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FORCE-FEEDING THE COUNTRYSIDE: the impacts of nutrients on birds and other biodiversity

Evidence review

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Evidence review

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This document is a summary of a full scientific review of the evidence: M A MacDonald (2006) *The indirect effects of increased nutrient inputs on birds in the United Kingdom: a review.* RSPB.

To receive a copy of the full review document or further copies of this summary please contact Jim Densham at the RSPB. This summary document can be downloaded from www.rspb.org.uk/waterwetlands

Improved grassland
Steve Austin (rspb-images.com)

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Contents

Executive summary

- Increased levels of nutrients are damaging habitats across the UK. Nutrient pollution force-feeds the countryside, altering plant growth rates, changing plant communities and disrupting the food chain for wildlife, including birds.
- Governments must take tougher action to ensure the efficient use and recycling of nitrogen and phosphorus, and limit losses to the environment. The knowledge and technologies exist to achieve this, through capturing and re-using the nutrients present in organic wastes. Now, policies are required to put this knowledge into practice, through a mixture of better regulation, incentives and education.
- Without tougher action, the UK will be unable to meet a wide range of international and national commitments to safeguard water quality, reduce the pollution of raw water supplies, and protect wildlife.
- In the UK, twice as much nitrogen and three times as much phosphorus are present in natural systems, compared to before the industrial revolution[1]. The sources of this pollution are fertilisers, fossil fuel combustion and sewage effluent.
- The availability of inorganic fertilisers helped to drive agricultural intensification in the twentieth century, resulting in widespread changes to crop and grassland management. Those changes boosted yields, but also damaged farmland wildlife, including birds.
- Red-backed shrike is now extinct in the UK; its decline was largely driven by management change linked to fertiliser application to grassland. This process also helped drive corncrake and cirl bunting to the brink of extinction in the UK; these two species are slowly recovering as a result of intensive conservation effort.
- Increased nutrient concentrations in aquatic habitats can increase the size of populations of some birds, but, almost always damage other parts of wetland ecosystems, and often compromise the habitat and food requirements of specialist birds such as bittern.
- Moorland and heathland habitats are sensitive to increases in nutrient loadings, as a result of atmospheric nitrogen deposition. Many moorland birds benefit from a mosaic of heather and grass moorland, but some species are known to be sensitive to large-scale loss of heather cover, including red grouse and stonechat. The importance of atmospheric nitrogen deposition to overall losses of heather is probably relatively small compared to other processes, such as afforestation and increased grazing intensity; but contributes to the overall degradation of these vulnerable habitats.

Hay meadow
Andy Hay (rspb-images.com)

1 Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC.

Lapwing
Andy Hay (rspb-images.com)

Tidal creek and mudflats
Chris Gommersall (rspb-images.com)

Introduction

- **Nitrogen and phosphorus are essential elements for life, and people use them in a variety of forms everyday to grow crops and drive industrial processes. However, when they enter the natural environment in excess they can cause harm by accelerating plant growth and altering the balance and structure of natural systems.**
- **The amount of nitrogen and phosphorus entering the environment has increased dramatically over the last century, with serious effects on habitats and species.**

Human activity is altering the fertility of the countryside. Industrialisation and agricultural intensification have been accompanied by dramatic changes to the natural cycling of plant nutrients (specifically nitrogen and phosphorus). There have been large increases in the amounts of plant nutrients released into the environment as pollution, which are causing long-term threats to the health of the earth's ecosystems, and compromising the quality of water supplies across the globe[1]. Serious effects on many natural and semi-natural habitats, collectively known as 'eutrophication', or 'over-enrichment', have been documented from all parts of the world. These changes have been accompanied by declines in a wide range of species in the United Kingdom, including some birds.

This report discusses the impact of increased plant nutrient availability on biodiversity. It summarises a more detailed review of the evidence for indirect or food-chain effects of phosphorus and nitrogen on UK bird populations[2]. The excessive use of nutrients also has wider costs for society. Water companies spend millions of pounds a year removing nutrients from drinking and waste waters, and the external costs of industrial production of nitrogen based fertilisers, in terms of greenhouse gas emissions, are immense. These issues are not discussed further in this report but are important when considering the costs and benefits of taking action to reduce nutrient pollution.

Nutrients and fertility

The elements nitrogen and phosphorus are essential for plant

Forms of pollutant

Nitrate NO_3	Soluble form of nitrogen used in fertilisers to promote plant growth but in excess can lead to eutrophication
Phosphate PO_4	Compound form of phosphorus used in fertilisers and detergents. Promotes plant growth and can lead to eutrophication
Ammonia NH_3	Gas which is highly soluble, forming Ammonium (NH_4) in water, can contribute to eutrophication and acid rain
Nitrogen oxides NO_x	Greenhouse gas produced from fuel combustion. Deposited on land from the atmosphere and can cause acid rain
Nitrous oxide N_2O	Powerful greenhouse gas released during the breakdown of organic matter and fertilisers, and from industrial processes. Deposited on land from the atmosphere

Classification of the trophic status of inland standing waters

Total P (µg/l)	
Ultra-oligotrophic	<4
Oligotrophic	<10
Mesotrophic	10–35
Eutrophic	35–100
Hypertrophic	>100

OECD, (Foundation for Water Research, 2000).

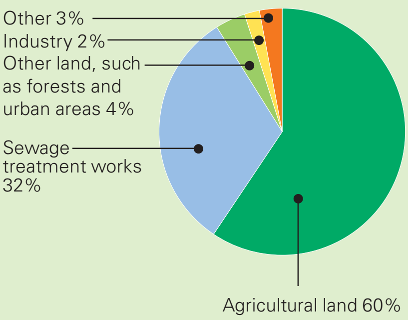
growth. In compound forms, as nitrates, phosphates, ammonium or oxides of nitrogen they can be absorbed and used by plants; but in some of these forms, and as gaseous ammonia or nitrous oxide, they can also be transported away from their intended targets. Habitats receive a background level of nutrients derived from natural processes but human activities have led to greatly increased amounts reaching the environment. Nutrient pollution stimulates plant growth, disadvantaging species that are adapted to low-nutrient conditions, and altering the structure and functioning of ecosystems.

