Relationships between recent changes in lowland British agriculture and farmland bird populations: an overview

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Agriculture has a long history of impacts on bird populations in Britain but the last 50 years have been marked by a remarkable increase of agricultural productivity that has profoundly altered farmland as a habitat for birds. There is close coincidence between the timing of changes in breeding bird numbers on farmland and the timing of fundamental changes within farming systems. The period between 1970 and the late 1980s was marked by progressive changes in both arable and grassland farming. Large declines in specialist farmland birds (ones that depend on fields for nest sites or food) became evident in the mid 1970s. Potential mechanisms by which these two sets of events are likely to be connected are reviewed. Changes in farming practices have affected food resources and habitat quality for birds at all seasons. The majority of farmland specialists have continued to decline since the late 1980s, even though the rate of change in agriculture has slowed. This suggests that a new carrying capacity for farmland birds has not yet been reached.

Agricultural activities are among the very strongest influences on the bird populations of Britain. Managed permanent grassland and arable land make up approximately 45% of the total land area of Great Britain and 59% of England and Wales (Barr *et al*. 1993, MAFF and SOAEFD June Census for 1995). Furthermore, lowland landscapes in Britain are highly fragmented and semi-natural habitat often survives merely as isolated patches embedded in intensive farmland. Consequently, the total numbers of birds living on, or in close proximity to, farmland is very high and for some species represents a large proportion of the British population (Gregory & Baillie 1998). Even birds living mainly within semi-natural habitats are not isolated from agriculture because they may be affected by spray drift and they may forage on farmed land at particular times of year or at certain stages of their life cycle, for example Golden Plovers *Pluvialis apricaria* that breed at high latitude but winter on western European farmland.

There have been at least three historical phases of agricultural change in recent centuries with particular significance for birds. Enclosure of open fields and common land from the 17th century onwards triggered continuing loss of rough grassland and heathland, and opened the way for progressive orderliness in the countryside and a range of agricultural innovations, especially in arable farming. Enclosure and associated habitat loss had immediate impacts on populations of open-country species, such as Great Bustard *Otis tarda* and Stone-curlew *Burhinus oedicnemus*. Inevitably, the new structures that were steadily imposed on the countryside affected a much wider range of species. The virtual disappearance of birds such as Whinchat *Saxicola rubetra* from the lowlands by the end of the 20th century can be regarded as the culmination of processes initiated some 300 years earlier. It is also worth noting that this phase of agricultural development actually generated new resources for some farmland birds, for example in the form of new crops such as roots and clover. The second major phase was the agricultural depression of the early 20th century that saw a general reduction in arable farming and abandonment of some farmland (Grigg 1989). Resources for birds associated with tilled land would probably have declined in many areas but some grassland birds and scrub-nesting birds would presumably have benefited. Waders that breed in wet undrained grassland, including Redshank *Tringa totanus*, Snipe *Gallinago gallinago* and Curlew *Numenius arquata*, increased in several lowland regions at this time (e.g. Brucker *et al*. 1992, Lack & Ferguson 1993). The depression years did not recreate habitats that were lost as a result of enclosure, rather they resulted in new habitats being formed, especially through abandonment of grassland. The third phase, the intensification that started with the drive for self-sufficiency during the Second World War, forms the focus of this paper.

This latest period of agricultural change is distinguished from those of earlier times by the application of a wide range of technology to elevate farming efficiency and yields to extraordinary levels. Wheat yields, for example, have risen inexorably and have more than doubled since 1950 (Fig. 1). In this paper, I summarise the key components of change in farming systems that have occurred since 1950, the changes that have occurred in farmland bird populations over this period and the mechanisms that probably link these two sets of events. First, however, it is

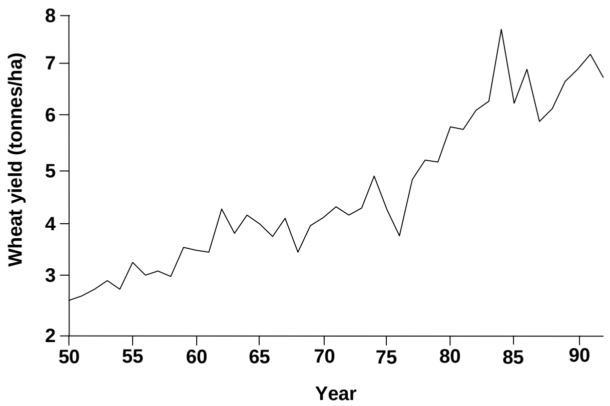


Figure 1. Trend in UK wheat yields (tonnes ha^{-1}), 1950 - 1992. Source: Ministry of Agriculture, Fisheries and Food.

useful to give some historical perspective to the issue.

Concern about the effects of modern agriculture on wildlife intensified during the early 1990s with heightened media awareness and proliferation of relevant research. There is now public and political recognition that farmland bird populations have declined severely and appreciation that this is indicative of wider changes in biodiversity. Declines in populations of farmland bird species have become one of the most pressing bird conservation issues in Europe (Pain & Pienkowski 1997, Tucker & Dixon 1997, Newton 1998). It should be recognised, however, that concern was being expressed many years earlier and that throughout the 1980s, and considerably earlier in the case of the Grey Partridge *Perdix perdix*, evidence had been accumulating that farmland birds were declining (Potts 1970, O'Connor & Shrubb 1986, Marchant *et al*. 1990). The reasons for the time lag in response from the media and conservation bodies centre on the strategic goals and politics of nature conservation, the wider environmental lobby and of agriculture itself. Human perception has also been relevant; there came a point when the declines were sufficiently sustained and of such a magnitude that they could be ignored no longer.

