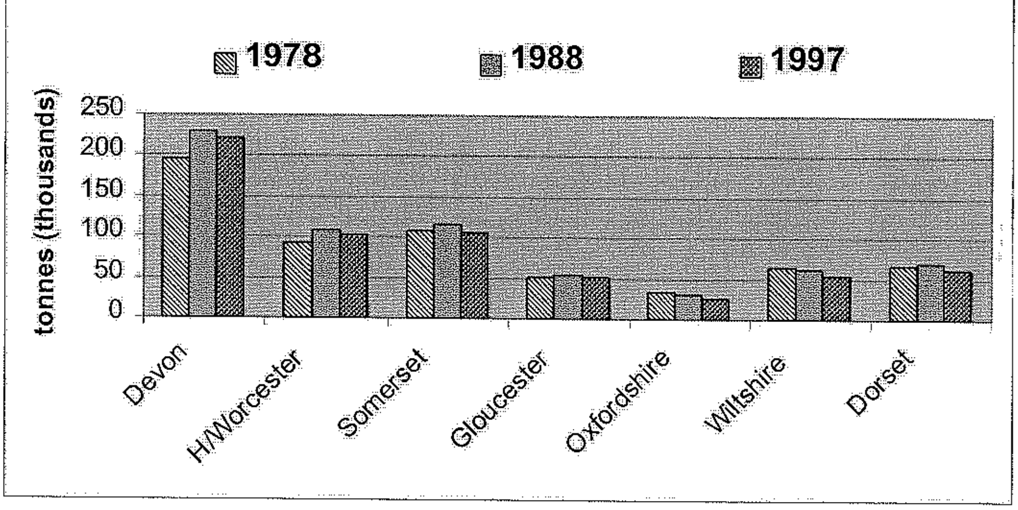


Fig. 4.4. Changes in total liveweight of cattle plus sheep in different counties of England between:



Bent spp. *Agrostis* spp	Marsh Thistle *Cirsium palustre*
Black Knapweed *Centaurea nigra*	Mat Grass *Nardus*
Blackthorn *Prunus spinosa*	Meadow Barley *Hordeum secalinum*
Blunt-flowered Rush *Juncus subnodulosus*	Meadow Thistle *Cirsium dissectum*
Bracken *Pteridium aquilinum*	Meadow Vetchling *Lathyrus pratensis*
Bramble *Rubus fruticosus*	Oil-seed Rape *Brassica napus* (Cruciferae)
Broad-leaved dock *Rumex obtusifolius*	Perennial Rye-grass *Lolium perenne*
Bryony *Tamus communisa*	Annual Meadow Grass *Poa annua*
Buttercup *Ranunculus acris*	Purple Moor Grass *Molinia caerulea*
Common Chickweed *Stellaria media*	Red Fescue *Festuca rubra*
Common Ragwort *Senecio jacobaea*	Reed Canary-grass *Phalaris arundinacea*
Creeping Bent *Agrostis stolonifera*	Reed Sweet-grass *Glyceria maxima*
Creeping Thistle *Cirsium arvense*	Rough Meadow Grass *Poa trivialis*
Crested Dog's Tail *Cynosurus cristatus*	Silverweed *Potentilla anserina*
Curled Dock *R. crispus*	Soft Rush *Juncus effusus*
Dog Rose *Rosa canina*	Spear Thistle *Cirsium vulgare*
Heather *Calluna volgaris*	Stinging Nettle *Urtica dioica*
Hawthorn *Crataegus monogyna*	Thistles *Cirsium*
Italian Rye-grass *Lolium multiflorum*	White Clover *Trifolium repens*
Lady's Bedstraw *Galium verum*	Yorkshire Fog *Holcus lanatus*
Marsh Fox-Tail *Alopecurus geniculatus*	
Marsh Ragwort *Senecio aquaticus*	

Appendix 1.1a Latin names of plants mentioned in the text.