Human nutrient use

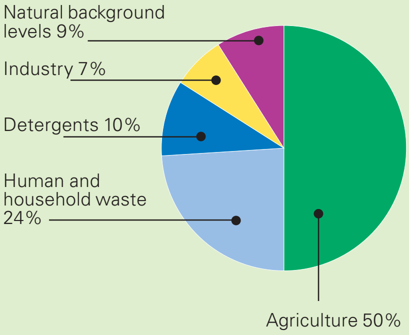
Nitrogen can be chemically fixed from the atmosphere, and is used in the manufacture of fertilisers and some other industrial processes. Phosphorus is mined from mineral reserves in countries such as Morocco. When processed these nutrients are used in a wide range of activities, including agriculture, industrial processes and the manufacture of detergents. Agriculture is a major user of nutrients; inorganic fertilisers applied to crops have facilitated large increases in yields. Fertilisers account for around 60% of the nitrogen used by people, and about 80% of all mined phosphate[3]. Phosphorus also enters agricultural systems as a nutrient in animal feed. Phosphate application to land rose sharply from the 1940s, exceeding 400,000 tonnes annually by 1950 (Figure 1)[4]. Total nitrogen use began to rise sharply from the early 1950s, and accelerated in the 1960s. Both phosphate and nitrogen fertiliser use peaked in the 1980s and have since fallen slightly, as a result of set-aside, and moves towards more efficient fertiliser use.

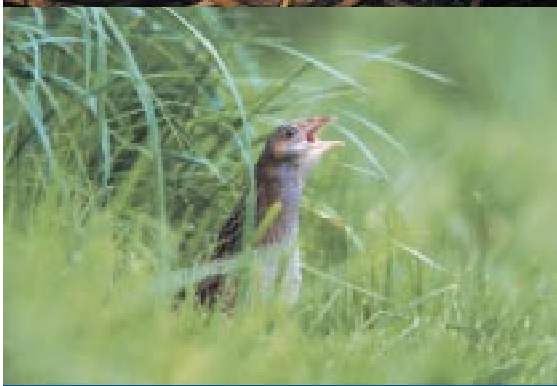
Outside the agricultural sector, phosphates are used in industrial processes and are an ingredient of many detergents. Phosphates aid the action of other detergent ingredients. However, when the washing process is complete the phosphates can enter watercourses via sewage treatment works. Recently, efforts have been made to reduce the phosphorus content of detergents, including banning their use in some European countries.

The main sources of nitrates in rivers in England and Wales in 2003 (source: WRc 2004)



The main sources of phosphorus in rivers in England and Wales in 1993 (source: Defra 2003)





Lapwing flock above wet grassland
David Kjaer (rspb-images.com)

Dead fish
David Kjaer (rspb-images.com)

Corncrake
Andy Hay (rspb-images.com)

Eutrophication
'The enrichment of water by nutrients, stimulating an array of symptomatic changes including increased production of algae and/or higher plants, which can adversely affect the diversity of the biological system, the quality of the water and the uses to which the water may be put.'
The Environment Agency (2000)

Sources of nutrients reaching the environment

The major sources of nutrient pollution are emissions from agriculture, industry, sewage discharges (nitrogen and phosphorus) and combustion of fossil fuels in industry and transport (nitrogen). Sources of nutrient pollution may be described as either 'point source', where they come from a fixed discharge point, (e.g. a sewage works), or 'diffuse', where they are lost from systems operating over a wide area (e.g. from some agricultural fields or atmospheric sources).

Because agriculture uses nutrients as an essential part of the growing cycle, it is a major source of nutrient pollution. Agriculture is estimated to account for approximately 70% of nitrogen and 50% of phosphorus entering water[5], of 90% of ammonia emissions[6] (the great majority arising from livestock wastes) and of 64% of nitrous oxide emissions[7].

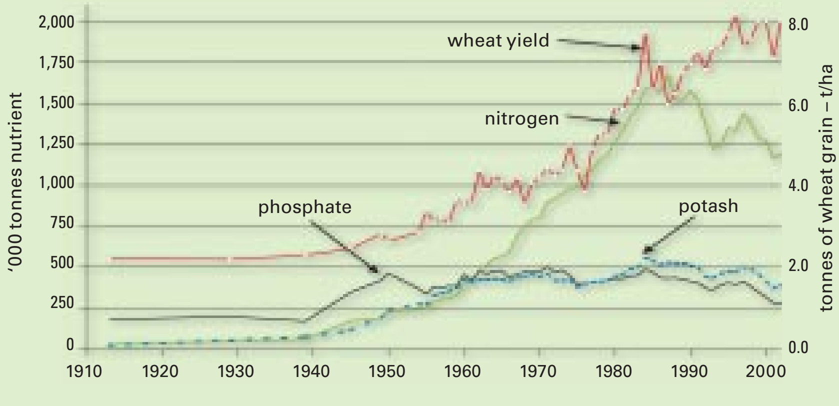
Domestic sewage and industrial effluent are major point sources of nitrogen and phosphorus. Our daily activities, including washing, cleaning clothes, flushing the toilet and discarding waste food, all add to the nutrient loads that appear in sewage. Much effort has gone into attempts to reduce nutrient loadings in effluent discharges, with some success; for example, water company investment to remove phosphate from sewage discharges is helping to improve the quality of water in the Norfolk Broads. Detergents have been identified as a major source of phosphorus in Forfar Loch[8], in Scotland, causing year on year algal blooms in summer, which are suffocating the loch. A campaign aims to raise awareness of this issue and urge people in Forfar to use phosphate-free detergents.

The burning of fossil fuel releases nitrogen to the atmosphere, as well as fixing nitrogen from the air via the combustion process. Eighty per cent of nitric oxide emissions and approximately 40% of nitrous oxide emissions come from human activity; mostly industry and motor vehicle use[9].

