In this paper, the main aspects of agricultural intensification that have led to population declines in farmland birds over the past 50 years are reviewed, together with the current state of knowledge, and the effects of recent conservation actions. For each of 30 declining species, attention is focused on: (1) the external causes of population declines, (2) the demographic mechanisms and (3) experimental tests of proposed external causal factors, together with the outcome of (4) specific conservation measures and (5) agri-environment schemes. Although each species has responded individually to particular aspects of agricultural change, certain groups of species share common causal factors. For example, declines in the population levels of seed-eating birds have been driven primarily by herbicide use and the switch from spring-sown to autumn-sown cereals, both of which have massively reduced the food supplies of these birds. Their population declines have been associated with reduced survival rates and, in some species, also with reduced reproductive rates. In waders of damp grassland, population declines have been driven mainly by land drainage and the associated intensification of grassland management. This has led to reduced reproductive success, as a result of lowered food availability, together with increased disturbance and trampling by farm stock, and in some localities increased nest predation. The external causal factors of population decline are known (with varying degrees of certainty) for all 30 species considered, and the demographic causal factors are known (again with varying degrees of certainty) for 24 such species. In at least 19 species, proposed causal factors have been tested and confirmed by experiment or by local conservation action, and 12 species have been shown to benefit (in terms of locally increased breeding density) from options available in one or more agri-environment schemes. Four aspects of agricultural change have been the main drivers of bird population declines, each affecting a wide range of species, namely: (1) weed-control, mainly through herbicide use; (2) the change from spring-sown to autumn-sown cereal varieties, and the associated earlier ploughing of stubbles and earlier crop growth; (3) land drainage and associated intensification of grassland management; and (4) increased stocking densities, mainly of cattle in the lowlands and sheep in the uplands. These changes have reduced the amounts of habitat and/or food available to many species. Other changes, such as the removal of hedgerows and ‘rough patches’, have affected smaller numbers of species, as have changes in the timings of cultivations and harvests. Although at least eight species have shown recent increases in their national population levels, many others seem set to continue declining, or to remain at a much reduced level, unless some relevant aspect of agricultural practice is changed.

Widespread population declines of farmland birds are of major conservation concern in Britain and other parts of Europe. Such declines have been rapid, massive and widespread, with some species experiencing more than 80% reductions in former numbers and range in less than 20 years (Tucker & Heath 1994, Fuller et al. 1995). Parallel declines have also occurred in other components of farmland biodiversity,
including insects and wild plants (Wilson 1992, Donald 1998, Sotherton & Self 2000, Preston et al. 2002). In this review, I shall assess the causal factors underlying the population declines of particular bird species in Britain, together with the effectiveness of various conservation measures that have been applied in recent years.

In most species affected, the main period of population decline seems to have occurred between 1970 and 1990 (especially 1975–85), although in some species (such as those affected by organochlorine pesticides) declines began earlier, and in others they continued into or beyond the 1990s (Table 1; see Fuller et al. 1995, Fuller 2000, Siriwardena et al. 1998, Chamberlain et al. 2001, Gregory et al. 2004 for Britain; Tucker & Heath 1994, Donald et al. 2001 for Europe as a whole). Substantial changes in the farmland bird populations of Britain are by no means new, however, as they have followed every major change in agricultural practice that has affected bird habitats and food supplies, at least over the 250 years for which documentation is available (Shrubb 2003). In the 19th century, the most marked changes occurred as semi-natural habitats, such as wetland, heath and moorland, were brought into more intensive use, but in the 20th century, the most marked changes occurred through the more intensive use of existing farmland. Compared with earlier changes, recent population changes have affected simultaneously a wider range of species, almost all of which have declined, only small numbers having apparently benefited, and increased in numbers or range (see later).

Farmland birds have been defined either narrowly, as those found primarily in farmed habitats, such as Grey Partridge and Corn Bunting (see Appendix for scientific names; only those of species not mentioned in Table 1 are given in the text), or broadly to include almost all landbirds that breed or winter in open habitats. The latter reflects the fact that almost all open land in Britain (70% of total land area) is used for agricultural production. In this paper, I shall adopt a broad view of farmland birds, as any species that have been conspicuously affected by recent changes in the methods of crop, meat or milk production. To exclude such species as Sparrowhawk and Black Grouse, merely because they do not breed in cultivated habitats, would be to ignore some of the most dramatic examples of bird species being affected by recent farming practice. Discussion is confined to 30 breeding species whose populations have declined markedly since 1950, and which have been studied in detail. Other declining breeding species are excluded, as are winter visitors.

**SOURCES OF INFORMATION ON BIRD POPULATIONS**

Evidence for the role of agricultural change in the declines of many bird populations has come partly from temporal and spatial correlations between particular types of agricultural change and particular bird declines (e.g. Chamberlain et al. 2000, Gates & Donald 2000, Shrubb 2003), but also from detailed field studies designed to find the crucial causal factors (see species notes and references to Table 1 given in the Appendix). The main sources of information on the changes that have occurred in British bird populations are the various wide-scale, long-term data-sets held by the British Trust for Ornithology (BTO). These include: (1) the Common Birds Census, recently (and after a period of overlap) replaced by the Breeding Bird Survey (BBS), both of which were designed to measure year-to-year changes in breeding bird abundance in various habitats, and have therefore revealed the extent and precise timing of decline in most affected species; (2) two Atlas projects, designed to map the breeding distribution of all British bird species in 10-km squares throughout the country, at about 20-year intervals (1968–72 and 1989–92) (Sharrock 1976, Gibbons et al. 1993); (3) the Ringing Scheme, providing recovery data from which the annual mortality rates of various species have been calculated, and thus enabling comparisons between periods of numerical stability, increase and decrease; (4) the Nest Record Scheme, from which the performance of individual breeding attempts of various species has been calculated, again enabling comparisons between periods of stability, increase or decrease; (5) periodic surveys of species of interest, not well covered by the other schemes.

All these schemes have strengths and weaknesses (Grice et al. 2004), but in our present context the main problem lies with nest record data (Crick et al. 2003). In multi-brooded species, nest records give no measure of the total seasonal production of young per pair, which is the measure needed to understand population changes. In some species, such as Corn Bunting and Turtle Dove, nest record data indicated an increase in individual nest success during a period of population decline, while more detailed data resulting from field studies indicated a shortening of the breeding season, and hence in the total seasonal...
Table 1. State of knowledge and outcome of conservation action in 30 bird species that have declined in Britain in association with recent agricultural change. See Appendix for species notes and references.