ants (Formicidae)	jewel beetles (Buprestridae)
aphids (Aphididae)	leaf beetle (Chrysomelidae)
blow-flies (Calliphoridae)	leatherjacket (Tipulidae)
bugs (Heteroptera)	mayflies (Ephemeroptera)
bush-crickets (Tettigoniidae)	midges (Chironomidae)
carabid beetles (ground) (Carabidae)	mirid bug *Leptoterna dolabrata*
caterpillars (Lepidoptera)	mites (Acari)
chafers (Coleoptera)	nematodes (Nematoda)
click beetles (Elateridae)	psyllids (Psyllidae)
crane-flies (Tipulidae)	rove beetle *Amischa analis*(Staphylinidae)
darkling beetles (Tenebrionidae)	sawflies (Symphyta)
dung beetles (Scarabaeidae)	scale bugs (Coccoidea)
dung-flies (Scatophagidae, Sphaeroceridae)	sitona weevil (Curculionidae sitona spp.)
earthworm *Lumbricus terrestris* (Annelida)	slug (Mollusca)
fruit fly *Oscinella frit* (Drosophilidae)	snail (Mollusca)
grass grub *Poruna* spp	soldier-flies (Stratiomydae)
grasshopper (Acrodidae)	spiders (Araneae)
harvestman (Opiliones)	springtails (Collembola)
hoverflies (Syrphidae)	weevils (Curculionidae)
ichneumon wasps (Ichneumonidae)	wireworms (Elateridae)

Appendix 1.1b Latin names of invertebrates mentioned in the text.

Barnacle Goose *Branta leucopsis*	Montagu's Harrier *Circus pygargus*
Barn Owl *Tyto alba*	Mute Swan *Cygnus olor*
Bean Goose *Anser fabilis*	Nightjar *caprimulgus europaeus*
Bewick's Swan *Cygnus bewickii*	Oystercatcher *Haematopus ostralegus*
Blackbird *Turdus merula*	Pheasant *Phasianus colchicus*
Black-headed Gull *Larus ridibundus*	Pied Wagtail *Motacilla alba*
Black-tailed Godwit *Limosa limosa*	Pink-footed Goose *Anser brachyrhynchus*
Blue Tit *Parus caeruleus*	Pintail *Anas acuta*
Brent Goose *Branta bernicla*	Quail *Coturnix coturnix*
Bullfinch *Pyrrhula pyrrhula*	Red-backed Shrike *Lanius collurio*
Buzzard *Buteo buteo*	Red-legged Partridge *Alectoris rufa*
Canada Goose *Branta canadensis*	Redshank *Tringa totanus*
Carrion Crow *Corvus corone*	Redwing *Turdus iliacus*
Chaffinch *Fringilla coelebs*	Reed Bunting *Emberiza schoeniclus*
Chough *Pyrrhocorax pyrrhocorax*	Ring Ouzel *Turdus torquatus*
Cirl Bunting *Emberiza cirlus*	Robin *Erithacus rubecula*
Common Gull *Larus canus*	Rook *Corvus frugilegus*
Corn Bunting *Miliaria calandra*	Ruff *Philomachus pugnax*
Corncrake *Crex crex*	Sedge Warbler *Acrocephalus schoenobaenus*
Curlew *Numenius arquata*	Short-eared Owl *Asio flammeus*
Dunlin *Calidris alpina*	Shoveler *Anas clypeata*
Dunnock *Prunella modularis*	Skylark *Alauda arvensis*
European White-fronted Goose *Anser albifrons*	Snipe *Gallinago gallinago*
Fieldfare *Turdus pilaris*	Song Thrush *Turdus philomelos*
Gadwall *Anas strepera*	Sparrowhawk *Accipiter nisus*
Garganey *Anas querquedula*	Starling *Sturnus vulgaris*
Golden Plover *Pluvialis apricaria*	Stock Dove *Columba oenas*
Goldfinch *Cardeulis cardeulis*	Stonechat *Saxicola torquata*
Grasshopper Warbler *Locustella naevia*	Stone Curlew *Burhinus oedicnemus*
Greater Black-backed Gull *Larus marinus*	Swallow *Hirundo rustica*
Great Tit *Parus major*	Swift *Apus apus*
Greenfinch *Cardeulis chloris*	Teal *Anas crecca*
Greenlandic Goose	Tree Pipit *Anthus trivialis*
Greylag Goose *Anser anser*	Tree Sparrow *Passer montanus*
Grey Partridge *Perdix perdix*	Tufted Duck *Aythya fuligula*
Hen Harrier *Circus cyaneus*	Turtle Dove *Streptopelia turtur*
Herring Gull *Larus argentatus*	Wheatear *Oenanthe oenanthe*
Hobby *Falco subbuteo*	Whimbrel *Nemenius phaeopus*
Jackdaw *Corvus monedula*	Whinchat *Saxicola rubetra*
Kestrel *Falco tinnunculus*	White-fronted Goose *Anser albifrons*
Lapwing *Vanellus vanellus*	Whitethroat *Sylvia communis*
Lesser Black-backed Gull *Larus fuscus*	Whooper Swan *Cygnus cygnus*
Linnet *Carduelis cannabina*	Wigeon *Anas penelope*
Little Owl *Athene noctua*	Woodlark *Lullula arborea*
Long-eared Owl *Asio otus*	Woodpigeon *Columba palumbus*
Magpie *Pica pica*	Wren *Troglodytes troglodytes*
Mallard *Anas platyrhynchos*	Wryneck *Jynx torquilla*
Meadow Pipit *Anthus pratensis*	Yellowhammer *Emberiza citrinella*
Merlin *Falco columbarius*	Yellow Wagtail *Motacilla flava*
Mistle Thrush *Turdus viscivorus*	