Transport of nutrients

Nitrogen reaches the environment in a number of forms. Nitrates are highly soluble and are generally lost to the wider environment through leaching and run-off. About a third of the nitrogen in fertiliser applied in the UK is lost to surface water and groundwaters[10 5]. In addition to nitrates, there are numerous gaseous forms of nitrogen. Some nitrogen escapes as inert atmospheric nitrogen, which returns harmlessly to the air. Some is emitted in as ammonia gas, which tends to be deposited close to its source (generally animal manures). Finally, some is converted into and emitted as nitrogen oxides and nitrous oxide; these are powerful greenhouse gases and are transported over large distances in the atmosphere. Phosphorus occurs in fewer forms than nitrogen. Soluble, biologically available phosphorus is discharged in large quantities from sewage works, particularly where these have limited treatment facilities. The majority of agricultural phosphorus in contrast, is bound to soil particles and transported in the form of sediment run-off. Such sediments can release their phosphorus when they become phosphorus-saturated or are disturbed (for example, when lake sediments are perturbed by boat traffic or bottom-feeding fish) or if there is a change in water chemistry such as pH or salinity.

Figure 1
Long-term trends in UK fertiliser consumption, with related output changes illustrated by the yield of wheat grain (sources: Rothamsted, Defra, AIC)



The scale of nutrient pollution

On a global scale, human activity has more than doubled the fixation of nitrogen gas from the atmosphere into forms that can affect the environment[9 11]. Humans have also tripled the amount of biologically available phosphorus since the industrial revolution[1].

Nutrients exist within the environment at 'background levels', as a result of natural processes such as rock weathering and decomposition of organic material. However, in human-altered systems (which effectively comprise the whole of the UK), nutrient levels have risen substantially. Both nitrate and phosphate levels in UK rivers showed upward trends from the 1930s and 1940s, when records began[10]. Similar trends have been found for nitrate in groundwater and in lakes and lochs in the UK. Recent success in reducing point-source pollution have improved pollution records for some sectors, although levels of nitrogen and phosphorus in aquatic systems have still risen dramatically, over the long term. Recent trends show annual nitrogen loads to rivers in England and Wales increased from 503 kilotonnes in 1983 to 514 kilotonnes in 2003[12], whereas phosphorus concentrations showed a downward trend at most sites[13]. UK ammonia emissions in 2004 were 336 kilotonnes, down 12% since 1990[5] but still much higher than 50 years ago, because of the increased use of nitrogen in feeds and fertiliser[14]. The levels of atmospheric nitrous oxide have also fallen, by 45% between 1990 and 2004[7], largely as a result in reductions in industrial pollution.

There is strong evidence that nutrients entering the environment over time have had effects on the vegetation of the UK and elsewhere. Eutrophication is proposed as a major cause of historical shifts in the flora of the UK, with flower-rich farmland habitats having largely disappeared[15], and many plant species becoming locally extinct. Plant species and communities that are typical of low fertility (soils or waters) have been especially hard hit. Conversely, species with a preference for fertile sites or water bodies were more successful in the late twentieth century than they had been in the 1950s[16].

English Nature has classified 20,733 hectares of England's designated Sites of Special Scientific Interest (SSSI) as being in unfavourable condition due to water pollution from agriculture[17]. This accounts for over 7% of England's SSSI network and includes some land within RSPB reserves, such as the Ouse Washes (see Case Study, page 14). A recent review of nutrient pollution in the Scottish water environment was carried out by SEPA[18]. This review identified 146 rivers and 17 lochs which show damage from inputs of nutrients from sewage discharge, diffuse agricultural pollution and other sources. The total length of rivers affected by eutrophication in Scotland is 2,184 km, the equivalent to 8.6% of the river network. Point source sewage discharge affects 1,544 km and diffuse agricultural inputs 1,598 km of rivers. Some water bodies are affected by nutrient inputs from both sources. One such area suffering impacts from nutrient pollution is the Loch of Strathbeg RSPB reserve, designated a SSSI, a Ramsar site and SPA (see Case Study on page 14).

Impacts on vegetation have knock-on consequences for a range of wildlife, which rely on the affected habitats for food and shelter. Birds may be affected by changes to plant and invertebrate food sources and nesting sites. The studies which follow, identify the impacts of nutrient pollution on three types of habitat, and examine the implications for birds species associated with these.

Water violet
Peter Creed

Farmland

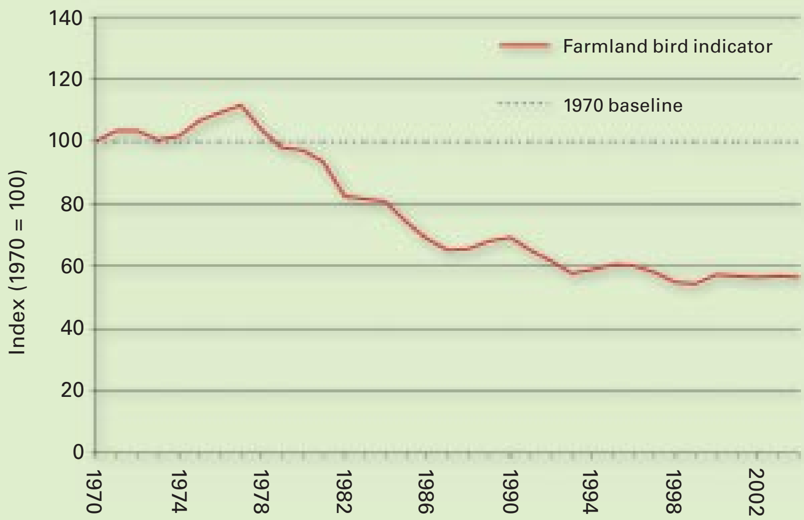
- **Agriculture differs from other sectors, as farmland is deliberately fertilised. Nutrients are essential to plant growth and their presence is key to achieving good yields. The availability of plentiful inorganic supplies of nutrient has helped to change the way crops, including grassland, are grown and managed.**
- **Problems arise when nutrients cause negative environmental consequences on farmland, or when unused nutrients are dispersed from the agricultural system.**
- **Some organisms are directly affected by the toxicity of nutrients applied to the land, but the majority of wildlife impacts are indirect.**
- **Indirect effects of nutrients include:**
  1. **losses of habitat and food resources, associated with the decline in mixed farming as farms polarise into intensive specialist units;**
  2. **changes in the species richness and vegetation structure of farmed habitats, resulting in reduced invertebrate food resources; and**
  3. **the replacement of hay with silage production, with a consequent loss of invertebrate and seed resources, and an increase in disturbance from cutting and grazing.**