<table>
<thead>
<tr>
<th>Species</th>
<th>External causal factor</th>
<th>Demographic causal factor</th>
<th>Experimental test</th>
<th>Local conservation action</th>
<th>Agri-environment scheme</th>
<th>National policy change</th>
<th>Recent national population trend</th>
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<td><strong>Seed eaters</strong></td>
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<td>1 House Sparrow</td>
<td>F+N</td>
<td>S* (R)</td>
<td>+</td>
<td>+</td>
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<td></td>
<td>S</td>
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<tr>
<td>2 Tree Sparrow</td>
<td>F</td>
<td>S* (R)</td>
<td>+</td>
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<td>S</td>
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<td>3 Linnet</td>
<td>F</td>
<td>(R)</td>
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<td>S</td>
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<td>4 Twite</td>
<td>H+F</td>
<td>S†</td>
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<tr>
<td>5 Bullfinch</td>
<td>H+F</td>
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<tr>
<td>6 Yellowhammer</td>
<td>F</td>
<td>S* (R)</td>
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<td>S</td>
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<tr>
<td>7 Cirl Bunting</td>
<td>F</td>
<td>R</td>
<td>+</td>
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<tr>
<td>8 Reed Bunting</td>
<td>H+F</td>
<td>S* (R)</td>
<td>+</td>
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<td>S</td>
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<td>9 Corn Bunting</td>
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<td>R</td>
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<td>10 Turtle Dove</td>
<td>H+F</td>
<td>R*</td>
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<td><strong>Other passerines</strong></td>
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<td>11 Skylark</td>
<td>H+F</td>
<td>R</td>
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<td>12 Meadow Pipit</td>
<td>H(+F)</td>
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<tr>
<td>13 Yellow Wagtail</td>
<td>H+F</td>
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<tr>
<td>14 Starling</td>
<td>F</td>
<td>S R†</td>
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<td>15 Blackbird</td>
<td>H+F</td>
<td>S* (–)</td>
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<td>16 Song Thrush</td>
<td>H+F</td>
<td>S* (–)</td>
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<td><strong>Waders and others</strong></td>
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<tr>
<td>17 Lapwing</td>
<td>H+F</td>
<td>– R*</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>S</td>
</tr>
<tr>
<td>18 Snipe</td>
<td>H+F</td>
<td>R</td>
<td>+</td>
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<td>I</td>
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<tr>
<td>19 Curlew</td>
<td>H+F(+P)</td>
<td>R*</td>
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<td>D</td>
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<tr>
<td>20 Redshank</td>
<td>H+F</td>
<td>R</td>
<td>+</td>
<td></td>
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<td>D</td>
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<tr>
<td>21 Stone Curlew</td>
<td>H+M</td>
<td>R</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>I</td>
</tr>
<tr>
<td>22 Corncrake</td>
<td>H+M</td>
<td>R</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>I</td>
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<td><strong>Gamebirds</strong></td>
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<tr>
<td>23 Grey Partridge</td>
<td>H+F(+P)</td>
<td>S R</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>S</td>
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<tr>
<td>24 Black Grouse</td>
<td>H+F(+P)</td>
<td>R</td>
<td>+</td>
<td>+</td>
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<td>D</td>
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<td>25 Red Grouse</td>
<td>H+F(+P+D)</td>
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<td><strong>Birds of prey</strong></td>
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<tr>
<td>26 Sparrowhawk</td>
<td>Pesticide</td>
<td>S R</td>
<td>(+)</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>S</td>
</tr>
<tr>
<td>27 Merlin</td>
<td>Pesticide</td>
<td>S R</td>
<td>(+)</td>
<td>+</td>
<td></td>
<td>+</td>
<td>I</td>
</tr>
<tr>
<td>28 Peregrine</td>
<td>Pesticide</td>
<td>S R</td>
<td>(+)</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>I</td>
</tr>
<tr>
<td>29 Kestrel</td>
<td>H+F+N</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td>B</td>
</tr>
<tr>
<td>30 Barn Owl</td>
<td>H+F+N</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td>D</td>
</tr>
</tbody>
</table>

1External causal factors: declines in habitat areas (H), food supply (F), nest-sites (N), or increases in predation or nest trampling (P), parasitic disease (D) and losses to machinery (M).

2Demographic causal factors: survival (S) or reproduction (R). *In a mathematical model, a change in S or R could account on its own for the observed rate of decline. R values in parentheses indicate that change in nest success has been documented during the decline, but total seasonal productivity has not been studied. –indicates no change. †Continental study only.

3Scientifically designed experiment to test the effect of a proposed limiting factor, which is changed in one or more treatment areas, but not in control areas, and the response of the population is compared between areas.

4Management action taken in one or more areas (often nature reserves) which was followed by an increase in breeding density.

5A scheme in which farmers are compensated for loss of production in return for carrying out some conservation-friendly activity including set-aside.

6National policy changes, usually promoted by legislation or subsidy schemes. Bird-friendly changes include the growing of oilseed rape, which has probably benefited some seed-eating birds, notably Linnet and Reed Bunting (see text), and reduction in the use of organochlorine pesticides, which benefited some predatory birds, and probably also some seed-eaters.

7Based mainly on Breeding Bird Survey data, up until the year 2002: D, declining; I, increasing; S, stabilized at low level.
production of young (compare nest record data for Corn Bunting and Turtle Dove from Siriwardena et al. (2000) with seasonal data from Brickle & Harper (2002) and Browne & Aebischer (2003)).

Because of this difficulty, other means have been sought to provide reliable estimates of seasonal productivity. For example, Newton (1999) used end-of-breeding ratios of juveniles to adults in netted samples to assess the annual productivity of Bullfinches over a 5-year period (see also Proffitt et al. 2004). Similar trapping data, as from the BTO Constant Effort or other netting schemes, might provide reliable estimates of seasonal productivity in other species (du Feu & McMeeking 1991; Peach et al. 1996), providing that such measures are restricted to a brief period at the end of the breeding season, and at dates appropriate to the species concerned. The advantage of such measures is that they incorporate the effects, not only of brood numbers, but also of immediate post-fledging survival, which is another (usually unknown) component of reproductive success. Clearly, we need good measures of seasonal production, if we are fully to understand the demographic parameters that have underlain population declines.

In addition to the BTO data, other wide-scale or long-term information on some bird species is held by other organizations, such as the Game Conservancy Trust, the Centre for Ecology and Hydrology and the Royal Society for the Protection of Birds. Additional (usually shorter-term) information is held by the many individuals or university groups who have conducted detailed studies of individual species in particular localities. In recent years, most such field studies have been aimed mainly at addressing conservation problems (see later examples).

**COMPONENTS OF AGRICULTURAL INTENSIFICATION**

The main problem in finding causes of bird population declines is that agricultural intensification is not a single process, but has several components, each of which can affect different species. Moreover, these various aspects of change have occurred more or less simultaneously and interdependently, which makes the role of any one change hard to separate from the confounding effects of others. Thirdly, the problems have mostly been studied retrospectively, only after the agricultural changes and bird population declines had been underway for several years.

The main components of recent agricultural change in Britain can be listed as follows, while data on the extent or spatial scale of each type of change can be found in Chamberlain et al. (2000), Fuller (2000) and Shrub (2003):

1 Massive increases in the use of agro-chemicals, both pesticides and fertilizers. Rising pesticide use is reflected in increases in the range of chemicals used, the acreage treated and the numbers of applications per year. Some such chemicals, notably the organochlorine insecticides, have had direct effects on birds, causing reproductive failures or enhanced mortality (Newton 1979, 1986, 1998, Ratcliffe 1993), while others have affected birds indirectly through reducing their food supplies (Potts 1986, Newton 1995, 1998). Herbicide use reduces weed growth and seed production, which leads not only to loss of immediate food supply, but to long-term depletion of the seed bank in the soil. Progressive increases in the numbers of herbicides, modes of action and formulations available have gradually expanded the range of weed species that can be controlled effectively in each crop type. Weeds also support insects, which form important foods for some bird species (Potts 1986). Direct pesticide effects were evident in some birds of prey and (mainly in the years around 1960) some seed-eaters; indirect effects are evident in a wide range of seed- and insect-eaters.