Appendix 1.1c Latin names of birds mentioned in the text.

Species	INTERCEPT	pPAST	pPAST*pPAST	EASTING	NORTHING	Deviance	DF	Deviance/DF
Blackbird	3.42 **	2.40 **	-2.98 **	0.0007 NS	-0.0017 **	2874.409	9844	0.292
Bullfinch	-1.79 **	2.69 **	-2.09 **	0.0029 **	-0.0031 **	11809.95	9844	1.200
Barn Owl	-3.77 **	-3.54 **	2.78 **	0.0019 **	-0.0010 **	1823.314	9844	0.185
Blue Tit	1.10 **	5.68 **	-4.83 **	-0.0001 NS	-0.0008 **	7248.365	9844	0.736
Buzzard	7.27 **	1.37 **		-0.0231 **	-0.0060 **	3503.329	9845	0.356
Crow	3.73 **	3.18 **	-2.16 **	-0.0059 **	-0.0012 **	8793.509	9844	0.893
Corn Bunting	1.10 **	-1.92 **	-2.07 **	-0.0025 **	-0.0015 **	7516.388	9844	0.764
Chaffinch	2.95 **	6.75 **	-6.20 **	-0.0032 **	-0.0007 **	5274.447	9844	0.536
Cirl Bunting	7.52 **	17.13 **	-33.69 **	-0.0171 **	-0.0690 **	36.382	9844	0.004
Curlew	-3.55 **	3.23 **	-0.82 *	-0.0066 **	0.0093 **	5751.66	9844	0.584
Dunnock	1.36 **	3.07 **	-3.71 **	-0.0001 NS	-0.0010 **	9959.72	9844	1.012
Grasshopper Warbler	-2.62 **	0.51 NS	-0.96 *	-0.0018 **	-0.0005 *	2338.317	9844	0.238
Goldfinch	0.68 **			-0.0004 **	-0.0016 NS	13531.11	9846	1.374
Golden Plover	-48.78 **	90.91 **	-54.44 **	0.0027 **	0.0085 **	56.676	9844	0.006
Greenfinch	0.06 NS	2.82 **	-3.27 **	0.0020 **	-0.0021 **	12179.67	9844	1.237
Great Tit	-0.07 NS	4.94 **	-4.10 **	0.0012 **	-0.0016 **	10978.74	9844	1.115
Hobby	-2.88 **	-0.72 **		0.0010 **	-0.0053 **	1561.334	9845	0.159
Jackdaw	0.86 **	4.32 **	-3.79 **	-0.0029 **	0.0000 NS	12726.77	9844	1.293
Kestrel	-2.06 **			0.0035 **	0.0000 **	12781.3	9846	1.298
Lapwing	-3.12 **	2.34 **	-1.74 **	0.0016 **	0.0047 **	12390.07	9844	1.259
Long-eared Owl	-6.59 **	4.43 **	-5.19 **	-0.0029 **	0.0029 **	232.339	9844	0.024
Linnet	-0.49 *	0.56 NS	-0.98 **	0.0013 **	0.0005 **	13414.55	9844	1.363
Little Owl	-2.40 **	3.03 **	-2.57 **	-0.0002 NS	-0.0016 **	5988.198	9844	0.608
Mistle Thrush	-2.35 **	5.12 **	-4.09 **	0.0020 **	-0.0003 NS	13002.46	9844	1.321
Magpie	3.19 **	3.92 **	-3.33 **	-0.0031 **	-0.0049 **	10234.95	9844	1.040
Montagu's Harrier	0.21 NS	-1.66 NS	-10.15 **	0.0008 *	-0.0312 **	63.292	9844	0.006
Meadow Pipit	-3.39 **	-3.43 **	4.28 **	0.0023 **	0.0036 **	8890.263	9844	0.903
Nightjar	-21.64 **	-4.09 **	8.09 **	0.0207 **	0.0079 **	47.35	9844	0.005
Grey Partridge	-1.46 **	1.03 **	-2.41 **	-0.0014 **	0.0030 **	9507.942	9844	0.966