Farmland covers 75% of the UK and therefore exerts a great influence on its landscapes and resident wildlife. Agriculture has intensified in many parts of the UK in the twentieth century. In part, this has been made possible by the availability of inorganic fertilisers and has led to changes in the crop and non-crop vegetation which form the basis of the food chain, affecting invertebrates, and ultimately birds and other wildlife. For example, there has been a decline of almost 50% in farmland bird populations since 1970, as indicated by the Farmland Bird Index (Figure 2). Organic and inorganic fertiliser use affects non-

Arable field margin
Roger Tidman (rspb-images.com)

Cirl bunting
Mike Lane (rspb-images.com)

Figure 2
UK farmland bird indicator (source: RSPB/BTO/Defra)



crop plants and some invertebrates directly, and other wildlife indirectly. Some invertebrates, notably earthworms[19 20], may be killed by heavy applications of organic and inorganic fertiliser, due to short term toxic ammonia concentrations, salinity and desiccation, but most impacts on invertebrates are indirect due to changes in vegetation (Table 1). Birds may be affected by fertiliser use via several indirect mechanisms (Table 2).

The use of fertilisers is only one of several factors that have promoted the intensification of agriculture; other technological improvements and policies have also changed the way in which crops and grassland are produced and managed with similar results. It is therefore difficult to disentangle the impact of nutrients in fertilisers from those caused by other aspects of agricultural intensification. However, in some cases there is strong evidence that increased fertiliser use is the major driving force, and changes in nutrients within farmland have affected the plant species richness of fields, vegetation structure, farm management and the landscape.

Species richness

The diversity of plant species in the countryside is affected by nutrient enrichment. Increased fertiliser applications generally reduce plant species richness or biodiversity in all farm fields, not just grassland. Plant biodiversity in farmland may be positively correlated with invertebrate species richness, due to the increased opportunities for specialist invertebrates[19 21]. For example, in arable field margins of southern England plant diversity is linked to butterfly and predatory beetle species richness and abundance[22]. Loss of plant species diversity thus has the potential to reduce invertebrate species diversity. Invertebrate abundance, however, is not necessarily linked to either plant species richness or invertebrate species richness.

Vegetation structure

Fertiliser applications affect crop sward structure by promoting faster and earlier spring growth, leading to taller, denser swards. In arable fields, this, together with crop breeding and pesticide development, has helped to drive the shift from spring-sown to autumn-sown crops. The resulting reduction in over-winter seed resources has affected seed eating birds, such as the yellowhammer and linnet. In grassland, the faster and earlier growth is generally cut for silage or intensively grazed, leading to short (although still dense) and homogeneous swards. Invertebrates that eat plants may benefit from the increased nutrient content of fertilised crops and grass, and the increased shoot and root growth resulting from fertiliser application. Similarly, wintering geese, which graze on grass, prefer

Table 1
Summary of direct and indirect effects of fertiliser application on some invertebrate groups (source: MacDonald, 2006)

Group	Effects
Earthworms (Lumbricidae)	High levels of organic and inorganic fertilisers toxic, but positive long-term response to organic fertiliser
Spiders (Araneae)	Favoured by processes that increase prey abundance, but affected by intensive management that reduces the suitability of sward architecture
Moths and butterflies (Lepidoptera)	Abundance and species richness reduced by loss of host plants and changes to microclimate
Beetles (Coleoptera)	Specialist species disadvantaged by loss of host plants; some large species unable to complete life cycle under intensive management
Craneflies (Diptera: Tipulidae)	Favoured by increased organic content and nutritive value of sward (following application of organic fertiliser); sensitive to cutting regime
Leafhoppers etc. (Hemiptera: Auchenorrhyncha)	Favoured by increased nutritive value and primary productivity, but specialists disadvantaged by loss of plant species; removed by intensive management
True bugs (Hemiptera: Heteroptera)	Favoured by increased nutritive value and primary productivity, but specialists disadvantaged by loss of plant species; removed by intensive management
Grasshoppers and crickets (Orthoptera)	Unsuitable habitat caused by growth of dense grass sward; inability to complete life cycle due to cutting regime and microclimate

fertilised fields. Management recommendations for these important winter visitors to the UK include fertiliser application to grassland and grazing by livestock.

Many indirect effects on invertebrates are negative. Changes to sward structure probably have the greatest effects on invertebrate abundance. These effects are most clearly observed in grassland under intensive grazing and/or cutting regimes. Invertebrates that are adapted to a specific grass sward structure will be negatively affected by fertiliser application and associated management practices. Grasshoppers and crickets are an example of this, as their habitat requirements are poorly met in intensively managed improved grassland[23]. Furthermore, these and other large insects are disproportionately affected by disturbance arising from grazing and cutting, as their longer life cycles and relatively low ability to recolonise mean that they are more likely to disappear from intensively managed farmland.

Several bird species have suffered from reduced abundance and/or availability of their invertebrate food sources. Species reliant on large invertebrates, such as cirl bunting and red-backed shrike, are especially sensitive. The loss of large soil dwelling invertebrates is also suggested as a major cause of reduced productivity of breeding waders in grassland[24 25]. Birds, such as snipe, starling and chough, that feed on soil invertebrates may be affected by reduced access to these food items in dense swards.