2 Removal of hedges and other uncultivated areas to produce larger fields and more land for crop production. This activity has greatly reduced the amount of semi-natural habitat that existed within the agricultural matrix. Some bird species both nest and feed within such habitat, while others nest there but feed in neighbouring fields. In addition, mechanization has brought a change in hedgerow management, many former tall and thick hedgerows being converted to short, narrow ones, with effects on bird populations (for relationships between hedgerow structure, verge features, landscape context and bird populations, see Arnold 1983, Osborne 1984, Green et al. 1994, Parish et al. 1994, Macdonald & Johnson 1995, Gillings & Fuller 1998, Hinsley & Bellamy 2000). Such changes are likely to have affected most hedgerow-nesting species, and others using semi-natural habitats.

3 Change from spring ploughing to late summer ploughing of cereal stubbles soon after harvest. This change has removed the supply of spilled grain and other seeds on the ground, on which many seed-eaters formerly fed in winter, as well as the spring-sown grain itself, which was an important dietary component of several species at a time of year when other foods were scarce. It is likely to have affected all seed-eating species that fed in winter stubbles (for further
recent declines of farmland bird populations in Britain

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Discussion declines (Norris 1947, Aebischer et al. 2000). This procedural change also affected invertebrate food supply and weed seeds provided by fresh till in spring and the short-vegetation (including under-sown stubble) nesting and feeding habitat favoured by Lapwings, Skylarks, and others (autumn-sown cereals having grown too tall and dense by spring). Spring-sown cereal crops were also managed with less chemical input.

4 Extensive land drainage, which, through lowering the water-table, changed wet grassland to dry grassland or enabled a change to cereal culture. This has affected many dampland species, notably certain waders, but probably also other species, such as European Starling, which feed on invertebrates from near the soil surface.

5 The trend from mixed farms, producing a variety of plant and animal products, to monoculture arable (mainly in the east) or monoculture grassland (mainly in the west). This change has reduced the diversity of habitats available on individual farms, affecting species such as Lapwing, which depended on a localized mixture of habitats, or Skylark, which benefited from being able to move from one crop-type to another during the course of a single breeding season. It also led to a reduction in the area of root crops (important because of weed growth, Hancock & Wilson 2003), oats and other minority crops (providing seed-rich winter stubble), and the almost total elimination of bare fallow (an important habitat for several nesting species). Probably many species were affected by this change, including sparrows, finches, buntings and Skylarks (Robinson 2001).

6 The trend to earlier harvesting dates, caused by a combination of earlier sowing dates, earlier ripening cereal varieties and a change from hay to silage (grass harvested green at an earlier growth stage, allowing repeated cuts through the season). This means that more cultivation procedures (including harvest) fall within bird breeding seasons, causing greater destruction of eggs and chicks of field-nesting species, such as Yellow Wagtail and Corn Bunting (e.g. Crick et al. 1994, Court et al. 2001, Henderson et al. 2004). In at least the Corncrake and Stone Curlew, destruction of eggs and chicks can be sufficient to cause population declines (Norris 1947, Aebischer et al. 2000).

7 More intensive grassland management, involving use of inorganic fertilizer and more frequent reseeding (Vickery et al. 2001). The fertilizer stimulates grass growth, making it no longer suitable for some ground-nesting bird species, and eliminating through competition many broad-leaved plant species. Loss of plant diversity in turn reduces insect diversity and abundance. Re-seeding reduces invertebrate densities in the soil (which increase with age of grassland, Tucker 1992). The increase in grass growth can support increased densities of cattle or sheep, or more frequent cutting for silage, both of which result in greater destruction of eggs and chicks. This change is likely to have affected all grassland species. Moreover, the sward assumes a more uniform and denser structure, and generally lacks the tussocks favoured by many species of ground-nesting birds, or the bare patches in which they can feed.

8 In upland areas, a massive increase in sheep-stocking densities, which changes habitat structure, sward height and composition, and reduces plant flowering and seeding, together with the densities of insects, many of which are eaten by birds. Probably almost all species of open upland habitats are affected.

Over the years, increasing mechanization and technology have underpinned some of these changes, and at one time or another most have been encouraged by commodity price support and by payment of grants or subsidies, which made previously uneconomic practices profitable (for historical development of agricultural policy see Shrubb 2003). While some changes occurred more or less simultaneously over the whole country, others occurred earlier in the drier east than in the wetter west. The general trends were towards loss of grass to give more arable in the east, and loss of arable to give more ‘improved’ grass in the west, producing generally less diverse landscapes in both regions.

Processes leading to population declines

In studying population declines, it is important to distinguish between the external (environmental) factors that cause a decline and the intrinsic demographic factors (such as reduced survival or reproductive rate) that underlie the decline (Newton 1991, 1998, Green 1995). Thus, within suitable habitat, a population might be said to decline because of food shortage (the ultimate cause) or because of the resulting mortality (the proximate mechanism). In attempts to manage bird populations, it is the external limiting factors that must be changed before any lasting change in population level can be achieved; the necessary demographic changes will follow naturally. However, knowledge of the demographic changes can often help to pinpoint the external causal factors, or at least to distinguish whether
population decline is associated with reduced breeding production or reduced survival.

The series of events that lead to some population declines are short and simple. For example, the killing of chicks during grass-cutting can reduce the reproductive rate of Corncrakes to such an extent that it causes rapid population decline (Norris 1947, Green et al. 1997). This is a single-step process, which can be easily identified. Likewise, the destruction of clutches during the rolling and harrowing of arable fields in spring can lead to population decline in Stone Curlews (Green & Griffiths 1994). Population declines of other species are due to longer, multi-step sequences of events, which are much harder to work out. Some well-researched examples are given in Figures 1–4, and the Appendix.

CURRENT KNOWLEDGE OF POPULATION DECLINES AND EFFECTIVENESS OF CONSERVATION MEASURES

In this section, I discuss the state of current knowledge and conservation action for 30 species of birds that are thought to have declined in Britain because of some aspect of agricultural change. They do not include all such declining species, but those discussed have been well enough studied to examine in detail. Some of these 30 species, such as Corn Bunting and Grey Partridge, are obvious farmland specialists, while others, such as Merlin and Black Grouse, are not normally regarded as farmland species, but have nevertheless been greatly affected by changes in agricultural practice. For each of these species, six main questions are addressed:

1 What have been the agricultural drivers of population decline, e.g. drainage, herbicide use, increased stocking densities?
2 Have the above agricultural changes brought about reductions in habitat area, food or nest-sites, or increases in predation, parasitism/disease, human-induced mortality or competition, all of which fall under the heading of ‘external limiting factors’?
3 What are the demographic changes that have brought about population decline: reduced survival, reduced reproduction or both? As we are dealing with national populations, the effects of any change in movement patterns (immigration/emigration) can be ignored.
4 Has the proposed limiting factor (habitat, food or whatever) been tested by experiment or by local conservation action (as in nature reserve management or nest-site provision), resulting in increased breeding density?
5 Has the species concerned been shown to benefit by increased breeding density from any agri-environment scheme, including set-aside (leaving arable land fallow), or any other national policy change (but note that some existing schemes may not have operated for long enough to have yet promoted measurable changes in bird breeding densities)?
6 Has a previous substantial decline in population been reversed, giving a sustained and statistically significant increase over five or more recent years (up to 2002)?