OVERVIEW OF RECENT CHANGES

Pattern of concern about farmland birds and their habitats

Most impacts of agriculture on birds can be classified as either direct or indirect. Direct impacts are of two kinds - ones that involve loss of habitat and ones where machinery, human disturbance or pesticides cause increased mortality or breeding failure. Indirect impacts are those that act either by altering the food resources or the quality of nesting and foraging sites of birds. Indirect effects tend to be relatively difficult to measure. Whilst these categories are useful, in reality there is a continuum of impacts between total habitat destruction and subtle reduction in habitat quality through food depletion or changes in vegetation structure by crop management. Concern in the late 1950s and 1960s focused almost exclusively on direct impacts, notably on the effects of organochlorine pesticides and the loss of habitat, especially hedgerows (Moore 1987). In the 1970s, conservation agencies concentrated on reducing the loss of semi-natural habitats to agricultural development (NCC 1977).

Organochlorines were responsible for both lethal and sub-lethal effects on birds. In the 1950s there was high mortality of seed-eating birds due to the use of cyclodiene seed dressings (Cramp & Conder 1961) and raptors experienced increased mortality and reduced breeding output (Newton 1995). Restrictions on the use of cyclodienes, implemented from 1962 onwards, have now alleviated these problems. Significant direct impacts of pesticides may still be occurring (Burn 2000) but current emphasis has moved to the potential indirect effects of pesticides (Campbell *et al*. 1997).

Loss of semi-natural habitat and uncropped areas of special value to wildlife as a result of agricultural activities was probably most severe over the period 1950 to 1980. Destruction of hedges still occurs (Barr *et al*. 1993), but rates of loss appear to have been highest in the 1960s (O'Connor & Shrubb 1986). Losses of ancient woodland to agriculture were also high in the post-war decades but these have now been stemmed by better site protection (Peterken 1993). Many farm ponds have disappeared over the same period (Moore 1987). There has been continuous decline in the area of unimproved lowland grassland between the 1930s and the early 1980s amounting to an overall reduction of 92% (Fuller 1987). This latter process could be regarded as one of habitat degradation rather than habitat loss because much of the grassland remains in place, albeit in an improved form. The disappearance of seasonally flooded grassland (Dargie 1993) as a result of drainage should, however, be regarded as habitat loss because the transformation is so great.

I suggest that two aspects of habitat loss have been especially significant in the context of farmland bird populations: destruction of hedgerows and the decline in wet grassland. The significance of hedgerow loss has been controversial. Murton & Westwood (1974) argued that hedgerows were suboptimal habitats for the majority of species, though more recent work indicates that individual hedges vary enormously in their breeding bird assemblages (e.g. Green *et al*. 1994) and in the abundance of berries they offer for wintering birds (Sparks & Martin 1999). Hedges may also be important corridors for dispersal of species through farmed landscapes, though critical evidence is lacking. Approximately half of Britain's hedges have been lost since 1947 (Barr & Parr 1994), which represents a huge reduction in available habitat for many birds on farmland. Nonetheless, this does not appear to have been a principal driver of *recent* (post-1970) declines in farmland bird populations because these have occurred both in areas with and without loss of hedges or other habitat features such as ponds (Gillings & Fuller 1998). The drainage and improvement of wet meadows has led to the widespread decline of several bird species (Beintema *et al*. 1997). The first large-scale surveys of breeding waders on wet meadows were conducted in 1982 in response to concern that species such as Redshank and Snipe were becoming scarce throughout much of lowland Britain as a consequence of loss of wet grassland (Smith 1983).

It appears that large-scale structural changes in lowland landscapes may be behind us and that, in broad terms, impacts of habitat loss on bird populations were probably at their peak during the 1950s and 1960s. Of course localised habitat loss continues to the present day, but indirect effects are likely to have become increasingly significant in lowering the carrying capacity of farmland for birds. This process must have been especially strong during the 1970s and 1980s, a period of enormous change in farming systems (see below). The many potential effects of changes in crop management on the foods available to birds were highlighted by O'Connor & Shrubb (1986). The best understood and longest researched example of an indirect effect is the Grey Partridge (Potts 1970, 1986, 1997, Potts & Aebischer 1995). The principal cause of decline has been a reduction in chick survival brought about through reduction of insect food as a consequence of (a) insecticide use, (b) herbicides removing the food plants of insects and (c) reduction of undersowing. Massive reduction of arable weeds and associated depletion of the seed-bank by herbicides must also have been of great importance to seed-eating birds (Newton 1995). Genetically modified (GM) crops represent the latest area of anxiety about potential effects of crop management, currently mainly in rape, maize and beet. The primary concern is that widespread use of herbicide-tolerant and insect-resistant GM crops may result in further reduction of insect and seed-food resources within fields (e.g. Johnson 1999).

Alongside the trend of increasing concern about the significance of indirect impacts of agriculture, there has been a growing recognition that agricultural impacts have been profound in *both* arable and grassland systems. There has been a tendency to equate intensive farming with arable farming but the changes that have occurred in grassland management have been just as fundamental as those in arable (Vickery *et al*. 1999). There has been little research into the effects on commoner birds of changes in management of lowland neutral grasslands in the wider countryside. There has, however, been work on waterfowl in wet meadows and grazing marshes (Self *et al*. 1994, Evans *et al*. 1995, Milsom *et al* 1998) and on effects of grassland management on particular scarce species, notably Corncrake *Crex crex* (Green & Stowe 1993, Green 1996) and Cirl Bunting *Emberiza cirlus* (Evans *et al*. 1997).

Summary of recent population trends of birds on farmland

Britain is fortunate in that population trends of its commoner and widespread farmland birds have been monitored since the 1960s by the Common Birds Census (CBC) (Marchant *et al*. 1990). Using annual CBC data, trends in the abundance of breeding birds on lowland farmland have been described by Fuller *et al*. (1995) and Siriwardena *et al*. (1998). Distributional changes of farmland birds were also summarised by Fuller *et al*. (1995) using breeding bird atlas data. In addition there has been substantial research and survey on relatively rare or localised species that depend on farmland including Stone-curlew (Green 1988), Corncrake (Green 1996) and Cirl Bunting (Evans *et al*. 1997). Key points from these analyses are summarised below. A farmland specialist is defined as a species that either nests in fields or relies on fields substantially for its food.