Increased crop growth can also contribute to the drying of soil, forcing soil dwelling invertebrates, such as earthworms, deeper into the soil.

Land management

Fertilisers have facilitated changes in land management that have affected wildlife. These changes are particularly significant in pastoral landscapes, and include the production of silage, which has largely replaced hay production. This shift has had radical effects on vegetation. It has also had highly significant effects on farmland bird populations, operating via three pathways:

1. reduced invertebrate food due to frequent cutting;
2. reduced seed resources as grass is cut before setting seed; and
3. destruction of adults, chicks and nests.

Early and frequent cutting of grass for ensiling affects sward structure, and reduces the seed available for farmland birds, such as the yellowhammer[26]. Destruction of adults, chicks and nests during silage cutting is a major cause of reduced productivity in nesting birds such as whinchat and corncrake[27]. Where fertilised grass is not cut, it can support higher stocking densities of grazing livestock. Intensive grazing and silage cutting directly remove invertebrates, and intensive grazing can lead to increased nest trampling in ground nesting species such as skylark[28] and lapwing[29]. These species may also suffer higher predation rates in intensively managed fields, either because taller swards may reduce their ability to detect predators, or because reduced sward heterogeneity decreases nest concealment.

Farming systems

The use of inorganic fertilisers has led to changes in patterns of land-use, by releasing farmers from the need to include fertility-building leys, with or without grazing, in the crop rotation. As a result, there has been a loss of mixed farming and, in general, a polarisation of agriculture towards arable farming in the south and east, and pastoral farming in the north and west of the UK. Bird species such as starling, cirl bunting and lapwing that prefer the juxtaposition of arable fields and pasture have been disadvantaged by the trend away from of mixed farming[30 31].

Figure 3
Flow diagram illustrating the expected mechanisms for indirect effects of nutrient inputs on birds in farmland

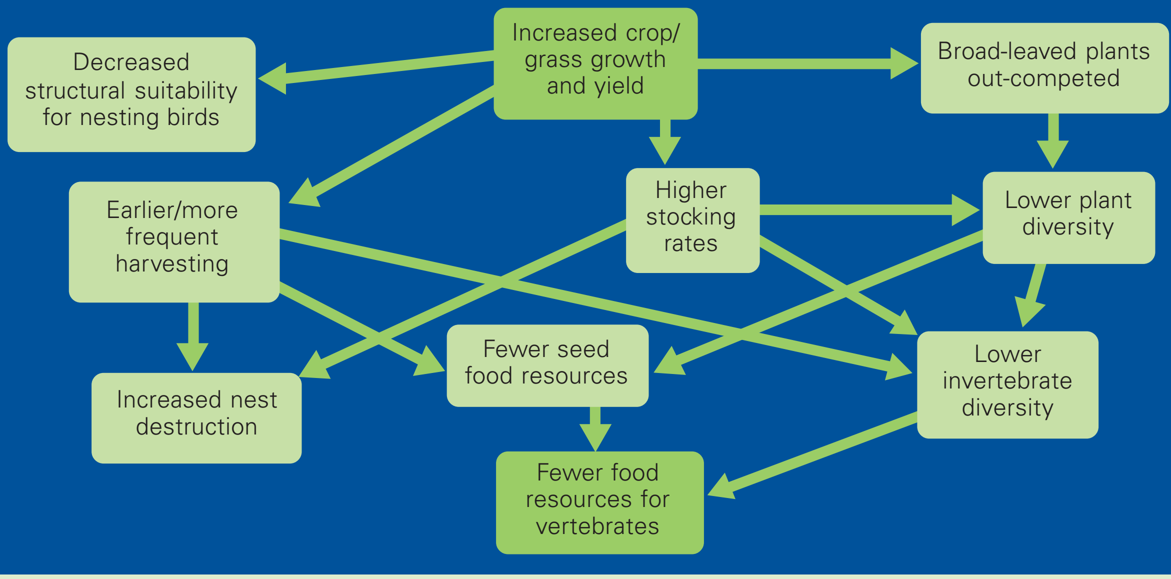
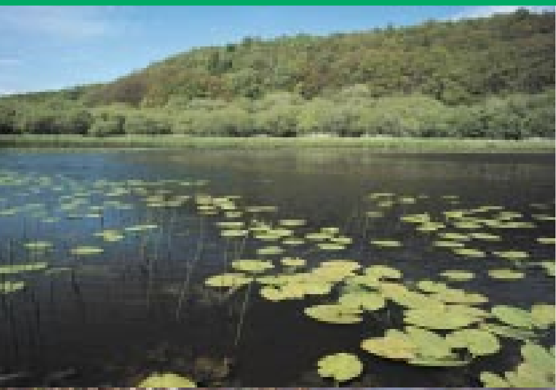


Table 2
Summary of suggested ways in which application of fertilisers has indirectly affected farmland birds in the United Kingdom (source: MacDonald, 2006)

		Mechanism by which fertiliser use may have indirectly affected a bird species[1]							
Species	**Listing**	**Reduced abundance of epigeal/foliar invertebrates**	**Reduction in sward suitability for ground nesting birds**	**Reduced abundance/ availability of soil invertebrates**	**Reduced abundance/ availability of seed food resources**	**Nest trampling**	**Nest destruction by cutting for silage**	**Increased predation in homogeneous swards**	**Loss of mixed farming landscapes**
corncrake	red						P		
lapwing	amber	C+	P			C		C	C+
snipe	amber			C				C	
curlew	amber	C+						C	
redshank	amber	C+							
turtle dove	red				C-				
skylark	red	P-	P		C-	C	C	C-	
swallow	amber								C
yellow wagtail	amber		C+	C			C		
whinchat	green	C					C+		
red-backed shrike	red	C+							
chough	amber			C+					
starling	red			C+					C
tree sparrow	red	C			C-				
linnet	red				C-				
yellowhammer	red	C			C-				C
cirl bunting	red	P			C-				C+
reed bunting	red	C			C-				C
corn bunting	red	C			C-		C		C