Pheasant	1.29 **	-0.62 NS	-0.81 *	0.0010 **	-0.0008 **	11446.55	9844	1.163
Pied Wagtail	-1.82 **	1.26 **		0.0002 NS	0.0028 **	12832.3	9845	1.303
Quail	-1.26 **	3.31 **	-4.86 **	-0.0055 **	-0.0026 **	1401.706	9844	0.142
Robin	1.27 **	5.88 **	-4.97 **	-0.0005 NS	-0.0015 **	7894.597	9844	0.802
Reed Bunting	-2.54 **			0.0023 **	0.0009 **	10505.57	9846	1.067
Redshank	-9.26 **	4.22 **	-1.52 **	0.0066 **	0.0051 **	3622.798	9844	0.368
Red-legged Partridge	-1.62 **	-1.18 **	-2.58 **	0.0047 **	-0.0011 **	9427.817	9844	0.958
Rook	0.78 **	3.39 **	-3.16 **	-0.0019 **	0.0001 NS	12677.6	9844	1.288
Ring Ouzel	-41.45 **	80.13 **	-43.19 **	-0.0100 **	0.0020 **	32.197	9844	0.003
Skyark	1.04 **	-1.90 **		0.0023 **	-0.0001 NS	10581.47	9845	1.075
Stonechat	-3.82 **	3.26 **	-1.43 *	-0.0044 **	-0.0059 **	404.163	9844	0.041
Stock Dove	0.83 **	1.51 **	-2.21 **	-0.0016 **	-0.0017 **	13111.18	9844	1.332
Starling	-1.16 **	4.04 **	-3.32 **	0.0048 **	0.0001 NS	7595.357	9844	0.772
Sparrowhawk	-0.78 **	0.68 NS	-0.80 *	-0.0035 **	0.0008 **	7181.051	9844	0.729
Swift	0.05 NS	0.58 NS	-1.05 **	0.0010 **	-0.0002 NS	13209.31	9844	1.342
Swallow	1.58 **	1.51 **	-1.31 **	0.0001 NS	0.0005 **	6818.705	9844	0.693
Snipe	-9.23 **	1.94 **		0.0077 **	0.0050 **	3359.044	9845	0.341
Song Thrush	-1.05 **	1.36 **	-1.11 **	0.0040 **	-0.0001 NS	11376.96	9844	1.156
Sedge Warbler	-2.86 **	-0.93 **		0.0029 **	0.0013 **	8744.792	9845	0.888
Turtle Dove	-5.88 **	-0.25 NS	-1.83 **	0.0127 **	-0.0027 **	7859.632	9844	0.798
Stone Curlew	-6.96 **	-2.68 **	4.01 **	0.0049 **	-0.0088 **	171.452	9844	0.017
Tree Pipit	-4.95 **	2.25 **		-0.0005 NS	0.0025 **	3353.283	9845	0.341
Tree Sparrow	-3.41 **	1.74 **	-2.56 **	0.0025 **	0.0029 **	9696.855	9844	0.985
Wheatear	-6.43 **	-4.24 **	6.61 **	0.0020 **	0.0040 **	1897.583	9844	0.193
Whinchat	-4.40 **	3.01 **	-1.45 **	-0.0039 **	0.0032 **	1895.876	9844	0.193
Whitethroat	0.48 *	1.00 **	-2.22 **	0.0007 *	-0.0013 **	13046.92	9844	1.325
Woodlark	-45.52 **	117.48 **	-78.11 **	-0.0009 *	-0.0303 **	59.728	9844	0.006
Woodpigeon	3.44 **	2.40 **	-3.18 **	0.0002 NS	-0.0020 **	3671.456	9844	0.373
Wren	2.05 **	3.86 **	-3.33 **	-0.0005 NS	-0.0015 **	6644.092	9844	0.675
Yellowhammer	0.95 **	3.97 **	-5.90 **	0.0010 **	-0.0001 NS	9401.586	9844	0.955
Yellow Wagtail	-2.64 **	0.15 NS	-1.49 **	0.0027 **	0.0007 **	8708.772	9844	0.885