1. Farmland specialists have, on average, undergone larger contractions of range than species associated with other habitats.
2. A high proportion of farmland specialist birds have declined in abundance since the 1960s. In contrast, habitat generalists have tended to increase. The declines in farmland specialists have been, or are likely to have been, paralleled by declines in invertebrates and plants that form their main foods (Potts 1991, Wilson *et al*. 1999).
3. Declines of many farmland specialists mainly started in the mid- to late 1970s. Exceptions include Grey Partridge, for which bag records show a decline since at least the 1950s (Potts 1986), Stone-curlew, which has been declining for much of the 20th century (Green 1988), and Yellowhammer *Emberiza citrinella,* which started to decline in the mid-1980s (Kyrkos *et al*. 1998). Population declines of most farmland specialists have continued since the mid-1970s. Declines have been especially marked among seed-eating species.
4. The only farmland specialist to decline significantly in the period 1968-75 was Whitethroat *Sylvia communis*, whereas in the period 1976-95 statistically significant declines were evident for Grey Partridge, Skylark *Alauda arvensis*, Linnet *Carduelis cannabina*, Starling *Sturnus vulgaris* and Yellowhammer (Siriwardena *et al*. 1998, Table 1). Additionally, several other farmland specialists showed large, but statistically non-significant, decreases since the mid-1970s: Tree Sparrow *Passer montanus*, Turtle Dove *Streptopelia turtur*, Corn Bunting *Miliaria calandra* and Lapwing *Vanellus vanellus*.
5. Two farmland specialists have increased since the 1960s: Goldfinch *Carduelis carduelis* and Stock Dove

Columba oenas, the latter probably being a recovery from earlier effects of organochlorine seed dressings and herbicides (O'Connor & Shrubb 1986).

Viewing population changes for the commoner and widespread birds in general on farmland, not just the farmland specialists, there has been considerable diversity in the pattern of population change since the 1960s (Siriwardena *et al*. 1998). This point is illustrated in Fig. 2, which presents an overview of patterns of population change in 28 farmland bird species in southern Britain. It identifies species that have shown similar patterns of population change on lowland farmland. Scores of 28 species are plotted for the first two axes of a Principal Components Analysis of their annual farmland CBC index values. The analysis was conducted on the correlation

Table 1. Major trends in arable farming since approximately 1960 with potential implications for birds. References are given where there is strong evidence to support a suggested mechanism.

Mechanisation

Trend: Escalating use of machinery since the 1950s (Fig. 3).

Implications: (1) Increasing concentration of cultivation into the autumn has become possible with loss of food associated with stubbles and bare ground in winter and spring. (2) Combines have eliminated ricks and rickyards, which gave concentrations of food for seed-eaters. (3) Less grain spillage and cleaner stubbles also leave less food for birds in autumn and winter. (4) Rapid, large-scale application of pesticides and fertiliser is now possible. (5) Mechanised hedgerow management allows more frequent cutting of hedges and creates different structures to traditional hedge-laying. (6) Mechanised flailing of verges, banks and ditches may remove nesting habitat and food e.g. for Yellowhammer. (7) Possibly more nest losses of ground-nesting birds in some crops.

Fertilisers

Trend: Huge increase in nitrogen inputs (Fig. 4). Less farmyard manure (FYM), more inorganic nitrogen.

Implications: (1) Dense, fast-growing crops do not usually offer suitable nesting sites for Lapwings and Skylarks (Hudson *et al.* 1994, Wilson *et al.* 1997). (2) Golden Plover and Lapwing feed only in cereal fields with short vegetation (Mason & MacDonald 1999). (3) FYM inputs to cultivated fields can increase earthworm numbers leading to higher bird usage, a benefit that has presumably diminished (Tucker 1992).

Pesticides

Trend: Increasing applications of an expanding range of synthetic herbicides, fungicides, insecticides and molluscicides.

Implications: (1) Direct effects have been most evident through past use of organochlorines. Current direct effects cannot be discounted (Burn 2000). With declining food supplies, individual birds may be more stressed and more susceptible to direct effects. Implications for avian physiology of synergisms between chemicals are unknown. (2) Most pesticides can act in some way to reduce potential food resources for birds (Campbell *et al.* 1997). Reduction of the seed-bank as a food source for granivores especially in winter but also for breeding Turtle Doves and Linnets. Reduction of invertebrates as a source of chick food for several species; Grey Partridge is the clearest example (Potts 1986).

Reduction in spring sowing of cereals

Trend: Progressive reduction in ratio of spring- to autumn-sown cereal since 1970 (Fig. 5).

Implications: (1) Reduction in overwinter stubbles as a food source for seed-eating birds (Evans 1996, 1997). (2) Spring crops frequently too tall and dense for Skylarks and Lapwings (Hudson *et al.* 1994, Wilson *et al.* 1997). (3) Reduction in bare cultivated ground as a feeding site in spring e.g. for thrushes feeding on invertebrates and seed-eaters feeding on seed brought to the surface.

Simplification of rotations

Trend: Mixed systems using grass leys, often within complex arable rotations, have become rare with the advent of synthetic, easily applied fertilisers and pesticides. Much arable farmland now uses simple rotations with several years of cereal followed by a break crop, often oilseed rape or sugar beet.