[1] P = proven (eg by recovery or experimental study), P- = proven, but fertiliser use is secondary to other causes of mechanism, C = correlation, C+ = strong correlation, C- = correlation, but fertiliser use is secondary to other causes of mechanism



Lake at Wood of Cree, RSPB reserve
Paul Collin (rspb-images.com)

Bittern
Andy Hay (rspb-images.com)

Aquatic habitats

- **Nutrients dissolved in water or attached to sediment reach aquatic habitats and can change plant growth patterns in delicate ecosystems, such as shallow lakes and reedbeds.**
- **Moderate increases in nutrients may promote an increased supply of plant food for invertebrates and birds in some circumstances, for example around sewage outfalls in estuaries and in some river systems.**
- **However, at higher nutrient levels, the changes to ecosystem functions resulting from eutrophication are detrimental.**
- **Aquatic birds can be adversely affected by: changes in the abundance and species composition of swimming and bottom dwelling invertebrates; changes in the abundance, size, and species composition of available fish prey; and reductions in habitat quality as a result of accelerated succession or changes in vegetation structure.**

The food-chain effects of eutrophication can be complex and highly localised in aquatic systems. Hence, changes in bird populations are not always downwards and some bird species may benefit from a moderate increase in nutrients whilst others can be extremely sensitive to even small changes. Increases in nutrient concentrations may be beneficial to birds up to a point, but after this, radical changes occur to the habitat on which they rely for food and nesting sites.

Open freshwater

Shallow freshwater lakes are especially susceptible to eutrophication. They tend to exist in either a clear-water state dominated by plants, or a phytoplankton-dominated, turbid-water state[32 33]. Lakes can shift between the states relatively suddenly, with switching triggered by a variety of processes, including changes in fish community and physical disturbance of vegetation. Importantly, the likelihood of switching is strongly influenced by

Table 3
The effects of nutrient increases on birds using aquatic habitats (source: MacDonald, 2006)

Group	Response	Typical species
Dabbling plant and invertebrate-feeding waterfowl	Increase initially as aquatic plant growth increases but ultimate decline due to loss of food resources at high nutrient levels	Mute swan, coot, wigeon, pintail
Diving bottom-feeders (fresh waters)	Increase initially but ultimate decline due to loss of food resources and reduced water transparency	Goldeneye, pochard, tufted duck, scoters
Diving bottom-feeders (coastal waters)	Increase due to greater food availability resulting from modest nutrient increase	Scaup, goldeneye
Pursuit divers (oligotrophic lakes)	Decline due to reduced water transparency and changes to fish size distribution	Red-throated diver, black-throated diver
Pursuit divers (mesotrophic lakes)	Possible increase due to increased prey abundance	Goosander, red-breasted merganser, great-crested grebe
Reedbed specialists	Decline due to loss of reed, increased rate of succession and reduced food resources	Bittern, other possibilities include bearded tit and water rail
Shorebirds (waders and wildfowl)	Increase due to greater food availability, except where macroalgal mats are persistent; specialist feeders may decline	Oystercatcher, dunlin, grey plover, knot, redshank (and other waders), wintering geese; shelduck (decline)
Gulls	Increase due to greater food availability	Common gull, great black-backed gull

nutrient levels, but both states are buffered against this switching to a certain extent, so that a clear-water state can persist at high nutrient levels, and a turbid-water state, once established, may persist after nutrient levels are reduced.

Invertebrate communities in freshwater are sensitive to nutrient inputs. Bivalve molluscs are especially sensitive to eutrophic conditions, whilst others, such as annelid worms are more tolerant. Eutrophication of shallow lakes, in England and elsewhere, leads to a reduction of fish diversity, with roach and bream becoming dominant at the expense of perch, rudd and tench[34]. Eutrophic conditions also change the invertebrates living at the bottom of water bodies, leading to a loss of sensitive species and food supply for birds, such as pochard, which dive from the surface to feed on them[35]. Nutrient enrichment may also alter the size class of fish prey, reducing the abundance of suitably small-sized individual fish. Fish favoured by eutrophic conditions may also compete with birds for food; this has been suggested as a cause of the decline of tufted duck in Lough Neagh[36 37]. Large zooplankton, such as water fleas, favour a clear-water state, because submerged plants (which rely on clear water) provide them with shelter from predatory fish[31]. In freshwater lakes, a shift in stable states to non-clear water results in a decline in food plants for herbivorous and omnivorous waterfowl.

Under certain conditions, extreme eutrophication can lead to huge increases in plant growth which starve water of oxygen. These anoxic conditions can kill both invertebrates and fish in an affected stretch of water.

Reedbed habitats

Reedswamp vegetation has declined across areas of western and central Europe[38] but despite there being some coincidence between reed decline and eutrophication, no cause and effect has been proven. In the Norfolk Broads, a relationship has been found between nitrate concentrations in water and the decline of a particular floating form of reed, known as hover[39]. Eutrophication may affect birds reliant on reedbed by accelerating the succession of the plant communities and by reducing the amount of open water present. The red-listed bittern is especially adapted to reedbeds, and may be affected by reduced food supply as one of its major food items in Britain is rudd, which performs poorly in eutrophic conditions[40 41.]

Upland freshwater lakes

In the absence of human activities causing inputs of nutrients, upland lakes in the UK are mostly low in nutrients, and support limited but specialised plant life. Because of this, these lakes can be particularly susceptible to small increases in nutrient loadings. For example, fish communities in upland lakes can be altered by nutrient pollution by encouraging the growth of fewer but larger individuals.