My attempts to answer these questions, mostly from published research findings, are summarized in Table 1, which also gives footnotes on each species with supporting references. Although species have been studied individually, they fall readily into distinct groups, according to the dominant agricultural drivers.

Seed-eaters

In all ten species considered, the main causal factor identified was decline in food supply (Table 1, Fig. 1), but some species have also suffered considerable reduction in habitat (Bullfinch and Turtle Dove through loss of tall hedgerows, Twite through loss of saltmarsh wintering habitat, and Reed Bunting through drainage of wet areas), and the House Sparrow perhaps also from reduction in nest-sites. Declines in food supply were caused mainly by:

1 herbicide use, which reduces current-year weed-seed production, and leads to long-term depletion of the seed bank in the soil; and
2 loss of winter stubble fields, with their associated weed-seeds and spilled grain, resulting from the switch from spring-sown to autumn-sown cereals. The relative importance of these seed sources varies between species, depending on their dietary needs, and the House Sparrow has probably also suffered from the increased bird-proofing of stores for grain and other animal feed. Herbicide use also reduced the abundance of weed-dependent insects that some seed-eaters feed to their young.

At least six seed-eating species have experienced a decline in survival rate during the period of decline; and in at least four of these, the measured decline in survival was found in a modelling exercise to be capable of accounting for the observed rate of population decline, without any concurrent change in reproductive rate. At least three species have experienced decline in seasonal reproductive rate, and in one (Turtle Dove) this was deemed sufficient on its own to account for the observed rate of decline. Changes in the success of individual nesting attempts
were recorded in seven species (in five increases, in two decreases), but as explained above, in multibrooded species these measures do not necessarily translate into changes in seasonal production. They are therefore of limited value in our present context.

At least five seed-eating species showed increased breeding densities after the local introduction of agri-environment schemes. The spread of oilseed rape (from less than 1% of arable land in the 1950s to more than 8% in 2000) has almost certainly provided additional food for several species (notably Linnet) and also additional nesting habitat for Reed Buntings. In some seed-eating species, local increases resulting from management action have been insufficient to reverse overall downward national trends, although numbers of five species seem to have stabilized in the last few years (Table 1). The only seed-eater that has shown substantial increase in response to management is the Cirl Bunting, which is effectively confined to parts of one county. Its numbers increased about four-fold over 10 years in response to increased food supplies provided by a targeted agri-environment scheme.

**Other passerines**

The Skylark is one of the most studied species. Its decline is attributed to loss of habitat: the replacement of rough grassland by managed grassland, and of spring-sown by autumn-sown crops (which soon grow too tall for nesting Skylarks), and also to reduction in food availability (mainly insects in summer, small weed-seeds in winter). There are insufficient ring recoveries to check for possible changes in mortality rates, but the breeding season is curtailed in arable farmland because of rapid crop growth, through which the habitat becomes unsuitable. Although some Skylarks switch from one crop to another during the course of the breeding season, not all pairs now have access to such alternative habitat, leading to a net reduction in offspring production. Skylarks have responded by increased breeding density and seasonal success to the provision of unsown patches in cereal fields, to unsprayed set-aside fields and to local agri-environment schemes, but such local effects have not so far reversed the national population decline.
The Meadow Pipit has suffered from loss of habitat (notably rough grassland), and probably also from decline in insect food supplies consequent upon overgrazing (see studies of Black Grouse), but is the least known of all the species listed in Table 1, and is in obvious need of further study. The Yellow Wagtail nests both in wet grassland and in dry, sparsely vegetated arable land. It has suffered from large reductions in nesting habitat, resulting from the drainage and more intensive management of grassland, and from the change from spring-sown to autumn-sown arable crops, which grow too tall and thick by spring. It has responded by increased density to raised water levels (and winter flooding) of some grassland nature reserves. The Starling has experienced a massive reduction in food supply, caused mainly by land drainage and more intensive grassland management, which has reduced the availability of invertebrates in the surface soil, and by reductions in the number of accessible feed-sites for farm stock. In some eastern areas, the conversion of former grassland to arable has also reduced the acreage of potential foraging habitat. Long-term population decline has been associated with reduced survival, and (in a Finnish study) with reduced breeding success. The Blackbird and Song Thrush have suffered from loss of habitat (especially hedgerows and field margins), and may also have experienced reductions in food supplies resulting partly from greater field drainage, which makes soil invertebrates less accessible. Both have experienced reduced survival, deemed sufficient in a modelling exercise to account for the observed rate of decline in the 1970s and 1980s, but both have shown some population recovery since 1994. Various management changes and predator control at the Allerton Research and Education Trust farm in Leicestershire were followed by substantial increases in the breeding density and seasonal productivity of both species, but as all changes were brought in simultaneously, it is as yet uncertain which were most important.

Waders, Corncrake and gamebirds

Four species have suffered mainly from the drainage of damp grassland. It is difficult to decide whether to put their declines down to loss of habitat or to loss of food, because as the ground dries, soil invertebrates become less accessible (Fig. 2). Drainage is usually followed by ploughing, re-seeding and fertilizer application, which in turn leads to more uniform sward structure, more rapid grass growth, decline in non-grass plant species (and associated insect populations), earlier and more frequent mowing, or increased stocking densities with sheep or cattle. Increased livestock numbers lead to greater disturbance of nesting birds (which may in turn lead to increased egg and chick predation), and increased trampling of nest contents. Nest failure rates have been quantified in relation to stocking densities of cattle and sheep from studies in The Netherlands (Beintema & Muskens 1987, Beintema et al. 1997). In addition to the effects of land drainage, Lapwings have largely disappeared from former mixed farming areas, which no longer offer the combination of spring-sown arable and unimproved grass fields in close proximity. In all four species, decline in population was associated with reduced reproductive success, and in two of them, reduced reproduction was deemed sufficient on its own to account for observed rates of decline.

At least three of the four dampland wader species listed in Table 1 have increased in numbers and nest success following the raising of ground-water levels on grassland nature reserves, and the Lapwing has responded in a similar way to at least one agri-environment scheme. However, the overall national populations of at least three species are still in decline, the Snipe having increased slightly in BBS

![Diagram](image-url)
counts in the last 8 years (as opposed to declining in surveys of wet meadow birds).

In the Stone Curlew, population decline has been attributed partly to loss from many areas of sparsely vegetated spring arable land, and short-sward semi-natural dry grassland, and partly to destruction of eggs and chicks on remaining suitable arable areas by farm machinery. Similarly, in the Corncrake, decline is attributed partly to loss of damp meadows, and partly to the destruction in remaining meadows of eggs and chicks during mechanized grass cutting. In earlier centuries, the losses were smaller because grass was cut by hand and later in the year, as it was used to make hay rather than silage. In both species, local conservation action, within the framework of appropriate agri-environment schemes, has greatly reduced nest losses, resulting in increased national population levels.

The three gamebirds listed in Table 1 have all suffered from loss of habitat and food supplies. When populations decline, landowners tend no longer to employ gamekeepers, and predation rates rise, further contributing to population declines. In the Grey Partridge, decline seems to result in the first instance mainly from reduction in the abundance of insects eaten by chicks, but reduction in field margins results in a scarcity of nesting habitat (and the more weed-rich and insect-rich cropland at the edges of fields, Green 1984), while lack of predator control results in greater predation both on nest contents and on adults, the incubating females being especially vulnerable. The series of events leading to population decline (Fig. 1) has been confirmed by experiment, and Grey Partridge populations have increased in response to local conservation measures (including the non-spraying of field edges) and agri-environment schemes, and the overall national population seems to have stabilized at a low level.