Implications: (1) Reduction in seasonal availability of nest sites or feeding sites to species with long breeding seasons (Schläpfer 1988, Wilson *et al.* 1997, Stoate *et al.* 1998) may lead to fewer nesting attempts and/or lower success. (2) Breeding Lapwings are affected by reduction of spatial heterogeneity of field types, preferring to nest on tilled land but to rear chicks on grassland (Galbraith 1988, Shrubb & Lack 1991). (3) Leys can have several benefits within arable systems: they are attractive to nesting Skylarks (O'Connor & Shrubb 1986), they can enhance earthworm densities (Neale 1996), where undersown in spring cereals they can enhance sawfly numbers, a preferred food of e.g. Grey Partridge (Potts 1997). (4) Greater diversity of winter feeding conditions is likely under complex crop rotations. (5) Bare fallow, now almost extinct, was probably similar to set-aside as an important feeding site for several species in summer and winter (see below).

Changes in crops

Trend: Principal changes in areas of crops since 1960 have included increases in wheat, rape and linseed and decreases in oats, barley and potatoes. Set-aside and linseed have been features of the 1990s. In addition, there has been development of new strains of crops that may have resulted in faster-growing, denser vegetation.

Implications: (1) Wheat appears less favoured than barley by several breeding bird species, notably Corn Bunting, but reasons are unclear. (2) Rape introduced new nesting and feeding opportunities (Burton *et al.* 1999, Moorcroft & Wilson 2000). (3) Set-aside preferred to winter cereals by a range of insectivorous and granivorous birds, presumably because it offers greater availability of seeds and invertebrates (Henderson & Evans 2000).

matrix of index values calculated by using log-linear regression on CBC data with TRIM software (Pannekoek & van Strien 1996). Axis 1 explained 56% and axis 2 explained 20% of the variance. Species with high scores on axis 1 (i.e. to the right end of the axis) are ones that have tended to decline the most, showing more or less sustained declines since the mid 1970s. These include several farmland specialists (Grey Partridge, Linnet, Corn Bunting, Tree Sparrow, Skylark, Turtle Dove, Starling) together with some more generalist species (Reed Bunting *Emberiza schoeniclus*, Dunnock *Prunella modularis*, Bullfinch *Pyrrhula pyrrhula*, Blackbird *Turdus merula* and Song Thrush *Turdus philomelos*). Species with a low score on axis 1 (Stock Dove, Chaffinch *Fringilla coelebs*, Great Tit *Parus major*, Jackdaw *Corvus monedula*) have mostly increased since the 1960s. Species with intermediate scores on axis 1 and high scores on axis 2 (i.e. towards the top of the axis) have tended to show an initial decrease followed by an increase (Whitethroat, Long-tailed Tit *Aegithalos caudatus*, Wren *Troglodytes troglodytes*, Robin *Erithacus rubecula*, Greenfinch *Carduelis chloris*, Goldfinch).

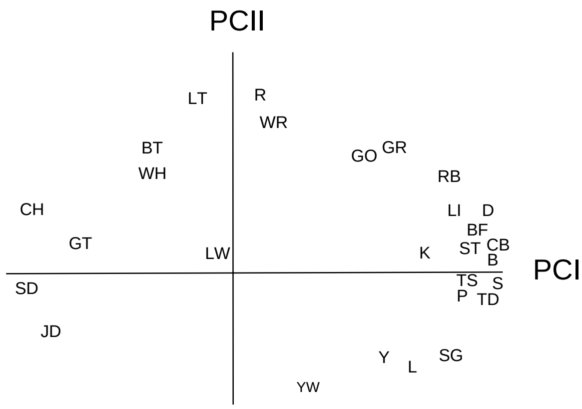


Figure 2. Locations of 28 farmland species on first two axes of a Principal Components Analysis of annual farmland CBC index values, 1969-1996. Index values were derived with TRIM software, which models bird counts using log-linear Poisson regression (Pannekoek & van Strien 1996). Data have been used from CBC farmland plots in lowland England and Wales. K = Kestrel *Falco tinnunculus*, P = Grey Partridge *Perdix perdix*, L = Lapwing *Vanellus vanellus*, SD = Stock Dove *Columba oenas*, TD = Turtle Dove *Streptopelia turtur*, S = Skylark *Alauda arvensis*, YW = Yellow Wagtail *Motacilla flava*, WR = Wren *Troglodytes troglodytes*, D = Dunnock *Prunella modularis*, R = Robin *Erithacus rubecula*, B = Blackbird *Turdus merula*, ST = Song Thrush *Turdus philomelos*, LW = Lesser Whitethroat *Sylvia curruca*, WH = Whitethroat *Sylvia communis*, LT = Long-tailed Tit *Aegithalos caudatus*, BT = Blue Tit *Parus caeruleus*, GT = Great Tit *Parus major*, JD = Jackdaw *Corvus monedula*, SG = Starling *Sturnus vulgaris*, TS = Tree Sparrow *Passer montanus*, CH = Chaffinch *Fringilla coelebs*, GR = Greenfinch *Carduelis chloris*, GO = Goldfinch *Carduelis carduelis*, LI = Linnet *Carduelis cannabina*, BF = Bullfinch *Pyrrhula pyrrhula*, Y = Yellowhammer *Emberiza citrinella*, RB = Reed Bunting *Emberiza schoeniclus*, CB = Corn Bunting *Miliaria calandra*.

Summary of recent changes in agriculture

The post-war transformation of agricultural output in the British lowlands has been made possible by huge technological developments operating in a political and economic environment that has encouraged efficiency and production. It is impossible to provide a comprehensive review here of the changes but I attempt to identify those that are likely to have been of particular importance to birds. For alternative accounts see O'Connor & Shrubb (1986), Stoate (1996), Pain & Pienkowski (1997), Chamberlain *et al.* (1999).

The post-war process of agricultural intensification of agriculture has rested mainly on three areas of technological development - mechanisation, fertilisers, pesticides - though other factors have been involved, including drainage and plant breeding. It is important to consider these three factors in turn because they have stimulated a wider complex of more or less simultaneous trends in farming practices with an associated web of implications for the quality of farmland as a habitat for birds.