Estuaries and coastal waters

Estuaries and coastal waters are generally better flushed through with water than freshwater lakes so the effects of eutrophication are generally less persistent. However, where eutrophication occurs it typically leads to a decline in plant communities such as seagrass and eelgrass beds, and their replacement by algal mats and phytoplankton blooms[42 43]. In intertidal mudflats, the presence of algal mats forces invertebrates closer to the surface of the mud to evade the oxygen depleted conditions caused by the algal growth. This provides a short-term flush of food for other organisms, including birds but if the mats persist, invertebrate abundance may decline severely and the food supply will be reduced in the long term[44].

In coastal areas small aquatic crustaceans such as the mud shrimp and polychaetes like ragworm are tolerant of eutrophic conditions and can provide abundant food resources to shorebirds. In tidal areas, shorebirds benefit from human influenced nutrient inputs, although birds with specialised prey requirements or foraging habits, such as shelduck, may not[45]. Immediately adjacent to point sources of nutrient pollution, such as sewage outflows, invertebrate numbers are reduced by the extreme conditions but in the surrounding areas they can be much higher[46]. However, the invertebrate communities are very different in composition from those found in naturally low-nutrient waters. Where sewage outfalls are removed, or where treatment is implemented, invertebrate biomass usually falls, although the diversity of species increases and more closely resembles that found in natural conditions. Historically, bird populations have risen in estuaries where sewage inputs have increased. Diving ducks are an example of a group of birds that have benefited from the increased food supplies around sewage outfalls, and their numbers have been shown to decline where outfalls have been removed or better treatment installed[44].

Heathland
Heath tiger beetle
Hen harrier
Andy Hay (rspb-images.com)

Moorland and heathland habitats

- **Upland moor and lowland heath habitats are naturally low in nutrients and are therefore sensitive to atmospheric nitrogen deposition.**
- **Heather (*Calluna vulgaris*) is sensitive to increased nitrogen availability, and increased nutrient loads can favour grasses; although generally some form of disturbance is required to cause moorland to shift from heather to grass dominance. The most common reason for this is increased grazing intensity, which is not necessarily related to nitrogen deposition.**
- **Some upland bird species, including red grouse and stonechat, are particularly sensitive to heather loss. It is possible that such species are adversely affected by the impacts of atmospheric nutrient deposition.**
- **Many moorland bird species benefit from a mixture of grass- and heather-dominated moorland. The effects of heather loss on these species will depend on the initial heather cover and spatial configuration, with most species only likely to be detrimentally affected by heather loss if it occurs over large areas.**

Upland moor and lowland heath, dominated by heather, are naturally nutrient-poor habitats that are sensitive to increases in inputs. Fertilisers are not generally applied directly to these habitats. Instead, increases in nutrient loading are the result of atmospheric nitrogen deposition. This source of nitrogen has increased enormously over the past century, despite some reductions over the past two decades.

Vegetation

There has been a decline in the extent of heather cover in both upland moorland and lowland heath in the United Kingdom in recent years. In England and Wales, the land area covered by heather fell from 631,400 to 509,800 hectares between 1947 and 1980[47]. In Scotland, heather cover declined by 23% (over 300 000 ha) in the period 1947–1988[48]. Causes of the decline include overgrazing (leading to invasion of grasses), afforestation (the cause of over half the heather loss in Scotland), conversion to farmland, and succession to scrub.

Atmospheric deposition of nitrogen increases the nitrogen content of heather leaves and decreases the root:shoot ratio. This change increases the plant's sensitivity to desiccation, and dieback can occur, especially during winter droughts. The heather beetle feeds exclusively on heather and this increased nitrogen content of heather foliage increases heather beetle larval growth[49]. It is therefore suggested that nitrogen deposition increases the probability of beetle outbreaks[50]. Dieback resulting from heather beetle attacks or desiccation may cause disturbance to heather sufficient for grasses to invade and both of these mechanisms may be increased by nitrogen deposition. Disturbance of heather by grazing animals has further effects on the cover of heather and grass on moorland, independent of the effects of nutrient inputs[51]. Between the 1970s and 1990s grazing intensity increased in many upland areas and has been a major cause of transition from heather to grass moorland. Increased nitrogen deposition may have facilitated increased grazing intensity by improving the forage quality of moorland (through increased nitrogen content of foliage and increased grass cover), although such increases in grazing intensity were driven primarily by other factors (such as agricultural funding mechanisms). The scale of the contribution of nitrogen deposition to this process is difficult to determine. These mechanisms for changing the composition of heather are also suggested as causes for the loss of lowland heath in western Europe. However, lack of management is also implicated, with succession to scrub and the cessation of burning being the main factors[52 53].

Birds

In upland moorland, the shift from heather to grass moorland, due to processes already described, is likely to be the most important effect of nitrogen deposition on birds. A recent study[54], which examined detailed relationships between bird abundance and vegetation characteristics, found that several species appear to use non-heather components of moorland, or require a mosaic of grass and heather cover. Based upon this and other moorland bird studies, there is sufficient evidence to estimate sensitivity to heather loss for fifteen species. Two species (red grouse and stonechat) are considered sensitive to heather loss, because they are strongly associated with mature heather cover for breeding and foraging. Six species (curlew, snipe, golden plover, skylark, whinchat and wheatear) are classed as having low sensitivity to heather loss. Indeed, some of these species are likely to benefit from the conversion of heather moorland to either grass or bracken, while for others the structure of moorland vegetation, rather than its floristic composition, appears to be more important in determining their abundance. A further seven species (black grouse, hen harrier, merlin, golden eagle, meadow pipit, ring ouzel and twite) are classed as moderately sensitive to heather loss. These species require a mosaic of heather and grass cover, and the effects of heather loss on birds will depend on the extent of initial heather cover and its spatial distribution. Most moorland birds are not favoured by continuous heather cover, and are only likely to be detrimentally affected where heather loss occurs across relatively large areas. Nitrogen deposition may contribute to such losses, but their main drivers remain processes such as afforestation and intensive grazing. Furthermore, populations of some moorland birds may currently be determined by processes other than availability of habitat, such as human persecution[55].