In Black Grouse, which are now mainly confined to moorland and other rough grazing land in the uplands, numerical declines have been attributed primarily to increased stocking densities, which reduce the sward height and the diversity of plant populations (Fig. 3). Insects suitable for chicks decline in abundance, leading to greatly reduced chick survival, and hence to population decline. Populations in several experimental areas have responded to reduced livestock densities (and greater insect abundance),

Figure 3. Proposed sequence of events through which the overgrazing of open upland vegetation causes population declines in grouse and other species. The relative contributions of food-plant reduction (route A) and insect reduction (route B) seem to have varied between species. For references, see Appendix.
I. Newton

Birds of prey

Three raptor species suffered massive population declines in the late 1950s and 1960s through the direct effects of organochlorines on breeding success and survival (Fig. 4). These chemicals are persistent, and highly fat-soluble, so they accumulated in the tissues of prey species, from which they concentrated to even higher levels in some raptor species. The chemical DDE (the main metabolite of the insecticide DDT) caused eggshell thinning, which led to egg breakage and reduced breeding success, while the more toxic cyclodiene compounds (aldrin and dieldrin) killed birds outright. These various effects were tested on captive birds of related species. As a result of these and other findings, the use of organochlorines was progressively reduced over a period of years, and almost ceased from 1986 onwards. Accordingly, the three species that had been most affected in Britain (Sparrowhawk, Peregrine and Merlin) steadily recovered through the 1970s and 1980s, and in 20 years they had recolonized regions from which they had been extirpated. This is a major conservation success story, and the main threat to these birds may now stem from declines in their various prey species or from illegal persecution.

Two other birds of prey, the Kestrel and Barn Owl, also suffered from organochlorine use, but showed only regional population declines, from which they rapidly recovered in the 1970s (Newton et al. 1991, 1999). Since then, they have declined more generally, owing mainly to the loss and overgrazing of...
rough grassland that supports their principal prey species, the Field Vole Microtus agrestis. In addition, both have suffered, at least in some areas, from reductions in the availability of nest-sites, mainly tree cavities, but (in the Barn Owl) also disused cottages and farm buildings. Both species have responded by increased breeding density and success to improvements in food supply (brought about by fencing out sheep from rough grassland) and by provision of artificial nest-sites in areas where natural sites were scarce. Unless the trends in grassland management and nest-sites can be reversed, these two species seem destined to decline further.

**SUMMARY OF FINDINGS**

Of the various changes on farmland in recent decades, four emerge as the major drivers of declines in bird populations: (1) pesticide use (especially herbicides); (2) late summer ploughing of cereal stubbles, followed by rapid re-sowing and early crop growth; (3) drainage and intensification of lowland grassland management; and (4) increased stocking densities (mainly cattle in the lowlands and sheep in the uplands). Each of these changes has had serious effects on a wide range of species. Other changes, such as the removal of hedgerows and earlier harvesting of grass and cereals, have affected a smaller range of species. Most of these changes have resulted in reductions in bird habitats and/or food supplies, which have emerged as the main limiting factors underlying population declines in 27 of the 30 species considered (the only exceptions being the three raptor species whose populations collapsed following the introduction of organochlorine insecticides) (Table 2). Other evidence for the importance of food supplies has come from studies of crop damage, where breeding or wintering densities, survival or predation rates have been recorded as higher than in the past. Several species of predators, notably Red Fox Vulpes vulpes, Carrion Crow Corvus corone and Magpie Pica pica, have increased in numbers during recent decades. Their increases have been attributed to reductions in the numbers of game-keepers, and to increases in food supplies, contingent upon changes in land-use. In upland areas, increased sheep densities have led to ecological overgrazing in many areas, and to increased sheep mortality, which has provided more carrion. In lowland areas, the decline in Grey Partridge numbers has encouraged many landowners to rear and release large numbers of Pheasants Phasianus colchicus and Red-legged Partridges Alectoris rufa, an activity which also provides more food to sustain predator populations. The greater areas of short-sward grassland may also have favoured corvid populations, as it provides additional foraging habitat for these birds.

Yet other studies have linked the temporal change in regional or local agricultural practice with the timing of declines in invertebrate and bird densities (Benton et al. 2002).

Predation has not emerged as the main causal factor for any of the species considered, only as a secondary or associated factor, chiefly in ground-nesting birds. All the species listed, as with most other bird species in Britain, suffer from predation, and in some species predation rates have been recorded as higher than in the past. Several species of predators, notably Red Fox Vulpes vulpes, Carrion Crow Corvus corone and Magpie Pica pica, have increased in numbers during recent decades. Their increases have been attributed to reductions in the numbers of game-keepers, and to increases in food supplies, contingent upon changes in land-use. In upland areas, increased sheep densities have led to ecological overgrazing in many areas, and to increased sheep mortality, which has provided more carrion. In lowland areas, the decline in Grey Partridge numbers has encouraged many landowners to rear and release large numbers of Pheasants Phasianus colchicus and Red-legged Partridges Alectoris rufa, an activity which also provides more food to sustain predator populations. The greater areas of short-sward grassland may also have favoured corvid populations, as it provides additional foraging habitat for these birds.

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**Table 2. Summary of existing knowledge and conservation action for 29 species in Britain whose populations have declined during the past 50 years in association with agricultural changes. From data in Table 1.**

<table>
<thead>
<tr>
<th>Causal Factor</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agricultural driver known</td>
<td>30</td>
</tr>
<tr>
<td>External causal factor known</td>
<td>30</td>
</tr>
<tr>
<td>Demographic causal factor known</td>
<td>24</td>
</tr>
<tr>
<td>Experimental test positive</td>
<td>15</td>
</tr>
<tr>
<td>Local conservation action, positive response</td>
<td>10</td>
</tr>
<tr>
<td>Agri-environment scheme positive response</td>
<td>12</td>
</tr>
<tr>
<td>Other policy change, positive response</td>
<td>3 (+2)</td>
</tr>
<tr>
<td>National population increase</td>
<td>8 (27%)</td>
</tr>
</tbody>
</table>

1Habitat reduction 20 species, food reduction 25 species, nest-site reduction three species, pesticide poisoning three species, agricultural operations two species, predation four species, parasites/pathogens one species, competition no species (see text).

2Species: 1, 2, 4, 6–11, 14–28.

3Species: 1, 2, 7, 11, 15–17, 22–24, 26–30.

4Species: 13, 17, 18, 20–24, 29–30.

5Species: 1, 6–9, 11, 14, 17, 21–24.

6Species: 3, 8, 26–28.

7Species: 7, 15, 16, 18 (see text), 21, 22, 27, 28.

Species numbered as in Table 1.

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Some land-use changes may predispose prey species to extra predation (Evans 2004): examples include the draining and re-seeding of grassland, which supposedly makes ground nests more visible or accessible to predators; hedge removal, which for some species concentrates nests in smaller areas of remaining habitat that are easier for predators to search; and reductions in food-supplies, which make hungry passerine broods call more, and attract the attention of predators (e.g. Evans et al. 1997, Brickle et al. 2000). Nest success of some species in different areas has been correlated with densities of predators (notably corvids, Stoate & Szczur 2001), and predator removal studies have led to increased nest success and breeding density in a number of species, including Red Grouse, Golden Plover Pluvialis apricaria and Lapwing on heather moors (Tharme et al. 2001), and Grey Partridge, Song Thrush, Blackbird and other passerines on farmland (Tapper et al. 1996, Stoate & Szczur 2001, Donald et al. 2002). On the other hand, no relationships emerged between local trends in songbird numbers and local trends in Magpie or Sparrowhawk numbers, two predators sometimes suspected of causing declines in songbird populations (Gooch et al. 1991, Dix et al. 1998, Thomson et al. 1998).