Mechanisation

Manual labour on farmland has steadily declined since at least the 1950s and farming operations have become dependent on efficient use of machinery (Fig. 3). As an example, by the early 1970s large combine harvesters were the norm for cereal harvesting throughout lowland England. Agricultural consequences of mechanisation include rapid cultivation and harvest of arable crops, the increasing concentration of cultivation into the autumn season, fast mowing of grass fields and the ability to treat extensive areas with fertilisers and pesticides. More fundamentally, mechanisation has altered the capital structure of farming, with large crop areas required to finance the expenditure. This has been a factor leading to increased field sizes and geographical polarisation of arable and pastoral farming.

Fertilisers

Changes in fertiliser practice have been of two kinds. There have been massive increases in nitrogen inputs, both on tilled land and permanent grassland since the 1960s. The increase was sustained throughout the 1970s and well into the 1980s (Fig. 4). Inputs of inorganic phosphorus and potassium are also widespread. Type of fertiliser has changed, with increasing reliance on inorganic fertiliser and less on farmyard manure (FYM). The obvious agricultural benefit has been enhancement of crop growth and yields. Perhaps a more fundamental implication has been that increased use of inorganic fertilisers has reduced reliance on fertility-building leys and on mixed systems of arable and livestock farming that would generate

Figure 3. Trend in numbers of combines and the workforce (numbers of labourers) on UK farms since 1950. Source: Ministry of Agriculture, Fisheries and Food. Note that this figure cannot give the full picture with respect to combines because combine capacity has continued to increase and the apparent decrease since 1970 reflects the predominance of large machines with high capacity.

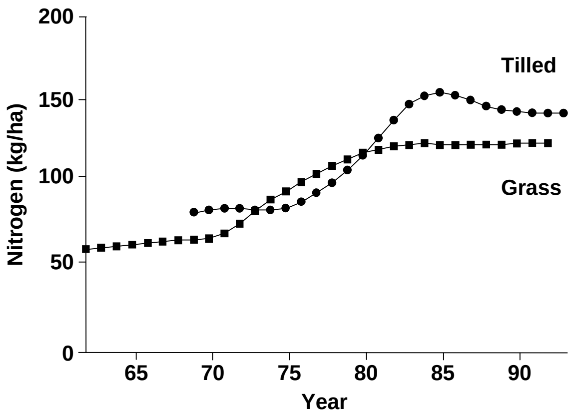


Figure 4. Nitrogen inputs (kg ha^{-1}) on tilled land and permanent grassland in England and Wales. Original values have been smoothed using a running median procedure. Source: Wilkinson (1997).

manure. A consequence has been the demise of leys established by undersowing cereal crops. There has been a trend for arable and livestock farming to become geographically polarised, with increasing dominance of arable in the south and east of Britain and of pastoral farming in the north and west.

Pesticides

There has been escalating dependence of arable farming on synthetic pesticides since the 1950s. This has manifested itself in a large and complex array of chemical products (herbicides, insecticides, fungicides, molluscicides), an increase in the total area treated, and the number of applications per year (Campbell *et al.* 1997, Chamberlain *et al.* 1999). Herbicides have a relatively long history of heavy use dating back to the 1950s, though applications in England and Wales, in terms of spray hectares, have more than doubled since the late 1970s. Foliar fungicide use in cereals started in the mid-1970s and increased steadily for 20 years to a point where applications in terms of spray hectares were similar to those of herbicides. Insecticide and molluscicide usage, though at a lower level of application than herbicides and fungicides, has increased markedly during the 1980s and 1990s. A summary of the temporal pattern of pesticide use in cereal crops is given in Fig. 3 in Potts (1997). The purpose of pesticides is to control a wide range of crop pests and diseases. Less obviously, they have been responsible for two major changes in arable farming. First, pesticides have allowed autumn sowing of cereals through the development of herbicides capable of selectively killing grass weeds. Spring sowing has consequently decreased enormously since the early 1970s (Fig. 5). Second, pesticides have largely removed the need to control disease by traditional rotations. This, coupled with changes in fertiliser use (see above), has been a driving factor in the demise of mixed farming systems.

Major trends in arable farming since 1960 are listed in Table 1 and for grassland farming in Table 2, with brief summaries of potential mechanisms by which they may have affected birds. There is a substantial body of evidence that the invertebrate and plant food resources of specialist farmland birds have declined in response to intensification (Potts 1991, Wilson *et al.* 1999). It is beyond the scope of this paper to review how changes in agriculture have affected individual bird species and their food resources, but for species-based discussions see Baillie *et al.* (1997), Newton (1998) and other papers in this volume. Individual species have been affected by different components of intensification. Note that the processes behind the trends in Tables 1 and 2 are closely inter-related, that they have happened more or less simultaneously and that associated impacts on birds have occurred at all times of year. At the same time, changes to boundary features have been occurring in both arable and grassland landscapes (Barr *et al.* 1993). Hedgerows have been widely destroyed (see above) and there has been increasing mechanisation of hedgerow management. Notwithstanding recent establishment of many new hedges, the density of hedges in most lowland areas remains far lower than 50 years ago. The long-term effects on hedgerow structure of repeated mechanical trimming appear not to have been studied but Barr *et al.* (1993) recorded a 53% increase in 'relict hedges' between 1984 and 1990.

A new carrying capacity for farmland birds?