Whilst the plant communities of lowland heathland have undoubtedly suffered from eutrophication, birds are not a good indicator of environmental health for this habitat. Few bird species specialise in this habitat, and their populations are probably more affected by processes other than eutrophication.

Table 4
Predicted effects of loss of heather cover to moorland birds (source: MacDonald, 2006)

Species	Category[1]	Sensitivity	Likely reaction to loss of heather cover
Red grouse	Confined to heather moorland	high	loss of heather food resource; loss of nesting habitat
Black grouse	Major breeding habitat	moderate	increased predation and loss of food resource
Hen harrier	Breed mainly on moorland	moderate	loss of nesting habitat and prey items
Golden eagle	Feeding habitat	moderate	loss of nesting habitat and prey items
Merlin	Breed mainly on moorland	moderate	loss of nesting habitat and prey items
Golden plover	Breed mainly on moorland	low	strong effects unlikely
Snipe	Locally important breeding habitat	low	strong effects unlikely
Curlew	Major breeding habitat	low	strong effects unlikely
Skylark	Major breeding habitat	low	probable benefit from increase in grass cover
Meadow pipit	Major breeding habitat	moderate	loss of appropriate mosaic of habitats
Whinchat	Major breeding habitat	low	probable benefit from increase in bracken cover
Stonechat	Major breeding habitat	high	loss of nesting sites and appropriate mosaic of habitats
Wheatear	Locally important breeding habitat	low	probable benefit from increase in bracken or grass cover
Ring ouzel	Major breeding habitat	moderate	loss of nesting habitat and appropriate mosaic of habitats
Twite	Locally important breeding habitat	moderate	loss of nesting habitat

[1] Use of heather moorland as described by Thompson *et al.* (1995).

Pink footed geese at Loch of Strathbeg reserve
Chris Gommersall (rspb-images.com)

Cattle at the Ouse Washes reserve
Andy Hay (rspb-images.com)

Case studies

Impacts of nutrient pollution on RSPB nature reserves

Loch of Strathbeg

The Loch of Strathbeg is a 915 ha wetland reserve in north east Scotland. It has a range of biodiversity and geological features which have been recognised as important for wildlife at the international, national and local levels and has been designated as Site of Special Scientific Interest (SSSI), a Ramsar site and a Special Protection Area (SPA). It has been designated for breeding sandwich terns and its internationally important wintering populations of wildfowl, such as whooper swan, pink footed geese and teal. The loch and the surrounding areas of wet grassland, fens and drier grasslands support in excess of 20,000 waterfowl, including large numbers of breeding and wintering wildfowl and waders. There are also a wide range of plant communities supporting a number of uncommon species, such as creeping spearwort and slender-leaved pondweed.

According to Scottish Natural Heritage, a number of the conservation features at the Loch of Strathbeg are not currently in favourable condition. Many of these features depend directly or indirectly on the water quality of the loch and a burn feeding into the loch. Heavy siltation and increasing levels of nitrogen and phosphorus from agriculture are causing major problems in the loch, which is experiencing change in vegetation structure from macrophyte dominance to dominance by epiphytic algae. These changes in plant composition are having indirect impacts on key conservation features, including grazing wildfowl, coots and dabbling ducks.

Ouse Washes

An area of internationally important wetland, the Ouse Washes SSSI forms the largest example of washland in Britain. Designated as a Special Protection Area (SPA), the Ouse Washes attract nationally and internationally important numbers of waterfowl in winter, whilst in the summer they provide breeding habitat for waders such as snipe and black-tailed godwit. The site is also a Special Area of Conservation (SAC) for spined loach and a Ramsar site for a range of wetland features. The RSPB manages just under 1,450 hectares of wet grassland, ditch and fen habitats at Ouse Washes.

Large areas of the SSSI, however, are affected by a combination of prolonged summer flooding and a combination of diffuse and point source pollution, resulting in 86% of the SSSI being classified as in unfavourable condition (982 hectares of which is on the RSPB's reserve).

In particular, inputs of nutrients have gradually eroded the quality of aquatic plant communities in the rivers and ditches, which were once some of the most diverse in Britain[56]. The high nutrient loadings have considerably increased mat forming duckweed communities in the ditches. The nutrient inputs are also affecting the quality of the wet grassland habitats which are a key feature of the Washes, a Biodiversity Action Plan (BAP) priority habitat, and support important numbers of breeding wading birds such as snipe, lapwing and redshank.

Conclusions

- Increased levels of nutrients are adversely affecting natural and semi-natural habitats in the UK, reducing the diversity of plants and invertebrates found in our countryside.
- Strong causal links exist, in a number of cases, between nutrient pollution and knock-on effects on the food chain of wildlife, including birds. In several other cases, insufficient evidence exists to demonstrate this causal link at present, but there is a clear case for further research.
- Nitrogen and phosphorus in chemical fertilisers have helped to change the way crops, including grassland, are grown and managed. This in turn has reduced the variety of non-crop plant species in farmland, reduced invertebrate and seed resources for some birds, and increased the potential for disturbance by farm operations.
- Red-backed shrike is now extinct in the UK; its decline largely driven by fertiliser application to grassland. This process also helped drive corncrake and cirl bunting to the brink of extinction in the UK; these two species are slowly recovering as a result of intensive conservation effort.
- Nutrient pollution affects delicate aquatic ecosystems such as lakes, lochs and reedbeds. Whilst eutrophication may favour birds in some circumstances, in others it adversely affects the availability of suitable invertebrate and fish prey for habitat specialists such as bittern.
- Moorland and heathland habitats are naturally low in nutrients and sensitive to external nutrient inputs. While nitrogen deposition is not the major cause of the shift away from heather to grasses and other vegetation, it can exacerbate the effects of disturbance such as grazing. This can have knock-on consequences for birds such as the red grouse, which are adapted to heather dominated habitats.
- Knowledge and technologies exist to improve nutrient management in all sectors. Government needs to develop the right mix of policies to put these skills into practice, including better regulation, incentives and advice.

Reedbed
Matt Self (rspb-images.com)

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