Appendix 3.1

Species	INTERCEPT	pPAST	pPAST*pPAST	EASTING	NORTHING	Deviance	DF	Deviance/DF
Blackbird	4.623 **	-0.543 **		0.0013 **	-0.0006 **	55563.59	1085	51.21
Bean Goose	-16.285 **	-24.837 **		0.0183 **	0.0082 **	6041.52	1084	5.57
Bullfinch	1.547 **	-1.396 **	1.323 **	0.0018 **	-0.0008 **	5601.76	1084	5.17
Black-headed Gull	5.839 **	-3.188 **	3.888 **	0.0014 **	0.0011 **	5285122.37	1084	4875.57
Barn Owl	0.286 NS	-0.716 **	0.000 **	0.0000 NS	-0.0008 **	825.50	1085	0.76
Bewick's Swan	2.746 **	4.468 **		0.0028 **	-0.0019 *	64469.87	1084	59.47
Blue Tit	3.109 **	-1.666 **	2.334 **	0.0009 **	0.0003 NS	32331.04	1084	29.83
Buzzard	2.385 **	1.745 **	0.000 **	-0.0060 **	-0.0030 **	1777.59	1085	1.64
Carrion Crow	2.768 **	-3.715 **		0.0003 NS	0.0008 **	102390.49	1084	94.46
Corn Bunting	2.412 **	-6.164 **	3.014 **	0.0018 **	-0.0016 **	50579.85	1084	46.66
Canada Goose	1.944 **	-5.245 **	5.273 **	0.0019 **	0.0011 **	138982.49	1084	128.21
Chaffinch	5.289 **	-2.412 **	2.875 **	-0.0006 *	-0.0004 NS	220015.58	1084	202.97
Cirl Bunting	-1.193 NS	1.333 *	0.000 **	-0.0032 **	-0.0098 **	255.25	1085	0.24
Common Gull	1.052 NS	-4.811 **		0.0041 **	0.0041 **	1757087.31	1084	1620.93
Fieldfare	5.574 **	-3.166 **	4.094 **	-0.0001 NS	-0.0005 *	854493.32	1084	788.28
Great- Black-backed Gull	4.611 **	-1.496 **	0.000 **	-0.0003 NS	0.0000 NS	210778.71	1085	194.27
Greylag Goose	-4.435 **	-5.072 **	6.399 **	0.0045 **	0.0113 **	101995.53	1084	94.09
Goldfinch	2.164 **	-1.486 **	1.491 **	0.0020 **	-0.0014 **	20869.30	1084	19.25
Golden Plover	6.723 **	-1.294 **	0.000 **	-0.0022 **	0.0016 **	649411.40	1085	598.54
Greenfinch	4.257 **	-2.768 **		0.0010 *	-0.0007 *	121675.56	1084	112.25
Great Tit	2.252 **	-2.684 **	3.424 **	0.0011 **	0.0000 NS	19665.14	1084	18.14
Herring Gull	7.106 **	-1.105 **	0.000 **	-0.0034 **	0.0007 NS	641453.54	1085	591.20
Hen Harrier	-1.122 *	2.682 **		0.0037 **	-0.0023 **	1603.13	1084	1.48
Jackdaw	4.701 **	-3.557 **	3.996 **	0.0001 NS	0.0009 **	499295.27	1084	460.60
Kestrel	1.005 **	-0.547 **	0.000 **	0.0010 **	0.0004 **	1091.96	1085	1.01
Lapwing	6.724 **	-3.726 **		0.0005 NS	-0.0001 NS	2185246.70	1084	2015.91
Lesser Black-backed Gull	2.346 **	-9.112 **	10.556 **	-0.0011 NS	-0.0002 NS	308559.78	1084	284.65
Long-eared Owl	-4.103 **	0.000 **	0.000 **	0.0056 **	0.0007 **	1491.58	1086	1.37