I stressed in the introduction that farming has never been static, but during the last 50 years the period of approximately 1970 to 1985 stands out as one of extremely rapid and fundamental change in agriculture. This was the period when wheat yields took a major leap (Fig. 1), when nitrogen inputs rose steeply (Fig. 4), when the main reduction of spring sowing occurred (Fig. 5) and when

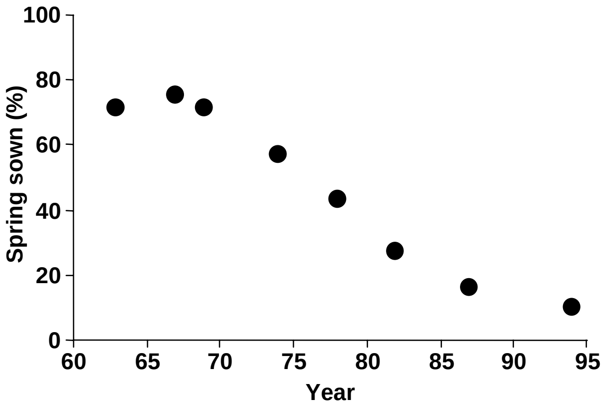


Figure 5. The percentage of all barley and wheat that was spring-sown in England and Wales since the early 1960s. Source: Ministry of Agriculture, Fisheries and Food.

production of silage overtook that of hay (Fig. 6). An ordination analysis by Chamberlain *et al*. (1999) of all available annual agricultural statistics for England and Wales for 1962 to 1995 confirms this impression. In this analysis, annual data for 32 agricultural variables were used, including areas of individual crops, livestock numbers, yields, timing of cereal sowing, fertiliser use and pesticide use. Annual scores on axis 1 of a Detrended Correspondence Analysis applied to the 32 variables were used as an overall measure of change in agricultural management when plotted against year. Until 1970 the scores were stable in the region of 0-0.2, but thereafter there was a progressive increase in scores across a wide gradient, until 1987 after when the scores stabilised at levels of 4.9-5.1. This demonstrates that agricultural management undertook a major shift between the early 1970s and mid-1980s. A similar pattern of temporal change is evident in bird assemblages as shown by ordination of annual farmland CBC indices for 21 widespread species (Chamberlain *et al*. 1999). The onset of bird changes lags behind those of agriculture by about five years. This is to be expected because population responses to habitat change may be buffered by density-dependent effects and site fidelity among individual birds. Furthermore, agricultural change was progressive and it is possible that a critical threshold of habitat change had to be exceeded before an effect on population level was detected.

This raises the question as to whether a new carrying capacity has been reached for farmland birds. Have population declines started to level out since 1988 as agricultural management has become relatively stable?

Table 2. Major trends in grassland farming since approximately 1960 with potential implications for birds.

Mechanisation

Trend: Escalating use of machinery since the 1950s.

Implications: Facilitated large-scale application of fertiliser but main immediate implication is increased losses of eggs and young of ground-nesting species e.g. Corncrake *Crex crex* (Green 1996).

Drainage and loss of rough grassland

Trend: Progressive reduction of rough grassland and drainage of wet meadows since 1930s (Fuller 1987).

Implications: (1) Large reduction in breeding habitat for waders that require damp areas. (2) Less habitat for wintering wildfowl and waders that use flooded fields. (3) Possibly reduced food for raptors that hunt voles. (4) Improved drainage can raise soil temperatures and enhance grass growth with similar consequences to fertilisers (Beintema *et al.* 1985).

Fertilisers

Trend: Huge increase in nitrogen inputs (Fig. 4). Less farmyard manure (FYM), more inorganic nitrogen and slurry.

Implications: (1) Dense, fast-growing grass is unsuitable for most, if not all, ground-nesting species. (2) Few species forage within dense tall swards, either in summer or winter (Milsom *et al.* 1998). (3) FYM inputs to grass fields are associated with higher bird usage, a benefit that has presumably diminished (Tucker 1992). (4) Increased use of slurry on grassland may have reduced invertebrate biomass (Vickery *et al.* 1999). (5) Nitrogen inputs to grassland can reduce invertebrate numbers with implications for summer food availability for insectivorous birds (Vickery *et al.* 1999). (6) Large reductions in floristic diversity ('weediness') and structural complexity of grassland occur, reducing diversity of seeds and invertebrates available to birds. (7) Earlier and multiple cuts of grass result in more nest losses. (8) Breeding seasons of some species have become earlier as a result of faster growth of grass (Beintema *et al.* 1985).

Switch from hay to silage

Trend: Switch from hay to silage production has been universal since the 1960s (Fig. 6).

Implications: Mechanised mowing and high fertiliser inputs are essential components of silage systems that are characterised by fast, dense-growing swards and multiple cuts (see above). In addition, hay fed to stock in winter can supply food for seed-eaters, especially buntings, but this is not the case for baled silage.

Changes in livestock

Trend: Increasing numbers of sheep between the mid 1970s and about 1990 to some extent reflect a shift away from dairy enterprises (Fig. 7).

Implications: Sheep produce tighter swards in lowland grassland than cattle with the following main implications (Fuller & Gough 1999). (1) Little cover for ground-nesting birds and predation pressure on them may have increased. (2) Reduced sward heterogeneity with fewer niches for invertebrates. (3) Species requiring short swards for feeding e.g. thrushes, corvids and wintering waders should have benefited.

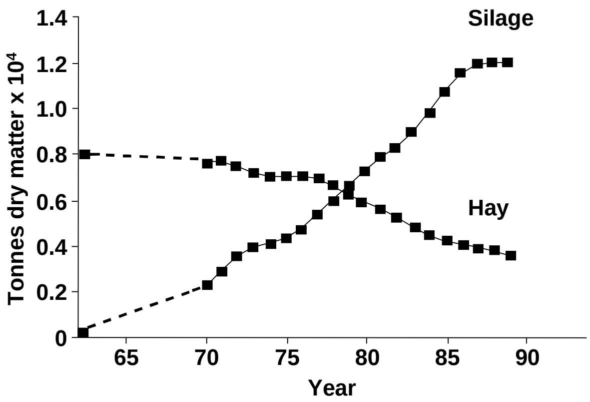
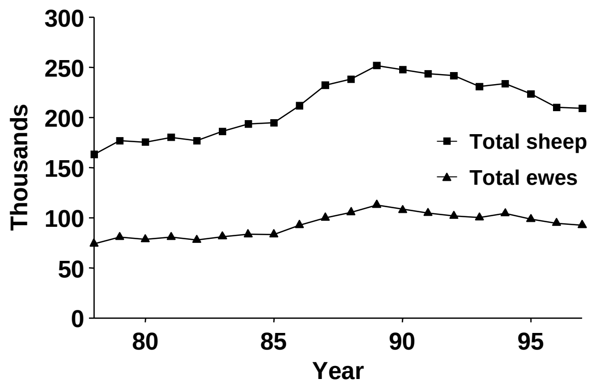


Figure 6. Production of silage and hay (tonnes dry matter x 10^4) in the United Kingdom. Source: Wilkinson (1997).