Disease is hard to detect in wild bird populations, but ‘louping ill’ has emerged as a factor leading to decline in Red Grouse densities in some areas. This viral disease often kills grouse, but persists in alternative hosts, which include sheep. Its incidence in grouse has increased greatly on some moors on which sheep densities are high, leading to marked declines in grouse densities. Because of its dependence on high sheep densities, frequent louping ill can be regarded as another legacy of recent agricultural policy.

Most species of birds overlap in their dietary and other needs with other bird species and with other animals. Resources used by one species are not then available to another. It is reasonable to suppose therefore that the densities of many species are lower than they might otherwise be, because of competition for shared resources, but the effects of competition are not necessarily greater now than in the past. So far as I am aware, increased competition has not been suggested as a factor in farmland bird declines. However, it is perhaps one additional factor worth examining in the House Sparrow. In former times, when House Sparrows were at their peak abundance, they were the only birds that lived in towns in such close association with people. They had access to everything edible that people provided. Their recent decline in urban areas has occurred over a period when increasing numbers of other seed-eaters (including Collared Doves Streptopelia decaocto) have been attracted into gardens by special food provision. It would be surprising if these other species did not also remove some food items that would formerly have been available to House Sparrows. In addition, the effect on other birds of releasing 20–30 million Pheasants into the countryside each year has never been assessed. Pheasants are normally fed with grain for most of the year (late summer to spring), which could benefit other birds, but they also find some of their own food, which could adversely affect other species.

Agricultural operations, leading to destruction of eggs or chicks, have been identified as a major causal factor in the population declines of two species (Stone Curlew and Corncrake), but also contribute to nest failures in other ground-nesting species, especially during the harvest of silage (for Skylark see Poulsen et al. 1998) or early ripening cereals (for Corn Bunting see Crick et al. 1994, Brickle & Harper 2002; for Montagu’s Harrier Circus pygargus in Europe see Arroyo et al. 2002).

Apart from the raptors affected by organochlorine pesticides, only three species that had declined have shown substantial increases in at least the last 5 years, namely Cirl Bunting, Corncrake and Stone Curlew. These three all have restricted distributions within Britain, and relatively small populations confined to farmland, which can be managed intensively within the framework of agri-environment schemes. Without continued year-by-year management, these species would all decline, and probably become confined to nature reserves or disappear from Britain completely within a few years. For three other species, BBS indicates smaller, but significant, increases over the past five or more years, namely Blackbird, Song Thrush and Snipe, although the evidence for the Snipe is equivocal (see Appendix).

Although it is too early to assess properly the effects of recently introduced agri-environment schemes, earlier schemes were most successful when targeted to the needs of particular species, such as Cirl Bunting, Lapwing, Stone Curlew and Corncrake, and of some seed-eaters through winter seed provision (Aebischer et al. 2000, Bradbury & Allen 2003). More recent schemes have led to localized increases in the breeding and wintering densities of several other species (Bradbury et al. 2004), but without detailed study, it is as yet uncertain whether these local...
increases were due to immigration, rather than to the improved survival and breeding success of local birds. Only a general improvement in survival or offspring production could lead to recovery of national populations. While reversing the declines in farmland birds requires substantial changes to existing farming systems, such changes do not necessarily require a reversion to previous systems, providing that appropriate management practices can be incorporated in other ways.

Considering the massive changes that have occurred on farmland in recent decades, during the drive for intensive crop production, it is perhaps surprising that not all species have declined. However, the few species involved have benefited in other ways, and a plausible reason for their lack of decline is usually apparent. For example, Woodpigeons Columba palumbus were once largely dependent in winter on the clover sown into cereal stubbles. As this crop disappeared in the 1960s, Woodpigeons began to decline, but soon increased again when a substitute winter food-supply, namely the young leaves of oilseed rape, became widely available (Inglis et al. 1990). Stock Doves Columba oenas have also increased greatly since the 1960s. Their numbers had previously been greatly reduced by organochlorine pesticides (O’Connor & Mead 1984), so at least part of their increase represents population recovery following reductions in organochlorine use, but latterly they may also have benefited from the spread of oilseed rape, the leaves of which form an important winter food. It is perhaps more surprising that three species of finches have not declined, namely Chaffinch Fringilla coelebs, Greenfinch Carduelis chloris and Goldfinch Carduelis carduelis. However, Chaffinches are major beneficiaries of Pheasant feed sites, which are maintained throughout the winter, and Chaffinches and Greenfinches have fed increasingly in gardens since the 1960s, following the provision of peanuts and other suitable seeds. The same is true for Goldfinches since the early 1990s, but in any case a large proportion of Goldfinches that breed in Britain winter further south, mainly in Spain where some favoured food-plants grow and seed throughout the winter (Newton 1972). However, further work is needed to determine whether these plausible guesses can be turned into well-founded fact.

In conclusion, gaps still exist in our understanding of the causal factors behind the declines in some species affected by agricultural change, as indicated in Table 1. In lesser-known species not discussed in detail here, such as Ring Ouzel Turdus torquata and Whinchat Saxicola rubetra, population declines may well be due to one or more of the same causal factors, in which case these species could also benefit from remedial measures designed for better-studied species. Despite the gaps in our knowledge, the main drivers of bird population declines are now clear, and it is these drivers that must be addressed if recoveries are to occur. One obvious way to reverse population declines would be to revert to traditional systems of land use, but such changes seem unlikely to happen, except on the small scale possible on nature reserves and other special sites. Alternatives include encouraging farmers to adopt different procedures, or finding different ways, within the context of modern agriculture, of providing the food or other resources that birds and other wildlife require. Both of these options require a shift in the subsidy system, so that farmers do not suffer financially from adopting more benign practices. Recent reforms to the Common Agricultural Policy, notably the de-coupling of subsidies from crop and meat production, may provide opportunities for more widespread conservation management. The main immediate requirements, however, are for continued monitoring of bird populations, at local as well as national levels, in order to assess the effectiveness of existing and new agri-environment schemes. Only by careful appraisal of the application and consequences of these schemes can their prescriptions be modified in future to achieve greater environmental benefits.

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REFERENCES


Recent declines of farmland bird populations in Britain


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**APPENDIX**

**Species notes and references to Table 1**

House Sparrow *Passer domesticus* – Declined in urban as well as in rural areas; several causal factors mooted, including decline of food supply (insects and seeds), increased predation from an expanding cat population, increased pollution from traffic in cities, and in some areas reduced availability of nest-sites (stemming from building repairs and conversions), but further work needed. In one experiment, responded to provision of extra food on some farms where numbers previously declined, but not on others where numbers were previously stable or increasing (Hole et al. 2002). Decreased survival during the years of...
decline (Siriwardena et al. 1999); also increased nest success (Siriwardena et al. 2000), but no information on possible change in duration of breeding season or total seasonal productivity. Other reference: Freeman and Crick (2002).