Linnet	5.136 **	-1.443 **		-0.0007 NS	-0.0005 NS	116145.11	1085	107.05
Little Owl	-1.000 **	-3.713 **		0.0014 **	-0.0007 **	1224.53	1084	1.13
Mistle Thrush	1.117 **	-3.791 **		0.0013 **	-0.0008 **	7143.00	1084	6.59
Magpie	2.140 **	-2.728 **	4.098 **	0.0002 NS	-0.0002 NS	15733.93	1084	14.51
Merlin	-0.168 NS	0.668 NS	-1.465 *	-0.0015 **	0.0015 **	922.57	1084	0.85
Meadow Pipit	3.466 **	-0.779 NS	1.122 *	0.0002 NS	-0.0017 **	38526.58	1084	35.54
Mute Swan	1.870 **	-2.798 **	2.014 **	0.0022 **	-0.0014 **	30059.61	1084	27.73
Grey Partridge	2.604 **	-3.943 **	1.852 **	-0.0006 NS	0.0014 **	11526.27	1084	10.63
Pink-footed Goose	11.231 **	8.003 **	-12.742 **	-0.0150 **	0.0089 **	692422.45	1084	638.77
Pheasant	4.403 **	-0.502 NS	-1.457 *	0.0006 NS	-0.0004 NS	81746.09	1084	75.41
Pied Wagtail	1.618 **	-5.119 **	6.511 **	0.0019 **	-0.0022 **	95246.88	1084	87.87
Robin	2.878 **	-0.462 NS	1.115 **	0.0011 **	-0.0017 **	9770.77	1084	9.01
Reed Bunting	2.911 **	-1.166 **	0.000 **	0.0011 *	-0.0009 *	30227.03	1085	27.86
Redwing	5.284 **	-1.848 **	3.477 **	0.0001 NS	-0.0019 **	696473.54	1084	642.50
Red-legged Partridge	3.321 **	-2.177 **		0.0015 **	-0.0013 **	12639.50	1084	11.66
Rook	4.798 **	-5.344 **	5.103 **	0.0009 *	0.0023 **	866909.18	1084	799.73
Skylark	5.657 **	-1.423 **	0.000 **	0.0011 *	-0.0025 **	264291.89	1085	243.59
Stonechat	1.596 **	0.000 **	0.000 **	-0.0022 **	-0.0053 **	1693.90	1086	1.56
Stock Dove	4.710 **	-3.844 **		-0.0003 NS	-0.0021 **	93786.94	1084	86.52
Starling	8.644 **	0.000 **		0.0001 **	0.0001 NS	25436638.38	1086	23422.32
Sparrowhawk	-0.269 NS	-2.814 **	3.301 **	-0.0004 NS	0.0005 **	736.16	1084	0.68
Snipe	2.971 **			0.0015 **	-0.0027 **	81149.84	1084	74.86
Snipe	0.001 **	-0.003 **	0.000 **	8.7415 NS	2.9708 **	82986.25	1	82986.25
Song Thrush	2.336 **	0.000 **	0.000 **	0.0032 **	-0.0027 **	15828.06	1086	14.57
Tree Sparrow	2.539 **	-0.927 **		0.0030 **	0.0011 **	76318.18	1085	70.34
Wigeon	4.368 **			0.0030 **	-0.0014 **	1091755.41	1086	1005.30
Woodpigeon	6.498 **	-4.542 **		0.0012 **	0.0008 **	1368288.25	1084	1262.26
Wren	2.744 **			0.0008 **	-0.0021 **	8069.23	1084	7.44
Whooper Swan	3.849 **	3.127 **	-6.047 **	-0.0095 **	0.0089 **	9932.83	1084	9.16
Yellowhammer	2.891 **	-5.793 **	4.509 **	0.0013 **	0.0010 **	61514.98	1084	56.75

Appendix 3.2