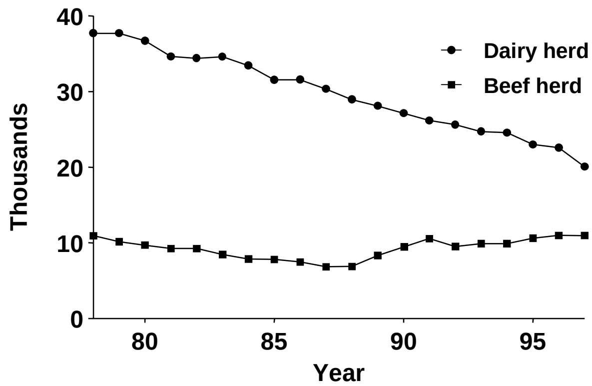


Figure 7. Numbers of sheep (top) and cattle (bottom) in Oxfordshire 1978 - 1997. Similar trends have occurred in most lowland counties. Source: MAFF June Agricultural Census.

Some of the developments of the last 10 years, especially the introduction of large areas of set-aside and oilseed rape, have been beneficial for several species (Table 1). One might, therefore, expect to find some evidence of stabilising population levels, or even recent increases, for formerly declining farmland birds.

To investigate this I examined population trends of 27 species over the period 1987 to 1996 to determine which, if any, species were still declining during this period. The species selected include all farmland specialists monitored by the CBC together with a sample of widespread generalists. TRIM software was used to model bird counts using log-linear Poisson regression (Pannekoek & van Strien 1996). Linear trends models were applied to give an indication of the overall trend for each species. Significant population changes over the 10-year period were determined from the confidence limits. Eleven species showed no significant change, six species increased significantly and 10 species decreased significantly (Table 3). Of the increasing species, Linnet is particularly interesting in that it is a farmland specialist that has decreased strongly since the 1960s (Siriwardena *et al.* 1998). The recent increase may be partly attributable to availability of oilseed rape as a food source (Moorcroft & Wilson 2000). The fact that a relatively large number of species have continued to decline after the period of major agricultural change suggests that a new carrying capacity has yet to be reached for farmland birds. Grey Partridge, Turtle Dove, Skylark, Tree Sparrow and Yellowhammer are all farmland specialists that have definitely continued to decline. However, more caution is needed in interpreting the recent trends of Lapwing, Starling and Corn Bunting because the models did not fit the data for these species. For Lapwing, however, there is independent evidence that the species has declined considerably since 1987 (Wilson *et al.* in press).

CONCLUDING THOUGHTS

There now exists a range of evidence based on intensive studies and on extensive correlational work that declines of farmland birds are closely linked with the massive intensification of agriculture in recent decades. The magnitude of change introduced into all lowland farming systems is such that the food resources and habitat quality for birds have been utterly transformed (Wilson *et al.* 1999). Most of the major components of agricultural change have had negative implications for birds. Exceptions are the introduction of certain new crops such as oilseed rape (Burton *et al.* 1999, Moorcroft & Wilson 2000), and set-aside (Henderson & Evans 2000), and while some species such as corvids may have benefited from intensive livestock grazing, others will have been disadvantaged (Fuller & Gough 1999).

Intensification is unlikely to have been the only factor affecting populations of farmland birds in recent decades. In particular, there have been increases in several avian and mammalian predators on farmland (Fuller *et al.* 1995). Strong evidence that predation, especially by corvids and foxes, can affect population levels of some farmland birds comes from research on the Grey Partridge (Tapper *et al.* 1996) and Curlew (Grant *et al.* 1999). Predation may, however, be facilitated by changes in land-use (Fuller &

Table 3. Estimated population change of selected species on farmland in lowland farmland in England and Wales, 1987-1996. Population indices were calculated using log-linear regression on CBC data with TRIM software (see Methods). Results are shown for linear trends models.

Category of change	Species	% change	95% confidence limits	Goodness-of-fit test[2,4]	Significance of linear trend[3,4]
Increase	Wren[1]	6.7	0.2 to 13.1	***	*
Increase	Robin[1]	48.3	38.6 to 58.0	ns	***
Increase	Whitethroat[1]	56.3	35.0 to 77.6	ns	***
Increase	Great Tit[1]	12.5	1.8 to 23.3	ns	*
Increase	Goldfinch	82.5	47.5 to 118.0	ns	***
Increase	Linnet[1]	27.4	7.5 to 47.3	ns	*
No change	Kestrel	17.7	-27.3 to 62.7	ns	ns
No change	Stock Dove	13.4	-13.9 to 40.7	ns	ns
No change	Yellow Wagtail[1]	-19.3	-54.3 to 15.7	ns	ns
No change	Dunnock[1]	-5.4	-13.4 to 2.7	ns	ns
No change	Song Thrush[1]	-13.3	-26.6 to 0.1	ns	ns
No change	Blue Tit[1]	4.2	-3.5 to 11.8	ns	ns
No change	Jackdaw	-9.6	-25.6 to 6.4	ns	ns
No change	Chaffinch[1]	-0.1	-6.0 to 5.6	ns	ns
No change	Greenfinch	7.7	-7.1 to 22.5	ns	ns
No change	Bullfinch	-22.8	-46.5 to 0.8	ns	ns
No change	Reed Bunting	-9.5	-28.9 to 9.9	ns	ns
Decrease	Grey Partridge[1]	-50.0	-65.7 to -34.4	ns	***
Decrease	Lapwing[1]	-20.3	-38.1 to -2.5	**	*
Decrease	Turtle Dove	-41.5	-64.2 to -18.7	ns	**
Decrease	Skylark	-15.6	-23.6 to -7.7	ns	***
Decrease	Blackbird[1]	-14.9	-20.2 to -9.5	ns	***
Decrease	Lesser Whitethroat	-24.3	-46.5 to -2.1	ns	ns
Decrease	Starling	-38.1	-46.0 to -30.2	***	***
Decrease	Tree Sparrow[1]	-70.8	-82.4 to -59.2	ns	***
Decrease	Yellowhammer[1]	-37.8	-44.6 to -31.1	ns	***
Decrease	Corn Bunting	-28.0	-48.5 to -7.5	**	*