Tree Sparrow Passer montanus – National population decline has exceeded 95%. In local conservation projects has benefited from provision of winter food (small seeds) and nestboxes, especially when sited near water, where insects are still plentiful (Field & Anderson 2004). Showed increased nest success during the years of decline, but no information on possible changes in duration of breeding season or total seasonal productivity (Siriwardena et al. 2000).

Linnet Carduelis cannabina – Reduced survival and nest success during the years of decline (Siriwardena et al. 1999, 2000), but no information available on possible change in duration of breeding season or on total seasonal productivity. In a French study, annual variations in production of fledglings influenced year-to-year population increase (Eybert et al. 1995). For importance of oilseed rape as a food source, see Moorcroft et al. (1997) and Moorcroft and Wilson (2000).

Twite Carduelis flavirostris – Has suffered in summer from loss of weeds from meadows near the moorland edge (through improved grassland management), and in winter from loss of weeds from arable land, and especially from loss of winter feeding areas of coastal saltmarsh, which have been converted to farmland (Atkinson 1998, Dierschke 2002). Additional reference: Brown et al. (1995).

Bullfinch Pyrrhula pyrrhula – Adverse habitat changes involving loss of tall thick hedgerows from farmland and loss of understorey shrubs from many deciduous woods (often through increased deer browsing). These changes also involve loss of food-plants, in addition to loss of farmland weeds. Furthermore, recovery of Sparrowhawk numbers may have confined Bullfinches to feeding close to cover (through a behavioural response), and thus reduced the total land area over which they can forage, compared with the 1960s (Newton 1967). The demographic cause of decline is uncertain (Siriwardena et al. 2001), but higher nest success was recorded during the decline (Siriwardena et al. 2000), with no information on possible change in duration of breeding season or total seasonal productivity. The latter is greatly influenced by the amount of late summer nesting (Table 1; Newton 1999, Proffitt et al. 2004).

Yellowhammer Emberiza citrinella – Breeding densities in different parts of Britain strongly correlated with the proportion of land under arable crops, with crop diversity and with hedgerow length. Decline began later than in some other seed-eaters, and most marked following loss of minority cereal crops from western areas now dominated by grass and non-cereal crops (Kyrkos 1997, Kyrkos et al. 1998). Individual nest success was higher during years of population decline (Siriwardena et al. 2000), but in one study on nine scattered farms total seasonal productivity was too low to maintain a stable population (Bradbury et al. 2000).

Cirl Bunting Emberiza cirlus – Decline attributed to lack of insect food for chicks in breeding season, and seeds in winter. Appropriate conservation measures, within the framework of an agri-environment scheme, promoted an increase in food-supplies, leading to a four-fold increase in the remnant population within 10 years (Evans & Smith 1994, Evans 1997, Wotton et al. 2000, Peach et al. 2001).

Reed Bunting Emberiza schoeniclus – Probably suffered from both land drainage and destruction of ‘rank patches’ (reducing nesting habitat) and decline in food supply (insects in summer, weed and grass seeds in winter). During the years of decline (1975–83) breeding numbers fell rapidly on arable and mixed farms, but remained relatively stable on pastoral farms (Peach et al. 1999). The decline was greater in northern Britain than in the southeast. Annual survival was lower during the years of decline (Peach et al. 1999), as was nest success (Siriwardena et al. 2000), and recent study suggests a decline in total seasonal productivity in some areas (Brickle & Peach 2004). Oilseed rape crops and small wetland features (such as ditches) now provide most nesting places in farmland. Additional reference: Burton et al. (1999).

Corn Bunting Miliaria calandra – National population decline has exceeded 80%. Fewer birds now raise a second brood than in the past, reducing the seasonal production of young (Brickle & Harper 2002), but success per nesting attempt was recorded as slightly higher during the years of decline (Crick 1997; Siritwadena et al. 1998). Nest survival was lower in localities with little invertebrate chick food (owing to pesticide use), which led to chick starvation and predation (Brickle et al. 2000). Population decline in Schleswig-Holstein, Germany, was attributed to increased chick starvation (Busche 1989). Benefits from low-input spring-sown cereals (barley), associated weedy winter stubbles and wide field margins. Other references: Donald and Evans (1994), Brickle and Harper (1999), Crick (1997), Donald and Forrest (1995), Donald et al. (1994).
Turtle Dove *Streptopelia turtur* – Decline attributed to reduction of tall hedgerows used for nesting and weed-seeds used as food (Browne & Aebischer 2001). Increased nest success recorded during the years of decline (Siriwardena et al. 2000), but reductions in duration of breeding season and in total seasonal productivity (Browne & Aebischer 2001, 2003).

Skylark *Alauda arvensis* – Adverse habitat changes include loss of rough grassland, switch from spring-sown to autumn-sown cereals (which grow too tall for nesting in spring), and conversion of mixed farms to cereal or intensive grass monocultures (Chamberlain & Gregory 1999); food shortages involve summer insects and winter seeds (Jenny 1990, Odderskaer et al. 1997). Breeding densities tend to be higher in permanent grass and set-aside than in autumn-sown or spring-sown cereals (Poulson et al. 1998; Wakeham-Dawson et al. 1998, Chamberlain et al. 1999a, Eraud & Boutin 2002); crops that do not favour breeding Skylarks, such as autumn-sown cereals and rape, have become increasingly prevalent in recent decades. Nest success was higher during the years of decline (Siriwardena et al. 2000), but several studies suggest reduction in the duration of the breeding season, because of earlier crop growth and lack of alternative habitat locally (a consequence of greater arable monoculture) (O’Connor & Shrubbs 1986, Wilson et al. 1997, Chamberlain & Crick 1999). No information on possible change in mortality. Breeding densities and seasonal productivity increased following the provision of unscoured patches (4-m squares at two per hectare) in autumn-sown cereal fields (Morris et al. 2004). Other references: Green (1978), Shläpfer (1988), Donald et al. (2001a, 2002), Robinson (2001), Pierce-Higgins and Grant (2002).

Meadow Pipit *Anthus pratensis* – In lowland, decline associated with loss of patches of rough grass. In upland, reduced breeding densities evident in heavily grazed, shorter swards (Vanhinsberg & Chamberlain 2001, Pierce-Higgins & Grant 2002). Intensive grazing of heather moorland encourages the replacement of heather by grass, which favours Meadow Pipits, whose densities decline under further grazing, which reduces sward height and diversity, and associated insect densities (Smith et al. 2001). No relevant data on demographic changes during the years of decline.

Yellow Wagtail *Motacilla flava* – Breeds in damp grassland and in dry sparsely vegetated arable land (Mason & Lyczynski 1980, Nelson 2001). Decline attributed to drainage and reductions in the area of damp grassland, and generally more intensive grassland management, and to change from spring-sown to autumn-sown crops. Decline most marked in pastoral regions (Chamberlain & Fuller 2001). No published information on possible change in reproductive or mortality rates, or on possible effects on population levels of events in African wintering areas. Yellow Wagtails have responded with increased breeding density to raised water levels in some grassland nature reserves. Additional references: Bradbury and Bradter (2004), Henderson et al. (2004).

Starling *Sturnus vulgaris* – Reduction of food supply caused by conversion of former grass to arable in eastern districts, and by more intensive management of grassland generally, leading to reduction in soil invertebrates, and also by reduction in the numbers of accessible feed-sites for farm stock. Reduced survival during the years of decline recorded for Britain, and reduced reproductive rate recorded in Finland (Tiainen et al. 1989). Other references: Feare (1994), Whitehead et al. (1995), Freeman et al. (2002).