[1] For these species, a model incorporating individual year effects fitted the data significantly better than did the linear trends model. However, with the exception of Wren and Great Tit, which did not show a significant increase with the year-effects model, the results were the same for both models with respect to significance of population trend.

[2] A significant goodness-of-fit (χ^2) test indicates that the model does not fit.

[3] Wald test of slope parameter.

[4] ns: not significant, *: $P < 0.05$, **: $P < 0.01$, ***: $P < 0.001$.

Gough 1999) and bird populations may also be less able to compensate for predation when habitat quality and food resources have been reduced. Subtle interactions have probably occurred between intensification and predation pressure and, at present, it is not possible to partition the effects of these two processes. While declines are unlikely to have been initiated by predation it is quite likely that predation has affected rates of decline in some farmland birds; this appears to be the case for the Grey Partridge (Potts 1986).

We have an array of potential mechanisms that have been operating more or less simultaneously (Tables 1 and 2). Isolating specific critical factors that initiated the population declines in the 1970s is an elusive goal for several reasons. For many species the concept of single critical factors seems unrealistic. Combinations of factors are likely to have acted to reduce breeding output, survival or both. For example, Corn Bunting and Yellowhammer may have been pressurised by a range of factors including loss of stubbles, reduction of the seed bank through herbicides, reduction of barley, reduction of insect food for nestlings by pesticides. Similar suites of species-specific mechanisms can be identified for other species (see other papers in this volume). The relative importance of these factors may vary regionally. Correlational studies of historical demographic and agricultural data cannot reveal with certainty the mechanisms involved because of the high level of intercorrelation in the agricultural changes (Chamberlain *et al.* 1999). In any case, there is no reason to assume that factors that initiated the declines are the same as those that are responsible for the continued declines of some species - current changes in the farming environment are obviously different from those operating in the 1970s. Understanding of *both* the initial causes of the decline and the current causes is highly desirable.

The environmental changes brought about by intensification have been rapidly and widely introduced. This has created a situation where there are no valid controls for taking an experimental approach at the farm scale when attempting to isolate critical factors. The very small number of traditionally managed farms, and the increasing number of organic farms, are predominantly isolated patches in intensive landscapes. Effects of management practices in surrounding landscapes are probably impossible to avoid, especially as birds show high levels of dispersal on a landscape scale (Paradis *et al.* 1998). Furthermore, organic farms cannot be regarded as true controls in this context because the majority have been managed intensively at some stage and it may take many years for seed-banks to become re-established, especially as weed control by cultivation alone is becoming increasingly effective (Fuller 1997).

It is not entirely clear why populations of some farmland birds have continued to drift downwards during the 1990s. One possibility is that food resources continue to diminish through, for example, the persistent and ubiquitous use of fertilisers and pesticides. Another is that predation may have become an increasingly important factor as habitat quality has deteriorated (see above). Nonetheless, the fact that the majority of specialist farmland birds have continued to decline implies that a new carrying capacity has not yet been reached. Note, however, that the analyses presented here are of linear trends for a 10-year period and that more detailed analyses of changing rates of decline are desirable, particularly as longer runs of data become available. It may not be possible to determine whether population trends have 'bottomed out' until many more years of post-intensification population data are available.

A further implication is that the CAP-related set-aside policy of the 1990s has had no marked impact on the population trends, though it is possible that declines of some species would have been stronger in its absence. This is of concern because, even though set-aside was not designed as an environmental initiative, it is likely to represent the largest removal of land from intensive production that we can reasonably expect for many years. This projects the problem with an uncomfortably sharp focus. We cannot be sure whether these populations will stabilise, and if they do, at what level and when. There are, however, some reasons for optimism. A better understanding is now emerging of the requirements of many farmland birds. Where appropriate habitat management is initiated, recovery of both birds and their food resources can be achieved (Wilson *et al.* 1999, Aebischer *et al.* 2000). The key issue is whether appropriate habitat change can be introduced into farming systems on a scale sufficient to enhance national populations of common and widespread farmland birds.

Without the efforts of BTO volunteers who have collected CBC data since the early 1960s we would be unaware of the scale of the decline in many of our farmland birds. I thank Mark Avery, Andy Evans, Dick Potts, Mike Shrubb and Juliet Vickery for their constructive comments on the manuscript and Dan Chamberlain, Jerry Tallowin and Adrian Chapman for discussion and advice. Su Gough and Nicki Read helped prepare the figures and manuscript. The writing of this paper was funded jointly by the BTO and the Joint Nature Conservation Committee (on behalf of English Nature, Scottish Natural Heritage, the Countryside Council for Wales and the Environment and Heritage Service in Northern Ireland). The Ministry of Agriculture, Fisheries and Food and the JNCC have funded several projects at the BTO that have contributed to the ideas presented here. The CBC has been funded by the JNCC and the BTO as well as, more recently, by a contract from the Department of the Environment.

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