Blackbird *Turdus merula* – Decline associated with loss of hedgerows and field boundaries, and land drainage which reduces food availability. In The Netherlands, the main demographic change was reduced annual survival (Dix et al. 1998). Increased breeding density and success followed various conservation measures (including predator control) at the Game Conservancy Trust’s farm in Leicestershire (Stoate & Szczur 2001).

Song Thrush *Turdus philomelos* – Decline associated with loss of hedgerows and field boundaries, and land drainage, which reduces food availability. Main demographic cause assessed as reduced survival, especially in years of prolonged summer drought or winter frost (Baillie 1990, Thomson et al. 1997, Robinson et al. 2004), judged as sufficient in a population model to account for decline at the observed rate, without any concurrent change in reproduction (Robinson et al. 2004). However, in one study, the breeding season was shortened in a dry arable area, compared to a more mixed farming area, leading to reduction in seasonal production of young, also judged as sufficient to cause population decline (Peach et al. 2004). Increased breeding density and success followed various conservation measures (including predator control) at the Game Conservancy Trust’s farm in Leicestershire (Stoate & Szczur 2001).

Lapwing *Vanellus vanellus* – Main adverse habitat change associated with the drainage of wet grassland (Fig. 2); also conversion of mixed farms to arable or ‘improved’ grass monocultures; change from spring-sown to autumn-sown cereals (which reduces the area of spring tillage, favoured for nesting); and
increased stocking densities on grassland (which leads to more disturbance, nest predation and trampling) (Beintema & Muskens 1987, Baines 1988, 1989, Beintema 1988, Galbraith 1988, Shrub 1990, Shrub & Lack 1991, Hudson et al. 1994, Wilson et al. 2001, Hart et al. 2002). No change in annual survival during the years of decline (Peach et al. 1994), so reduced reproduction proposed as the demographic cause; and in some local populations annual production measured as insufficient to offset expected annual mortality (e.g. Galbraith 1988). Seasonal productivity lower on improved than on unimproved grassland, owing to fewer replacement clutches and poorer chick survival (Baines 1989). In some localities, single pairs and small groups are more vulnerable to egg predation than larger groups, owing to the reduced effectiveness of communal nest defence (Seymour et al. 2003). Lapwings have responded with increased breeding density to local reserve management and agri-environment schemes (Ausden & Hirons 2002, Bradbury & Allen 2003). Additional references: Baines (1988, 1989), Crick et al. (1998), Shrub (1990), Henderson et al. (2001, 2003), Sheldon et al. (2004).

Snipe Gallinago gallinago – Main adverse habitat change is the drainage of wet tussocky grassland (e.g. Baines 1988). Even in some areas where birds still breed, the nesting season is shortened because the ground dries out earlier in the breeding season, leading to reduction in seasonal productivity (Green 1988a). Snipe have responded with increased breeding density to raised water levels in some grassland nature reserves but not in others (Ausden & Hirons 2002). Two count schemes gave conflicting results, BBS indicating an increase in recent years, and breeding wader surveys in meadows a steep decline. Additional reference: Crick et al. (1998).

Curlew Numenius arquata – Main adverse habitat change is the drainage of rough wet grassland (e.g. Baines 1988). High predation rates on eggs in some areas, such as Northern Ireland, where measured reproductive rates were too low to sustain populations and could account for recent rates of population decline (Grant et al. 1999). Fragmentation of habitats may also allow Foxes to search nesting places more efficiently. Other references: Berg (1992, 1994).

Redshank Tringa totanus – Main adverse habitat change is drainage of wet grassland (e.g. Baines 1988). On coastal saltmarsh, breeding densities declined more markedly during 1985–96 on sites that had experienced an increase in grazing pressure, from ungrazed/lightly grazed to moderately/heavily grazed, although some grazing by cattle was deemed beneficial to sward structure (Norris et al. 1998). Redshanks have responded with increased breeding density to raised water levels in some grassland reserves (Ausden & Hirons 2002).


Corncrake Crex crex – Main decline attributed to earlier and mechanized grass cutting (Norris 1947), but drainage and intensive grass cutting has also removed much previously suitable nesting habitat (Stowe et al. 1993). One of the last remaining populations of Corncrake in Ireland is in the Shannon ‘callows’, where mowing is forced late by unregulated winter and spring flooding (Shepherd & Green 1994). Breeding success and breeding density in various areas increased in response to later and more careful grass cutting (Green & Stowe 1993, Green et al. 1997, Green 1999, Green & Gibbons 2000).

Grey Partridge Perdix perdix – Population decline has exceeded 85%. One of the most thoroughly studied species, with proposed mechanisms tested by experiment (Fig. 1, Potts 1986, Rands 1985, Potts & Aebischer 1995, Tapper et al. 1996). Other references: Green (1984), Bro et al. (2000).

Black Grouse Lyrurus tetrix – Heavy grazing of moorland habitat causes decline in food-plants (for full grown birds) and insects (for chicks) (Fig. 3; Baines & Hudson 1995, Baines 1996, Jenkins & Watson 2001). Local populations responded, with improved breeding success and breeding densities, to reduced grazing within the framework of an agri-environment scheme, and some also responded in the same way to predator control (Calladine et al. 2002, Warren & Baines 2004).

Red Grouse Lagopus l. scoticus – Predation by raptors (especially Hen Harriers Circus cyaneus) can cause substantial population decline (Redpath & Thirgood 1997), but because some raptors and other predators are controlled on most grouse moors, long-term declines in Red Grouse densities are more often associated with loss of heather through overgrazing (Redpath & Thirgood 1997, Jenkins & Watson 2001). High sheep numbers in some areas also raise the incidence of louping ill, which is often lethal to grouse, accounting for some local declines (Duncan et al. 1979, Hudson & Dobson 1991).
Barn Owl *Tyto alba* – Main adverse habitat change is the loss or overgrazing of rough grassland, which supports the main prey species, the Field Vole *Microtus agrestis*; also loss of nest-sites through hedgerow tree removal and ‘barn conversion’, and collapse of old, disused cottages, previously suitable (Shawyer 1987, Ramsden 1998, Newton 2002). Population assessments in 1982–85 and 1995–97 put national numbers at 4500 pairs and 4000 pairs, respectively, but numbers fluctuate greatly from year to year, and the two figures result from different methodology, so may not be comparable (Shawyer 1987, Toms *et al*. 2001). Has responded by increased density and breeding success to the fencing out of sheep from areas of grassland (as in afforestation projects), and by increased breeding density to the provision of nestboxes in areas with insufficient nest-sites (Newton 2002).

Sparrowhawk *Accipiter nisus*, Merlin *Falco columbarius*, Peregrine *F. peregrinus* – Main declines from late 1950s to early 1960s, associated with the heavy use of organochlorine pesticides (Fig. 4). Populations recovered in subsequent decades following progressive reductions in organochlorine use, and their replacement by less persistent insecticides (Newton 1979, 1986, Ratcliffe 1993, Newton *et al*. 1997, 1999). The Sparrowhawk has stabilized or may have been in regional decline since about 1994.

Kestrel *Falco tinnunculus* – As for Barn Owl, except that old buildings are much less important as nest-sites (Village 1990).